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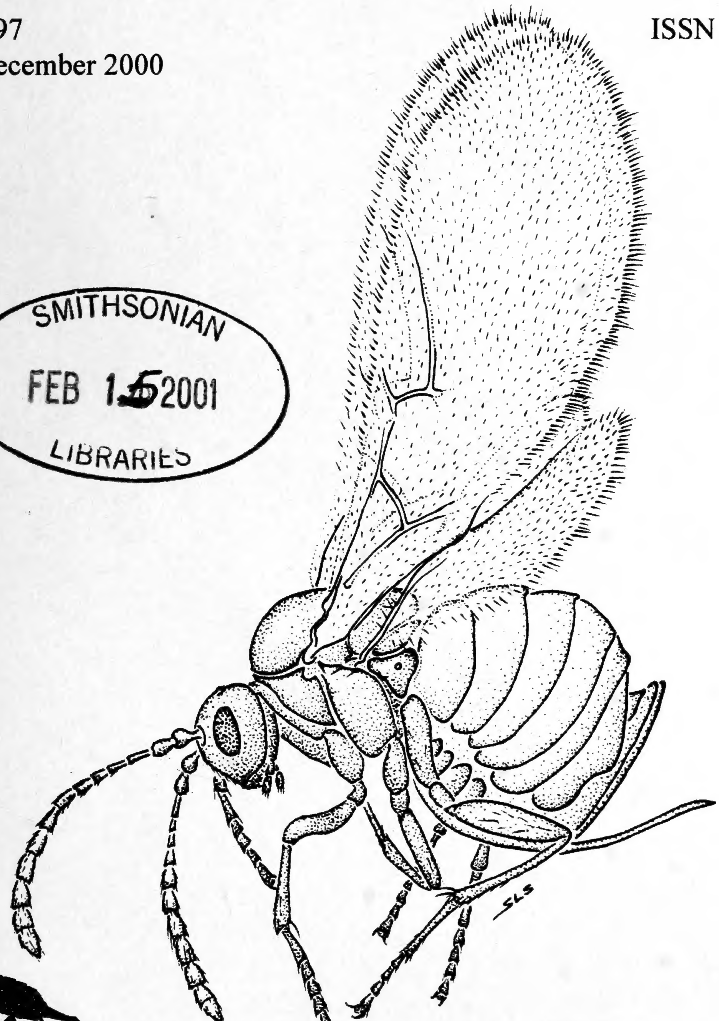

ESBC

COVER: The jumping gall wasp, *Neuroterus saltatorius* (Edwards) (Hymenoptera: Cynipidae), was first discovered in Canada in 1986 in the Victoria area. The wasp forms galls on Garry oak, *Quercus garryana* Douglas, British Columbia's only native oak, and has since spread to cover much of the host's distribution (primarily southeastern Vancouver Island). The insect's native range is the western United States, where it has several hosts in the white oak Family. The common name is derived from the bouncing action of tiny galls (1-1.5 mm) that fall from scorched leaves in summer, each containing an agamic female larva. Adult illustrated on cover (body length about 1mm) and text, by Stephanie Sopow.

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A new parasitoid (Diptera: Tachinidae) of *Acanthocinus princeps* (Coleoptera: Cerambycidae) in North America

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ABSTRACT

An undescribed species of *Billaea* Robineau-Desvoidy was reared from field-collected larvae of *Acanthocinus princeps* (Walker) maintained on artificial diet in the laboratory. *Billaea* is a novel larval parasitoid for *A. princeps* with natural parasitism levels of ca. 28%.

Key words: *Acanthocinus*, *Billaea*, larval parasitoid, *Monochamus*

INTRODUCTION

Cerambycid beetles are host to many parasitoids in the orders Hymenoptera (Linsley 1961; Krombein *et al.* 1979; Woolwine *et al.* 1996) and Diptera (Linsley 1961; Arnaud 1978; Campadelli and Gardenghi 1991; Tsankov and Georgiev 1991). Twelve species of Tachinidae, including *Zelia vertebrata* (Say), *Lixophaga variabilis* (Coquillet), *Ptilodexia canescens* (Walker) and *Chetogena floridensis* (Townsend) and eight species of *Billaea* Robineau-Desvoidy (Table 1), have been confirmed as larval or pupal parasitoids of Cerambycidae (Arnaud 1978; Campadelli and Gardenghi 1991; Tsankov and Georgiev 1991). We report the occurrence of a ninth, undescribed, species of *Billaea* reared from cerambycid larvae from British Columbia.

MATERIALS AND METHODS

In October and November of 1998 a total of 539 cerambycid larvae of the genera *Acanthocinus* and *Monochamus* were collected from beneath the bark of burned ponderosa pine, *Pinus ponderosae* P. Laws. ex C. Laws., about 17 km north of Lytton, B.C. on the Izman Forest Service Road of the Lillooet Forest District. We did not differentiate between larvae of the two genera. Each larva was immediately placed in artificial media [diet number three in Payne *et al.* (1975)] in a separate 60 mL glass jar. Temperature was maintained at 30°C through 17 November 1998, and then at 10, 15 and 6°C from 17 November 1998 to 8 January 1999, 8 January – 28 February 1999, and 28 February – 28 March 1999, respectively, to simulate diapause conditions. The photoregime was 14:10 L:D and the relative humidity was ca. 55%. To ensure consistency in the quality of food, all larvae were transferred to clean jars containing fresh diet at monthly intervals.

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RESULTS AND DISCUSSION

When the rearing programme was terminated in May 1999, 176 larvae were still alive, and 104 adult beetles, mostly *Acanthocinus princeps* (Walker) with a few *Monochamus scutellatus* (Say) (exact counts not kept) had eclosed. Of the 259 larvae that died, 151 had been parasitized by an undescribed *Billaea* Robineau-Desvoidy species (D. M. Wood[1] and J. E. O'Hara[1] pers. comm.). The cause of mortality is unknown for the remaining 108 larvae. A total of 56 of the parasitoid larvae were reared to adulthood. Parasitism by *Billaea* n. sp. exceeded 28% of the larvae originally collected, indicating that this tachinid is a significant source of mortality. This level of parasitism is much higher than the 0.6-7.5% levels of parasitism of *M. scutellatus* by *B. monohammi* (Townsend) (Soper and Olsen 1963), but is similar to levels of parasitism of *Saperda scalaris* L. by *B. triangulifera* Zetterstedt (Campadelli and Gardenghi 1991) and *S. populnea* L. by *B. irrorata* (Meigen) (Tsankov and Georgiev 1991) (28% and 9-19%, respectively).

Table 1

Cerambycid host records for the genus *Billaea* Robineau-Desvoidy (Diptera: Tachinidae) in North America and Europe. Nine species are currently placed in *Billaea* in North America (Wood 1987).

Location	Parasitoid	Host	Reference
North America	*B. rutilans* (F.)[1]	*Enapholodes atomarius* (Drury)	Fattig 1949
	B. monohammi (Townsend)[1,2]	*Monochamus scutellatus* (Say)	Aldrich 1932
		M. notatus (Drury)	Soper and Olson 1963
		M. titillator (F.)	Savely 1939
	B. nipigonensis Curran?[3]	*Rhagium inquisitor* (L.)[4]	Thomas 1955
	B. sp. prob. *satisfacta* (West)[3]	*R. inquisitor*	Soper and Olson 1963
	B. trivittata (Curran)[3]	*M. notatus*	Thomas 1955
		M. scutellatus	Thomas 1955
		M. titillator	Savely 1939
		R. inquisitor[4]	Thomas 1955
	B. interrupta (Curran)[5]	*Acanthocinus obseletus* (Curran)	Linsley and Chemsak 1995
Europe	*B. triangulifera* Zetterstedt	*Saperda scalaris* L.	Campadelli and Gardenghi 1991
	B. irrorata (Meigen)	*Saperda populnea* (L.)	Tsankov and Georgiev 1991

[1] reported as *Theresia* (Savely 1939; Fattig 1949)
[2] reported as *Eutheresia* (Soper and Olson 1963)
[3] reported as *Eutheresia* (Thomas 1955)
[4] reported as *Stenocorus inquisitor* (Thomas 1955)
[5] reported as *Eutheresia* (Linsley and Chemsak 1995)

The remains of two larvae from which *Billaea* n. sp. larvae had emerged were retained for identification. In both instances, the host larva was not completely consumed and the parasitoid larva had emerged from the posterior abdomen. The larval characteristics of both specimens were consistent with those of the genus *Acanthocinus* (Craighead 1923; and Duffy 1953), confirming *A. princeps* as a host of *Billaea* n. sp. This is not the first record of parasitism by a *Billaea* sp. of a host in the genus *Acanthocinus* (Table 1) although it is a novel host record for *A. princeps*. Voucher specimens of adult *Billaea* n. sp. have been

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deposited in the Canadian National Collection[1] (n=6) and at the Pacific Forestry Centre (n=50), Victoria, BC. The two specimens of *A. princeps* from which *Billaea* n. sp. emerged have also been deposited at the Pacific Forestry Centre.

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The economic and environmental impact of an IPM program on hazelnuts in Oregon

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ABSTRACT

An integrated pest management (IPM) program based on monitoring, parasite releases, and economic thresholds was implemented in the hazelnut industry in the early 1980's. To assess the economic and environmental benefits of the IPM program, growers were surveyed in 1981 to determine insecticide use in 1980, prior to the inception of the program, and in 1998 to quantify insecticide use in 1997, after the program had been adopted throughout the growing region. Survey respondents encompassed 23% and 20% of the hazelnut producing acreage in 1980 and 1997 respectively. Data indicate that the total number of annual spray applications was reduced by about 50%, resulting in an annual industry savings of over a half-million dollars.

Key words: IPM efficacy, pesticide use pattern, environmental impact, economic impact

INTRODUCTION

Integrated pest management utilizes alternate strategies in making pest control decisions by emphasizing increased information and by integrating cultural, biological and chemical control methods. It often results in environmental benefits through the decreased use of pesticides and associated reduction of environmental contamination. There are numerous examples of the development of IPM programs (Trumble *et al.* 1997), and many studies that evaluate the economic benefits of IPM programs (Trumble and Alvarado-Rodriguez 1993; Trumble *et al.* 1994; White and Wetzstein 1995; Headley and Hoy 1986), yet few document both the economic and environmental savings that result from a successful IPM program on a regional scale. Concerns over the impact of pesticide residues on food and in the environment (Pimentel *et al.* 1993) are causing industry-wide regulation of insecticide use and changing the way exposure to insecticides is assessed in the environment as set forth in the US EPA's Food Quality Protection Act of 1996. These concerns are causing the reduction or elimination of insecticides and changing our perspective of IPM from spray-based management to an ecosystem perspective by focusing on predators and parasitoids, and alternative methods of pest control.

Economics and insecticide use patterns are fundamental to IPM practices and should be used to measure program success. Studies suggest that it is conceivable to reduce pesticide use in the US by 35-50% without a significant loss of crop yield (Office of Technology Assessment 1979; National Academy of Sciences 1989). In our study, we summarize the reduction in insecticide use and economic impact of a program to control the major insect pests of hazelnuts (*Corylus avellana* L.).

The list of insects and mites associated with hazelnut trees is long, representing almost all of the major insect and mite groups. In Oregon, over 150 species have been found on hazelnut

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trees; most are harmless, over half are beneficial, only two-dozen or so species are injurious, and of those only six or so are considered important pests (AliNiazee 1998). Although there are numerous potential insect and mite pests on hazelnuts in Oregon, only four have warranted consistent insecticide application (AliNiazee 1994). It should be noted that pest incidence and importance change with time and orchard management practices.

Prior to the development of an integrated pest management program, insecticide use was widespread. This practice resulted in resistance by the filbert aphid, *Myzocallis coryli* (Goetze) (Homoptera: Aphidae) reoccurring every 1 or 2 years (AliNiazee and Messing 1995; Katundu and AliNiazee 1990), outbreaks of secondary pests, and rapid resurgence of primary pests. These outbreaks required repeated application of insecticides that further aggravated pest conditions. As a result, by the early 1970's, as many as five different insecticide applications were applied each season to control hazelnut insect pests (AliNiazee 1977).

Research conducted during the 1970's led to the formation of an integrated pest management program on hazelnuts in Oregon (AliNiazee 1977). In 1982, the USDA funded a 4-year project to develop an IPM program in Oregon hazelnut orchards. This program entailed the establishment of economic injury levels for hazelnut pests (Fisher 1984; Calkin *et al.* 1984; Calkin and Fisher 1985), and design and implementation of a scouting and monitoring program which remains in use by hazelnut growers (Olsen *et al.* 2000). These efforts resulted in establishing levels of tolerance (1%) and economic damage for the primary pest of hazelnuts, the filbertworm, and initiated pheromone trapping as a viable method of monitoring populations and timing spray applications. Before IPM, light trapping was used to determine adult emergence and time of spray application. However, there were no existing ways to measure population levels, therefore sprays were applied based on the presence of filbertworm moths in trap catches. In addition, sprays were applied to control other perceived insect pests based on their presence or simply by the calendar because there were no established economic levels of concern. Lack of knowledge of a pest's status strongly contributed to the overuse of insecticides on hazelnuts. As a direct result of the IPM program growers monitor their own orchards or employ field scouts to assess population levels. This level of current information enables growers to determine the need, timing and location of spray applications.

Concurrent with the establishment of the IPM program, a parasitic wasp (Messing and AliNiazee 1989) was released as a biological control of the filbert aphid. The success of this classical biological control program aided in the implementation of the IPM program in the1980's (AliNiazee 1991; AliNiazee and Messing 1995), and nearly eliminated all insecticide sprays applied against aphids. By allowing early-season beneficial insects to become established it also has indirectly reduced the application of insecticides on other insect pests in hazelnut orchards.

In this paper we present data from a survey of hazelnut growers conducted in 1981 prior to the inception of an IPM program on hazelnuts, and contrast it with data from a similar survey conducted in 1998, after adoption of the program by hazelnut growers. Our objectives in this study were to evaluate the economic and environmental impacts of an industry-wide IPM program to control the primary hazelnut insect pests.

METHODS

A survey of hazelnut growers was conducted in 1981 to assess grower pesticide use patterns in 1980, i.e., prior to the initiation of an IPM program in hazelnut orchards in Oregon (Progar and AliNiazee 1999). In 1998, a similar survey of Oregon hazelnut growers was conducted to determine changes in insecticide use patterns resulting from adoption of hazelnut IPM (i.e., in 1997). The number of hazelnut growers in Oregon has declined from over 1,000 to about 800, while the total area has increased, indicating a trend toward larger orchard size or grower-managed area (Rowley 1997). Table 1 summarizes the hazelnut area for each survey. The surveys represent 23.5% (171 responses) and 20% (80 responses) of total hazelnut-bearing area in 1980 and 1997, respectively. All insecticide quantities are expressed in kg of active ingredient (a.i.) because not all growers use the same pesticide formulations.

Table 1

Survey summary data of hazelnut orchard area in Oregon.

	1980	1997
Number of growers	1,063	826
Total hazelnut hectares	10,316	12,121
Bearing hectares	8,741	11,412
Non-bearing hectares	1,574	708
Hectares represented in the survey	2,383	2,501
Bearing hectares (survey)	2,058	2,291
Non-bearing hectares (survey)	325	210
% total hectares represented by the survey	23.50	20.07

The U.S. Bureau of Labor Statistics Consumer Price Index (CPI) regional index (Bureau of Labor Statistics Data 1998) was used to compare pest control costs between 1980 and 1997. The 1980 index value of 247 was compared with the 1997 index value of 469 to express 1980 dollars in 1997 values.

Costs for different pesticides increased disproportionately, e.g., a kg of Sevin® (carbaryl) increased in cost by 56% from 1980 to 1997; whereas Guthion® (azinphos-methyl) increased in cost by 157%. Many of the insecticides used in 1980 were no longer registered for use on hazelnuts in 1997, and newer, more efficient compounds were used in 1997 that were not available in 1980. Therefore, direct comparison of costs associated with specific insecticides cannot be made, however total pesticide costs can be compared. The cost to apply an insecticide treatment to a hectare of hazelnuts has increased from $20.34 (unadjusted dollars US) in 1980 to $50.06 (Seavert and Olsen 1999) in 1997.

RESULTS AND DISCUSSION

Filbertworm, *Cydia latiferreana* Walsingham (Lepidoptera: Tortricidae)

Filbertworm is the primary insect pest in hazelnut orchards. Because there is an industry standard of less than a 1% tolerance for filbertworm infestation, the percentage of hazelnut orchard area treated remains about the same before and after the IPM program (Table 2). However, the composition of the insecticides used to control filbertworm has changed and the amount of insecticide active ingredient (a.i.) has declined dramatically (Table 3).

Table 2

Primary pests in Oregon hazelnut orchards and percent of growers and orchard area using insecticides to control them.

Pest	% growers (1980)	% ha (1980)	% growers (1997)	% ha (1997)
Filbertworm	88.2	95.8	87.5	94.0
Filbert leafroller	38.1	57.1	16.2	28.6
Obliquebanded leafroller	5.9	6.4	2.5	2.5
Filbert aphid	48.8	69.0	5.0	6.3

Table 3

Estimated pesticide use and cost patterns to control filbertworm in Oregon hazelnut orchards. All estimates are based on % ha of bearing hazelnuts.

Insecticide	% growers	% ha	Mean # appls.	Mean rate a.i. (kg/ha)	Est. total kg a.i.	Est. insecticide cost ($US)	Est. total cost ($US)
1980							
No insecticide used	11.8	4.3					
Sevin (carbamate)	62.9	67.7	1.3	4.50	35,841	197,384	359,831
Zolone (organophosphate)	12.8	14.2	1.3	1.68	2,814	99,167	133,173
Guthion (organophosphate)	9.2	11.8	1.3	0.79	1,054	32,644	59,937
Diazinon (organophosphate)	2.3	1.1	1.0	1.11	108	1,485	3,440
Thiodan (organophosphate)	1.0	1.0	1.0	1.68	119	2,624	4,402
							$560,783
1997							
No insecticide used	12.5	6.0					
Asana XL (synthetis pyrethroid)	81.2	91.6	1.5	0.07	1,035	462,933	1,232,496
Guthion (organophosphate)	2.5	0.1	1.5	0.07	84	666	1,266
Lorsban (organophosphate)	2.5	0.1	1.5	2.07	50	14,990	26,988
Bacillus thuringiensis (biological)	1.2	2.2	1.0	1.11	281	2,512	15,082
							$1,275,832

In 1980, an estimated 39,916 kg (a.i.) of insecticides were applied to control filbertworm on approximately 96% of the hazelnut orchard area by 88% of the growers (Tables 2 and 3). In 1997, only an estimated 1,453 kg of insecticide (a.i.) were applied to control filbertworm by 87% of the growers on 94% of the hazelnut area, indicating higher efficiencies and effectiveness of insecticide application. The most common insecticide used in 1997 was Asana® (esfenvalerate, a pyrethroid), with a small fraction of Guthion® (azinophos-methyl) and Lorsban® (chlorpyrifos) (Table 3). Asana® was applied in amounts 10 to 20-fold less a.i. because it was more effective than insecticides applied 16 years earlier and can be applied in smaller amounts. Although the same portion of growers are treating the same percentage of area for filbertworm in 1997 as in 1980, the change from organophosphates (OP) and carbamate to esfenvalerate resulted in a large decline in the amount of insecticide a.i. applied and an enormous benefit to the environment. Only an estimated 5% of the growers used OP's on 0.21% of the hazelnut area in 1997 as opposed to an estimated 24% of the growers on 27% of the area in 1980 (Table 3).

There is currently an effective IPM system in place in commercial hazelnut orchards that incorporates an online degree-day model, and scouting and monitoring for adult filbertworm moths. The decrease in total pesticide use may be attributed to more efficient monitoring with pheromone trapping rather than the previous method of light-trapping, better timing and targeting of insecticide applications, more efficient spray equipment, and the shift from carbamate and organo-phosphate insecticides to synthetic pyrethroids.

Although the quantity of insecticide used to control filbertworm declined by an estimated 38,463 kg (a.i.) from 1980 to 1997, the estimated cost of control was $1,275,832 in 1997 vs. $1,066,658 in 1980 (converted to 1997 dollars), a 20% increase in expense to control filbertworm (Table 7).

Filbert Leafroller (European Leafroller), *Archips rosanus* (L.) (Lepidoptera: Tortricidae)

In 1980, an estimated 10,440 kg (a.i.) of insecticide were applied by 38% of the growers on 57% of the hazelnut area to control filbert leafroller (Tables 2 and 4). In 1997, 2,998 kg of insecticide (a.i.) were applied by 16% of the growers on 29% of the hazelnut area. Lorsban® was the primary insecticide applied followed by a small percentage of Guthion®. The area treated in 1997 was about half that of 1980 and less than a third the amount of pesticide a.i. was used to control leafroller, resulting in an estimated annual reduction of 7,445 kg of insecticide a.i. during the 16-year period (Table 4).

The adoption of an IPM program on hazelnuts has significantly reduced the use of insecticides to control filbert leafroller. The emergence of filbert leafroller is now predicted by degree-day modeling, and there are more accurate methods of monitoring to assess levels of economic injury. Also of importance are secondary effects attributed to the effective biological control of the filbert aphid. The elimination of the early-season treatments for the filbert aphid may enable the establishment of populations of beneficial insects that prey on filbert leafrollers. Few leafrollers have been observed in abandoned hazelnut orchards, in contrast to managed orchards where leafroller populations are continually building.

The estimated cost of insecticide treatment for the control of filbert leafroller was $213,688 in 1980 ($406,007 1997 dollars) . In 1997 the estimated cost was $274,190 (Table 4). This is a decrease in cost of $131,817 (Table 7), corresponding to a reduction of more than 7,445 kg of insecticide (a.i.), and a decrease of nearly 25% in the area treated with insecticide.

Obliquebanded Leafroller, *Choristoneura rosaceana* (Harris), (Lepidoptera: Tortricidae)

Obliquebanded leafroller (OBLR) populations occasionally increase to levels of economic injury. However, first generation OBLR populations are managed when sprays are applied to control filbert leafroller since they are present concurrently. In 1980, 1,862 kg of insecticide

Table 4

Estimated pesticide use and cost patterns to control filbert leafroller in Oregon hazelnut orchards. All estimates are based on % ha of bearing hazelnuts.

Insecticide	% growers	% ha	Mean # appls.	Mean rate a.i. (kg/ha)	Est. total kg a.i.	Est. insecticide cost ($US)	Est. total cost ($US)
1980							
No insecticide used	61.9	42.9					
Diazinon (organophosphate)	17.3	23.6	1.0	1.11	2,311	33,808	75,708
Sevin (carbamate)	13.1	22.4	1.0	3.50	6,850	37,783	77,585
Zolone (organophosphate)	4.2	5.9	1.0	1.48	759	26,581	36,998
Guthion (organophosphate)	1.2	2.9	1.0	0.84	214	6,691	11,935
Cygon (organophosphate)	<1	<1	1.0	0.37	29	356	2,134
Metasystox R (organophosphate)	<1	<1	1.0	0.27	13	772	2,550
Thiodan (organophosphate)	<1	<1	1.0	2.24	172	3,802	5,580
							$212,490
1997							
No insecticide used	83.7	71.2					
Lorsban (organophosphate)	15.5	26.6	1.0	0.94	2,864	88,471	240,994
Guthion (organophosphate)	1.2	1.9	1.0	0.32	134	11,078	33,246
							$274,190

Table 5

Estimated pesticide use and cost patterns to control obliquebanded leafroller in Oregon hazelnut orchards. All estimates are based on % ha of bearing hazelnuts.

Insecticide	% growers	% ha	Mean # appls.	Mean rate a.i. (kg/ha)	Est. total kg a.i.	Est. insecticide cost ($US)	Est. total cost ($US)
1980							
No insecticide used	94.1	93.6					
Sevin (carbamate)	2.9	3.9	1.0	4.50	1,514	8,338	15,199
Zolone (organophosphate)	1.2	1.1	1.0	1.68	165	5,806	7,797
Guthion (organophosphate)	<1	<1	1.0	0.57	10	1,512	3,290
Thiodan (organophosphate)	<1	<1	1.0	1.68	173	3,240	5,018
							$31,304
1997							
No insecticide used	97.5	97.5					
Asana XL (synthetis pyrethroid)	1.2	<1	1.0	0.07	4	4,296	11,438
Guthion (organophosphate)	1.2	1.9	1.0	0.34	149	7,614	21,897
							$33,335

Table 6

Estimated pesticide use and cost patterns to control filbert aphid in Oregon hazelnut orchards. All estimates are based on % ha of bearing hazelnuts.

Insecticide	% growers	% ha	Mean # appls.	Mean rate a.i. (kg/ha)	Est. total kg a.i.	Est. insecticide cost ($US)	Est. total cost ($US)
1980							
No insecticide used	51.2	31.0					
Diazinon (organophosphate)	16.5	20.9	1.0	1.11	2,053	28,269	65,494
Zolone (organophosphate)	10.6	17.7	1.3	1.51	3,051	108,284	149,258
Cygon (organophosphate)	9.4	21.3	1.3	0.57	1,359	17,539	66,809
Systox (organophosphate)	5.9	5.8	1.0	0.37	193	11,351	21,804
Metasystox R (organophosphate)	2.9	1.5	1.25	0.17	30	1,678	5,078
Guthion (organophosphate)	1.2	<1	1.0	1.11	68	3,024	4,802
Thiodan (organophosphate)	1.2	<1	1.0	4.47	50	6,480	8,258
Malathion (organochlorine)	<1	<1	1.0	0.12	10	95	1,872
							$323,374
1997							
No insecticide used	96.2	93.9					
Lorsban (organophosphate)	3.7	6.1	1.0	0.62	440	970	13,586
							$48,666

(a.i.) were applied by 6% of the growers to 5% of the hazelnut area to control OBLR (Tables 2 and 5). In 1997, 153 kg of insecticide (a.i.) were applied by 2.5% of the growers to 2.5% of the hazelnut area. The insecticides used were Asana® and Guthion®.

The pest status of the obliquebanded leafroller has declined in hazelnut orchards during the 16-year period between 1980 and 1997. However some growers (2.5%) still apply insecticides to control this pest. Cost adjustments between 1980 and 1997 show that an annual saving of over $26,000 was achieved by adopting IPM practices in hazelnut orchards (Tables 5 and 7). As observed with control of filbert leafroller, a decrease of greater than 50% in the total hectares treated occurred as a result of the establishment of an IPM program to manage pests in hazelnut orchards.

Filbert Aphid, *Myzocallis coryli* (Goeze) (Homoptera: Aphidae)

The most dramatic change in insecticide use patterns in hazelnut orchards has occurred in the control of the filbert aphid. In 1980, 6,809 kg a.i. of insecticide were applied by 49% of the growers on 69% of the hazelnut area to control this pest (Tables 2 and 6). In 1997, 440 kg of insecticide (a.i.) were applied by 5% of the growers to 6% of the hazelnut area. A 15-fold reduction in the volume of insecticides, and a 10-fold reduction in the area treated occurred during the 16-year interval between surveys.

The filbert aphid was a serious pest of hazelnuts; reproducing parthenogenetically, it has 6-8 generations each year (AliNiazee and Messing 1995). It was an ideal candidate for the development of resistance that occurred every 1-3 years (Katundu and AliNiazee 1990). Therefore, finding and establishing an effective biological control was highly desirable. From the results of natural enemy surveys, it was concluded that filbert aphid was a suitable candidate for a classical biological control program based on the introduction of a host-specific parasitoid. During the 1984-1985 seasons, *Trioxys pallidus* Haliday (Hymenoptera: Aphidiidae), an effective parasitoid from Europe was introduced by Messing and AliNiazee (1989) to control the aphid. The parasitoid readily established; studies conducted in 1987 and 1988 showed that *T. pallidus* had an average level of parasitism of 25 -50% (AliNiazee and Messing 1995). This biological control program is noted as one of the most successful introductions of a biological control agent on record (AliNiazee and Messing 1995), and it resulted in an important reduction in the use of insecticides on hazelnuts. An estimated 5% of the hazelnut growers are currently using insecticides on 6% of the filbert acreage to control filbert aphid - a reduction in the use of insecticides by 90% of the growers on 91% of the hazelnut area. This translates to a vast environmental benefit in terms of the total reduction of pesticides used in Oregon hazelnut orchards.

Not only has the establishment of the *T. pallidus* wasp had a favorable impact on the environment, but it has resulted in large economic savings as well. The reduction in pesticide use on hazelnuts has directly increased the profitability of growing hazelnuts in Oregon. The total area treated for filbert aphid was reduced from 69% to 6%, a reduction of 91%. This reduction of insecticide use on filbert aphid has resulted in an annual savings of nearly one-half-million dollars (Tables 6 and 7).

In summary, the insecticide use pattern on hazelnuts in Oregon has changed dramatically due to the establishment of a successful IPM program. A key component of this program was the successful release of a parasitic wasp as a biological control agent. Additionally, more effective sampling and monitoring methods for filbert leafroller and obliquebanded leafroller and the establishment of economic levels of injury have reduced the use of insecticides to control infestations. The adoption of an effective IPM system and effective biological control agent of a single pest have beneficially influenced the entire pest management strategy for hazelnuts; reducing grower costs by large amounts each year, and significantly reducing environmental pollution associated with the production of an agricultural commodity in an environmentally sensitive area.

Table 7

Costs to control hazelnut pests using the CPI ratio of 469/247 (1.9) to express 1980 costs as 1997 values.

Insect pest	Estimated cost to control in 1980	Value in 1997 $	Estimated cost to control in 1997	Estimated change
Filbertworm	560,783	1,065,488	1,275,832	+210,344
Filbert leafroller	212,490	403,731	274,190	-129,541
OBLR	31,304	59,478	33,335	-26,143
Filbert aphid	323,374	614,411	48,666	-565,745
Total	**$1,127,951**	**$2,143,108**	**$1,632,023**	**-$511,085**

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Enhancement of the activity of a nuclear polyhedrosis virus by an optical brightener in the eastern hemlock looper, *Lambdina fiscellaria fiscellaria* (Lepidoptera: Geometridae)

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ABSTRACT

The pathogenicity of a nuclear polyhedrosis virus originally isolated from *Lambdina fiscellaria lugubrosa* (Hulst) was compared between treatments with and without the optical brightener Blankophor P167 against *L. f. fiscellaria* (Guenée) in the laboratory. The brightener significantly enhanced viral activity by 7.5-fold in terms of LD_{50}, and by 22.9-fold in terms of LD_{95}. With the addition of the brightener, the virus killed *L. f. fiscellaria* larvae 1.5- to 1.8-fold faster than without the brightener.

Key words: nuclear polyhedrosis virus, *Lambdina fiscellaria fiscellaria*, optical brightener, virus enhancement

INTRODUCTION

The eastern hemlock looper (EHL), *Lambdina fiscellaria fiscellaria* (Guenée) (Lepidoptera: Geometridae), is one of the most destructive defoliators of balsam fir, *Abies balsamea* (L.), in eastern Canada (Hudak and Raske 1995). Outbreaks of EHL occur periodically, and each outbreak lasts several years before populations collapse abruptly. Viral diseases are suspected to play an important role in the collapse of outbreaks of this insect, although other field studies suggested that fungi are important mortality factors (Otvos *et al.* 1973). Cunningham (1970) isolated a multicapsid nuclear polyhedrosis virus (*Lff*MNPV) from an outbreak population of EHL. Previous laboratory studies revealed that larvae of EHL were susceptible to *Lff*MNPV and to other NPV viruses originally isolated from the western hemlock looper, *L. f. lugubrosa* (Hulst) or from the western oak looper, *L. f. somniaria* (Hulst) (Cunningham 1970). However, no satisfactory results have been obtained in a field spray trial with *Lff*MNPV against EHL (Cunningham and Kaupp 1995).

Optical brighteners act as whiteners, ultraviolet absorbers and protectants, thus they are widely used in detergent, paper, plastics, and organic coatings industries (Villaume 1958). Recently, optical brighteners were shown not only to protect insect viruses from the denaturing effect of UV radiation (Shapiro 1992), but also to enhance biological activity of several insect viruses against their respective hosts (Shapiro and Robertson 1992; Li and Otvos 1999a). Enhancement of viral activity by optical brighteners varied greatly from one virus-host system to another. Whether optical brighteners could enhance NPV activity against EHL was not determined previously. Here we report the results of laboratory experiments on EHL larvae exposed to various dosages of a nuclear polyhedrosis virus with and without Blankphor P167, an optical brightener that significantly enhanced activity of another NPV against the western spruce budworm (Li and Otvos 1999a). The objectives of this study were to determine 1) effects of the brightener on larval mortality of EHL (enhancement of viral activity), 2) effects of the brightener on the time-to-death of larvae killed by the virus.

MATERIALS AND METHODS

Experimental insects. Larvae were obtained from a laboratory colony of *L. f. fiscellaria*. The colony originated from larvae collected from the field in Québec and Newfoundland, and had been reared in the laboratory for one generation on artificial diet and natural foliage before the experiment (Li and Otvos 1999b). Following a 3 month diapause in darkness at 2.0 ± 0.5^{0}C and 100% R.H., the eggs of EHL were moved to a rearing room under conditions of 20 ± 1^{0}C, 55-60% R.H., and a photoperiod of 16:8 (L:D) h. Eggs were checked twice a day, and newly hatched larvae were transferred into 20-ml creamer cups (five larvae/cup) that contained a modified spruce budworm artificial diet without formalin (Robertson 1979). Larvae in the cups with diet were kept at the above rearing conditions for about 2 weeks before being transferred onto flushing young (1 m-high) grand fir trees, *Abies grandis* (Dougl. ex D. Don) housed in a cage (0.8 x 1.0 x 1.5 m) at a rate of about 100 larvae per tree. The detailed larval rearing techniques were reported by Li and Otvos (1999b). Fourth-instar larvae, < 24-h-old, were removed from the trees in the cages, and placed in 24-well tissue culture plates (one larva/well) without food for 16-20 h before bioassays. Fourth-instar larvae were chosen for the tests because they are large enough to consume a virus-contaminated artificial diet pellet within 24 h (see below), and because their susceptibility to virus is not significantly different from those of younger larvae (Cunningham 1970).

Virus inocula. A multicapsid nuclear polyhedrosis virus originally isolated from *L.f. lugubrosa* (*Lfl*MNPV) was found to infect EHL larvae (Cunningham 1970). *Lfl*MNPV was purified by repeated centrifugation (3,000 - 8,000 rpm for 30 min each time at 15 ^{0}C) and resuspension in sterile distilled water. Stock suspensions of *Lfl*MNPV were quantified by counting polyhedral inclusion bodies (PIB) using Wigley's method (1980) and stored at 2 ^{0}C before use. Inocula were diluted in distilled water or in the final concentration of 1% (wt/wt) of optical brightener Blankophor P167 (Bayer Corp., Pittsburgh, PA) to the desired concentrations in the bioassays. The 1% concentration was tested because it was an optimal concentration for enhancing viral activity (Argauer and Shapiro 1997; Li and Otvos 1999a).

Bioassays. Five viral concentrations from 39 to 5,000 PIB/μl and six from 39 to 10,000 PIB/μl were used in the treatments with and without brightener, respectively. In addition, one control (distilled water alone) was made for the treatment without brightener, and 1% Blankophor P167 without virus was used as a control for the treatment with brightener. One μl of each viral dilution or control was applied onto a small pellet [4.4 mg ± 0.1 (SE), n = 20] of artificial diet inside each well of a 24-well tissue culture plate. The diet pellets were large enough to fully absorb 1 μl of liquid and allowed larvae to ingest known amount of virus. Immediately after the virus was added to the pellets, one fourth-instar larva, fasted for 16-20 h, was placed into each of the wells. Larvae were confined in the wells by covering the tissue culture plates with lids and were allowed to feed on the treated diet plug for 24 h under conditions of darkness, 20 ± 1^{0}C, and 55-60% R.H. Preliminary tests indicated that higher proportion of larvae consumed the entire diet plug within 24 h in the dark than in the light. Twenty-four larvae were tested for each replicate, and three replicates were made for each dilution or control. Those larvae that consumed the entire pellet of diet were transferred to untreated fresh one-year-old foliage of grand fir in a 170-ml fluted food cup (Sweetheart Cup Co. Inc., Chicago, IL) (five per cup) and placed at 25 ± 1°C, 55-60% RH, and 16:8 (L:D) h. Larvae that did not consume the entire pellet of diet were discarded.

Data analysis. Mortality was checked twice per week, and foliage changed. Tests were terminated 31 d after treatment, by which time larvae had either died or pupated. The cumulative mortality by 31 d was analyzed using probit analysis (LeOra Software 1994) to estimate the lethal doses of LD_{50} and LD_{95}. Differences in LD_{50} or LD_{95} between treatments with and without Blankophor P167 were compared for significance ($P < 0.05$) using the lethal-dose ratio test (Robertson and Preisler 1992).

To determine the effect of the optical brightener on the time to death (LT_{50} or LT_{95}), the data on larval mortality over time was analyzed with a complementary log-log model (Preisler and Robertson 1989; Robertson and Preisler 1992). The LT_{50} and LT_{95} for both treatments were estimated at the concentration of 5,000 PIB/µl of *Lfl*MNPV. The lethal-dose ratio test (Robertson and Preisler 1992) was used to determine significant differences ($P < 0.05$) in LT_{50} or LT_{95} between the two treatments.

RESULTS AND DISCUSSION

Effects of the optical brightener on larval mortality of EHL. Larval mortality was low in both controls [4.2% (n = 72) for distilled water alone, and 4.3% (n = 70) for 1% optical brightener alone], indicating that the larvae tested were healthy and that optical brightener was not toxic to EHL larvae. The LD_{50} and LD_{95} for the treatment with *Lfl*MNPV plus 1% Blankophor P167 were significantly ($P < 0.05$) lower than those for the treatment with *Lfl*MNPV alone (Table 1), indicating that the brightener enhanced *Lfl*MNPV activity against *L. f. fiscellaria.* About 174 PIB per larva were required to kill 50% of the test larvae when virus was used alone, while only 23 PIB per larva were needed to kill the same percentage of larvae when 1% brightener was added to the *Lfl*MNPV suspension. To increase larval mortality from 50 to 95%, 42.8 times as much virus was required for the treatment using *Lfl*MNPV alone (i.e., an increase from 173.9 to 7443.3 PIB per larva). In contrast, only 14.1 times as much virus was needed for the treatment with *Lfl*MNPV plus 1% brightener to increase larval mortality from 50 to 95% (i.e., an increase from 23.1 to 326.6 PIB per larva). In terms of LD_{50}, the addition of the brightener enhanced viral activity by 7.5 times. In terms of LD_{95}, the brightener enhanced *Lfl*MNPV activity by 22.9 times (Table 1). The 7.5- to 22.9-fold enhancement of viral activity in this study was much lower than the 90- to 1,500-fold increases previously reported when stilbene brighteners were added to *Ld*MNPV against *Lymantria dispar* (L.) (Shapiro and Robertson 1992; Argauer and Shapiro 1997), but was comparable to the 1.8- to 13-fold increase in the virus-host system of *Cf*MNPV and *Choristoneura occidentalis* Freeman (Li and Otvos 1999a).

Several bioassays have been developed to study insect viruses in the laboratory. In this study, we used a bioassay in which the same known amount of virus was consumed by each test larva. This technique may have some advantages over surface-contamination or foliage dipping bioassays where larvae ingested unknown amount of virus. With the addition of optical brighteners to the virus, feeding behavior of the larvae may have changed and they may not have consumed the same amount of virus. Thus, the bioassay used in this study may give more reliable results on the effects of optical brighteners on viral activity.

Table 1

Effect of Blankophor P167 on activity of *Lambdina fiscellaria lugubrosa* multicapsid nuclear polyhedrosis virus (*Lfl*MNPV) against *L. f. fiscellaria* larvae.

					LD_{50} (PIB per larva)[c]		LD_{95} (PIB per larva)	
Treatment	n[a]	Slope ± SE	χ^2	df	Value (95% CL)	Ratio (95% CL)	Value (95% CL)	Ratio (95% CL)
*Lfl*MNPV alone	399	1.01 ± 0.11	7.18ns[b]	4	173.9 (49.4-401.1)	7.5 (3.5-16.3)	7443.3 (2494.9-73365.0)	22.9 (2.3-230.5)
*Lfl*MNPV + 1% Blankophor P167	322	1.43 ± 0.26	2.67ns	3	23.1 (9.7-37.1)		326.6 (203.0-783.8)	

[a] number of larvae that consumed the entire diet pellet, not including control larvae.

[b] ns, not significant, ($P > 0.05$); implying the probit model is appropriate.

[c] Ratio was calculated by dividing the LD_{50} or LD_{95} for the treatment with the virus alone by the LD_{50} or LD_{95} for the treatment with the virus plus 1% Blankophor P167. Lethal dose values (LD_{50} and LD_{95}) are considered different if the 95% confidence limits of the ratio do not include 1 (Robertson and Preisler 1992).

Table 2

Effect of Blankophor P167 on time to mortality of *Lambdina fiscellaria fiscellaria* larvae by *L. f. lugubrosa* multicapsid nuclear polyhedrosis virus (*Lfl*MNPV) at 5000 PIB/μl.

					LT_{50} (days)[c]		LT_{95} (days)	
Treatment	n[a]	Slope ± SE	χ^2	df	Value (95% CL)	Ratio (95% CL)	Value (95% CL)	Ratio (95% CL)
*Lfl*MNPV alone	63	4.49 ± 0.38	3.78ns[b]	5	13.6 (12.5-14.6)	1.5 (1.3-1.7)	31.5 (27.9-37.1)	1.8 (1.5-2.2)
*Lfl*MNPV + 1% Blankophor P167	56	5.87 ± 0.57	0.95ns	4	9.1 (8.3-9.8)		17.3 (15.6-19.8)	

[a] number of larvae that consumed the entire diet pellet, not including control larvae.

[b] ns, not significant, ($P > 0.05$).

[c] Ratio was calculated by dividing the LT_{50} or LT_{95} for the treatment with the virus alone by the LT_{50} or LT_{95} for the treatment with the virus plus 1% Blankophor P167. Lethal time values (LT_{50} and LT_{95}) are considered different if the 95% confidence limits of the ratio do not include 1 (Robertson and Preisler 1992).

Effects of the optical brightener on time to death of EHL larvae killed by *Lfl*MNPV. The times to death (LT_{50} or LT_{95}) for the treatment with *Lfl*MNPV plus 1% Blankophor P167 were significantly ($P < 0.05$) shorter than those for the treatment with *Lfl*MNPV alone (Table 2), indicating that larvae died faster when the brightener was added to *Lfl*MNPV suspensions. At the concentration of 5,000 PIB per larva of *Lfl*MNPV, 13.6 days were required to kill 50% of the larvae when virus was used alone, while only 9.1 days were needed to kill the same percentage of larvae when 1% brightener was added to *Lfl*MNPV suspensions. To increase the lethal time from LT_{50} to LT_{95}, 2.3-fold as long was required for the treatment using *Lfl*MNPV alone (i.e., an increase from 13.6 to 31.8 days). In contrast, only 1.9-fold as long was needed for the treatment with *Lfl*MNPV plus 1% brightener to increase the lethal time from LT_{50} to LT_{95} (i.e., an increase from 9.1 to 17.3 days). In terms of LT_{50}, larvae in the treatment with virus plus brightener died 1.5 times faster than those in the treatment with virus alone. In terms of LT_{95}, the brightener reduced the time to death by 1.8 times (Table 2).

The addition of 1% Blankophor P167 not only increased *Lfl*MNPV activity against *L. f. fiscellaria*, but also hastened larval death in the laboratory. Although several insect viruses have been operationally used in pest management programs (Cunningham and Kaupp 1995), one of the drawbacks is the slow killing of pests by viruses. In most cases, foliage protection is the main aim of pest management strategies. Thus, the slow-action of insect viruses may be a serious disadvantage in pest control programs because severe damage may occur before pests are killed. Hastening larval death by the addition of optical brighteners to insect viruses may be of significance in crop protection, because viruses may kill pests before serious damage occurs. Hastening larval death may also lead to earlier and greater horizontal transmission of the virus, which enhances the development of secondary infection and possibly terminates the outbreak of the pest (Otvos *et al.* 1989). More research is needed to test the efficacy of virus with the addition of optical brighteners in the field under natural conditions.

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The bee fauna (Hymenoptera: Apoidea) of southeastern Washington

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ABSTRACT

A survey of the species composition, distribution, and host plants of bees (Hymenoptera: Apoidea) was conducted in the Snake River area, the Colton area, and the Moscow Mountain area of southeastern Washington. Nineteen genera and 100 species occurred in the three areas. The number of species found in each family were: 1 Colletidae; 11 Halictidae; 31 Megachilidae; 27 Adrenidae; 15 Anthophoridae and 15 Apidae. Location and flowers visited are listed for each species.

Key words: bees, Hymenoptera, Apoidea, bee fauna, Washington State

INTRODUCTION

There are no published faunal studies of bees in Washington despite their importance in pollination and their high priority with respect to conservation of biodiversity (Williams *et al.* 1993). Most information on the native bee species occurring in Washington is difficult to access because it is in various systematic works dealing with particular taxa (families, genera).

Bee studies in Washington have, in many cases, been concerned with the role of bees as pollinators of commercial crops. Menke (1952) listed a number of genera of Apoidea associated with apple (*Malus* × *domestica* Borkh). The alkali bee (*Nomia melanderi* Cockerell) and the alfalfa leafcutter bee (*Megachile rotundata* (Fabricius)) are important pollinators managed by alfalfa growers and have been studied extensively in Washington (Menke 1954; Johansen *et al.* 1978; Eves *et al.* 1980). Bumblebees have been studied for pollination of red clover seed (Johansen 1960; Dade and Johansen 1962) and cranberries (Johansen 1967; Macfarlane *et al.* 1994). Other studies of native bees in Washington examined and related behaviors of *Anthophora urbana urbana* Cresson (Mayer and Johansen 1976), *Andrena vicina* Smith (Miliczky and Osgood 1995), and *Melissodes microsticta* Cockerell (Miliczky 2000).

Bee diversity on the Columbia Plateau is expected to be high. Stephen *et al.* (1969) estimated that 879 species occurred in northwestern North America, and Washington, Oregon, and Idaho formed the core of this region. Bees are thought to reach their greatest diversity in number of species in warm temperate, xeric regions (Linsley 1958; Michener 1979). Mountainous areas of moderate rainfall, varied floras, and soils suitable for ground nesting forms also support rich bee faunas (Linsley 1958). Washington offers large expanses of both types of habitat, especially the part of the state east of the Cascade Mountains. Here we document the species composition, distribution, and host plants of the native bees of southeastern Washington in the first comprehensive study of Washington's bee fauna.

MATERIALS AND METHODS

We sampled pollinator communities in three ecological regions of southeastern Washington: 1) The Snake River area is 15.3 ha located 21-26 km southwest of Pullman, WA along the Snake River Road 5-8 km below the Wawawai railroad siding (T.36N-R.43E of quadrangle 57). The elevation ranged from 183-207 m and the area is Upper Sonoran Life Zone (St. John 1937). 2) The Colton area is a 11.3 ha original Palouse prairie vegetation area 21 km south of Pullman, WA (T.37N-R45E of quadrangle 57). The elevation ranged from 808-853 m and the area is Arid Transition Life Zone (St. John 1937). 3) Moscow Mountain is about 24 km northeast of Pullman, WA (T.39N-R5W of quadrangle 58) The sample area was on a 22.6 ha slope at the 1450 m level in the Canadian Zone (St. John 1937).

In each area we observed and collected bees from 15 June 1962 to 22 October 1962 and from 30 March 1963 to 20 June 1963. One collector made weekly trips to each site for a minimum of 8 h per day during the spring, summer and fall; a total of 34 collecting trips. The majority of collecting and observations were from 0730 h to 1730 h though we did occasionally collect and observe from dawn to dusk. Whenever possible, bee species identifiable in the field (*Bombus*, and some *Andrea* and *Anthophora*) were released to maintain the populations. Unidentified flowers were first given a site number. The bees and time of visitation were recorded in reference to this number and then plant specimens were collected for identification.

We used the direct searching method and insect nets to capture bees on flowers or in flight. We used the taxonomic system of Michener *et.al.* (1994) and used LaBerge (1956a, 1956b, 1961), Stephen (1954), Stephen (1957), Stephen *et al.* (1969) and Thorp *et al.* (1983) to identify collected specimens. Most of the *Andrena*, *Mellissodes*, *Diadasia* and *Colletes* were determined by Wallace E. LaBerge. Voucher specimens for 89 species were deposited at the Insect Museum at Washington State University, Pullman, WA.

Plant names are those used by Hitchcock (1955), except for the majority of Compositae which are from St. John (1937). Flower specimens were compared with determined material in the Herbarium at Washington State University.

RESULTS

Six-hundred-and-seven bees were collected. The diversity of bee species was greatest at the Snake River site (18 genera, 64 species) followed by Moscow Mountain (14 genera, 54 species) and the Colton site (14 genera, 37 species) (Table 1). Six families of bees were found (Colletidae, Halictidae, Megachilidae, Andrenidae, Anthophoride and Apidae). Nineteen genera and 100 species occurred in the three areas. One genus of Colletidae, 4 genera of Halictidae, 5 genera of Megachilidae, 2 genera of Andrenidae, 6 genera of Anthophoride and 2 genera of Apidae (the honey bee (*Apis melifera* L.) was not included) occurred in the study areas. One species of Colletidae, 11 species of Halictidae, 31 species of Megachilidae, 27 species of Andrenidae, 15 species of Anthophoridae and 15 species of Apidae occurred in the study areas.

Twenty-one families of plants (80 species) were identified as sources of nectar or pollen (usually both) for the visiting Apoidea (Table 1). The effect of elevation on host plant distrubtion and phenology was reflected in the distrubtion and capture dates of bee species at all three locations. *Osmia nanula* Cockerell was found in the middle of May at the lowest elevation but one month later at the mountain area. *Halictus ligatus* Say, *H. tripartitus* Cockerell, *Andrena prunorum* Cockerell and *A. opaciventris* Cockerell were also captured later in the season at higher elevations. This same phenomenon was also shown by the six most common *Bombus* species. Queens of all six species were observed by mid-April at the Snake River area, about 2 weeks later at the Colton area, except for *B. occidentalis* Greene, and at the Moscow mountain area about 4 weeks later.

Table 1

List of bee species collected from three specific areas in southeastern Washington.
S = Snake River area, C = Colton area, M = Moscow Mtn. area.

Family and Species	Area	Flowers visited
COLLETIDAE (1 sp.)		
Colletinae		
Colletes californicus Provancher	M	*Mertensia paniculata*
HALICTIDAE (11 spp.)		
Halictinae		
Agapostemon cockerelli Crawford	M	*Rudbeckia occidentalis, Cirsium arvense, Cirsium vulgare*
Agapostemon texanus Cresson	S, C	*Convolvulus* sp., *Medicago sativa, Helianthus annus, Haplopappus* sp.
Agapostemon virescens (Fabricius)	S,M,C	C. *vulgare, Vicia* sp., *Helianthus annus, Rosa* sp., *Gaillardia aristata, Epilobium angustifolium, Gentiana calycosa,* Compositae
Halictus farinosus Smith	S	*Lomatium* spp., *Malus* × *domestica, Brassica campestris, Sisymbrium attissimum, Helianthus annus, Solidago* sp.
Halictus ligatus Say	S, M, C	*Helianthus annus, Cirsium arvense, Solidago* sp., *Hapiopappus* sp.
Halictus rubicundus (Christ)	S, M	*Lomatium* spp., *Trifolium repens, Taraxacum officinate, Ranunculus* sp., *Cirsium arvense*
Halictus tripartitus Cockerell	S, M, C	*Lomatium* spp., *Rosa* sp., Compositae, *Solidago* sp., *Trifolium repens, Ranunculus* sp., *Taraxacum officinale, Collinsia parviflora, Cirsium arvense*
Lasioglossum spp. sen. s.	S, M, C	*Lomatium* spp., *Malus* × *domestica, Balsamorhiza sagittata, Potentilla gracilis, Helianthella uniflora, Trifolium repens*
Lasioglossum spp. (*Dialictus*)	S	*Lomatium* spp.,*Malus* × *domestica, Gaillardia aristata*
Lasioglossum spp. (*Evylaeus*)	S	*Lomatium* spp., *Prunus avium, Malus* × *domestica, Prunus virginiana, Taraxacum officinale*
Rophitinae		
Dufourea sp.	M	*Phacelia heterophylla*
MEGACHILIDAE (31 spp.)		
Megachilinae		
Anthidium emarginatum (Say)	S	*Phacelia heterophylla*
Anthidium utahense Swenk	S	*Vicia villosa*
Hoplitis albifrons argentifrons (Cresson)	M	*Lupinus polyphyllus, Phacelia heterophylla*
Hoplitis fulgida fulgida (Cresson)	M	*Ranunculus* sp., *Delphinium nuttalliana, Physocarpus malvaceus, Phacelia heterophylla*
Hoplitis hypocrita (Cockerell)	S, M	*Balsamorhiza sagitatta, Lomatium* spp., *Penstemon attenuatus*
Megachile brevis Say	S	*Solidago* sp.
Megachile gemula Cresson	M	*Physocarpus malvaceus*
Megachile melanophaea calogaster Cockerell	M	none

Megachile parallela Smith	S	*Helianthus annus*
Megachile perihirta Cockerell	S, C	*Vicia villosa, Xanthium* sp., Compositae, *Solidago* sp., *Gaillardia aristata, Senecio serra, Cirsium vulgare, Cirsium arvense*
Megachile pugnata Say	S	*Erigeron speciosus*
Osmia atrocyanea atrocyanea Cockerell	S, M	*Malus × domestica, Balsamorhiza sagittata, Lupinus polyphyllus, Vicia villosa*
Osmia brevis Cresson	S, M	*Vicia villosa, Trifolium repens, Phacelia heterophylla*
Osmia bruneri Cockerell or *cobaltina* Cresson	S	*Penstemon lanatum*
Osmia californica Cresson	S	*Lomatium* spp., *Ribes aureum, Balsamorhiza sagittata, Gaillardia aristata*
Osmia calla Cockerell	S	*Vicia villosa*
Osmia coloradensis Cresson	M	*Trifolium repens, Arnica cordifolia*
Osmia juxta juxta Cresson	M	*Epilobium angustifolium*
Osmia kincaidii Cockerell	M	*Phacelia heterophylla, Collinsia parviflora*
Osmia lignaria Say	M	*Pyrus scopulina, Arnica cordifolia, Phacelia heterophylla*
Osmia montana Cresson	S	*Rosa* sp., *Gaillardia aristata*
Osmia nanula Cockerell	M, C	*Geranium viscosissimum, Ranunculus* sp.
Osmia nr. *nanula* Cockerell	S, M	*Vicia villosa, Trifolium repens*
Osmia nemoris Sandhouse	S, M	*Balsamorhiza sagittata, Arnica cordifolia*
Osmia nifoata Cockerell	M	*Pyrus scopulina*
Osmia nigrifrons Cresson	S	*Balsamorhiza sagittata, Vicia villosa*
Osmia pentstemonis Cockerell	S, M	*Penstemon albertinus*
Osmia pikei Cockerell	S	*Balsamorhiza sagittata*
Osmia subaustralis Cockerell	S	*Gaillardia aristata*
Stelis nr. *foederalis* Smith	M	none
Stelis subcaerulea Cresson	S, C	*Eriophyllum lanatum, Achillea millefolium*
ANDRENIDAE (27 spp.)		
Andrenina		
Andrena amphibola (Viereck)	C	*Agastache urticifolia*
Andrena angustitarsata Viereck	S, M, C	*Lomatium* spp.,*Malus × domestica, Prunus virginina, Pyrus scopulina, Rosa* sp., *Ranunculus* sp., *Physocarpus malvaceus, Rubus parviflorus*
Andrena auricoma (Smith)	M	*Potentilla* sp., *Achillea millefolium, Physocarpus malvaceus*
Andrena caerulea Smith	S, M	*Ranunculus* sp., *Prunus virginiana*
Andrena candida Smith	S	*Lomatium* spp.,*Prunus avium, Balsamorhiza sagittata*
Andrena chlorogaster Viereck	M	*Physcarpus malvaceus, Potentilla* sp.
Andrena crataegi Robertson	M	*Physcarpus malvaceus*
Andrena cressonii Robertson	S, C	*Lomatium* spp., *Balsamorhiza sagitata, Rosa* sp., *Prunus virginiana, Geranium viscosissimum*
Andrena helianthi Robertson	S	*Helianthus annus, Solidago canadensis*
Andrena hemileuca Viereck	M	*Pyrus scopulina*
Andrena merriami Cockerell	S, C	*Lomatium* spp., *Prunus avium*
Andrena microchlora Cockerell	S	*Lomatium* spp., *Malus × domestica, Ribes aureum*
Andrena miserabilis Cresson	M	*Physcarpus malvaceus*
Andrena nigrocaerulea Cockerell	C	*Geranium viscosissimum*
Andrena nivalis Smith	M	*Physcarpus malvaceus*

Andrena pallidifovea (Viereck)	S	*Eriophyllum lanatum*
Andrena perarmata Cockerell	S	*Lomatium* spp.
Andrena pertristis carliniformis Viereck & Cockerell	C	*Lomatium* spp.
Andrena prunorum Cockerell	S, M, C	*Lomatium* spp., *Sisymbrium attissimum, Philadelphus lewisii, Holodiscus discolor, Geranium. viscosissimum, Physcarpus malvaceus*
Andrena subsaustralis Cockerell	M	*Balsamorhiza sagittata*
Andrena subtilis Smith	S, C	*Rosa* sp.
Andrena topozana Cockerell	M	*Cirsium arvense*
Andrena trizonata Ashmead	M	*Phycarpus malvaceus*
Andrena vicina Smith	S, M, C	*Phycarpus malvaceus, Rosa* sp., *Geranium viscosissimum, Holodiscus discolor, Rubus parviflorus*
[1]*Andrena* sp. E new sp.	S, C	*Balsamorhiza sagittata, Lomatium* spp.
Panurginae		
Perdita lingualis Cockerell	S, C	*Rosa* sp., *Geranium viscosissimum, Helianthus annus*
Perdita wyomingensis sculleni Timberlake	S	*Holodiscus discolor, Achillea millefolium*
ANTHOPHORIDAE (15 spp.)		
Anthophorinae		
Anthophora bomboides Kirby	S	none
Anthophora pacifica Cresson	S, C	*Lomatium* spp., *Prunus armeniaca, Malus × domestica, Syringa* sp., *Balsamorhiza sagitatta, Ribes aureum*
Anthophora ursina Cresson	S	*Vicia villosa*
Diadasia enavata Cresson	S	*Helianthus annus*
Diadasia nigrifrons (Cresson)	C	*Sidalcea oregana*
Habropoda cineraria (Smith)	S	*Physcarpus armeniaca, Malus × domestica, Rosa* sp., *Ribes aureum*
Melissodes agilis Cresson	S	*Helianthus annus, Gaillardia aristata*
Mellisodes lupina Cresson	S	*Helianthus annus*
Melissodes metenua Cockerell	C	*Haplopappus liatriformis*
Mellisodes rivalis Cresson	C	*Cirsium vulgare*
Mellisodes robustior Cockerell	S	*Helianthus annus*
Synhalonia actuosa (Cresson)	S, C	*Balsamorhiza sagitatta, Malus × domestica, Prunus virginiana, Lupinus* sp., *Vicia villosa*
Synhalonia edwardsii (Cresson)	S	*Vicia villosa, Lupinus polyphyllus, Dipsacus sylvestris*
Synhalonia frater (Cresson)	S, M,C	*Balsamorhiza sagitatta, Malus × domestica, Syringa* sp., *Trifolium repens, Penstemon attenuatus, Brodiaea douglasii*
Xylocopinae		
Ceratina acantha Provancher	S, M, C	*Lomatium* spp., *Rosa* sp., *Penstemon triphyllus,Eriophyllum lanatum, Helianthus annus, Geranium viscosissimum, Cirsium lanceolatum*
APIDAE (15 spp.)		
Bombinae		
Bombus appositus Cresson	S, M, C	*Phacelia* sp., *Balsamorhiza sagittata, Vicia villosa, Agastache urticifolia, Brodiaea douglasii*
Bombus bifarius Cresson	M, C	*Anaphalis margaritacea, Epilobium*

		angustifolium, Rudbeckia occidentalis, Collinsia parviflora, Cirsium arvense, Phacelia spp., *Sisyrinchium albus, Lupinus polyphyllus, Vicia villosa, Penstemon* spp.
Bombus californicus F. Smith	S, C	*Vicia villosa, Sisyrincyhium albus*
Bombus centralis Cresson	S, M, C	*Epilobium angustifolium, Rosa* sp., *Rubus parviflorus, Malus × domestica, Geranium viscosissimum, Anaphalis margaritacea, Rudbeckia occidentalis, Collinsia parviflora, Sisyrinchium albus, Balsamorhiza sagittata, Lupinus polyphyllus, Trifolium repens, Mertensia paniculata, Dipsacus sylvestris, Vicia villosa, Agastache urticifolia, Penstemon* spp., *Brodiaea douglasii*
Bombus fervidus (Fabricius)	S, M, C	*Epilobium angustifolium, Rosa* sp., *Malus × domestica, Geranium viscosissimum, Anaphalis margaritacea, Rudbeckia occidentalis, Sisyrinchium albus, Medicgo sativa, Balsamorhiza sagittata, Cirsium lanceolatum, Lupinus polyphyllus, Dipsacus sylvestris, Vicia villosa, Agastache urticifolia, Brodiaea douglasii*
Bombus flavirons Cresson	M, C	*Epilobium angustifolium, Cirsium arvense, Sisyrinchium albus, Helianthus annus, Dipsacus sylvestris, Vicia villosa, Agastache urticifolia, Penstemon* spp., *Castilleja* sp.
Bombus griseocollis (Degeer)	S, M, C	*Epilobium angustifolium, Rosa* sp., *Solidago* sp., *Phacelia* sp., *Sisyrinchium albus, Medicgo sativa, Balsamorhiza sagittata, Helianthus annus, Lupinus polyphyllus, Vicia villosa, Penstemon* spp.
Bombus mixtus Cresson	M, C	*Epilobium angustifolium, Rudbeckia occidentalis, Collinsia parviflora, Phacelia* sp., *Sisyrinchium albus, Lupinus polyphyllus, Arnica cordifolia, Mertensia paniculata*
Bombus nevadensis Cresson	S, M, C	*Malus × domestica, Solidago* sp., *Phacelia* sp., *Medicgo sativa, Balsamorhiza sagittata, Cirsium lanceolatum, Trifoluim. repens, Dipsacus sylvestris, Vicia villosa, Agastache urticifolia, Astragulus* sp., *Penstemon* spp., *Brodiaea douglasii*
Bombus occidentalis Greene	S, M, C	*Epilobium angustifolium, Rosa* sp., *Rubus parviflorus, Malus × domestica, Phacelia* sp., *Sisyrinchium albus, Medicgo sativa, Balsqamorhiza sagittata, Cirsium lanceolatum, Lupinus polyphyllus, Trifoluim repens, Aconitium columbianum, Vicia villosa, Penstemon sp., Brodiaea douglasii*
Bombus rufocinctus Cresson	S, M	*Epilobium angustifolium, Geranium viscosissimum, Phacelia* sp., *Sisyrinchium albus, Brodiaea douglasii*
Bombus vagans Smith	M	*Sisyrinchium albus*
Psithyrus insularis (F. Smith)	C	*Epilobium angustifolium, Dipsacus*

		sylvestris, Agastache urticifolia
Psithyrus suckleyi (Greene)	S, M	*Epilobium angustifolium, Sisyrinchium albus, Agastache urticifolia, Brodiaea douglasii, Senecio viscosissimum*
Psithyrus variabilis (Cresson)	M	*Epilobium angustifolium*

[1] Species E in the collection of Dan Mayer; yet to be described.

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A comparison of traps and trap trees for capturing Douglas-fir beetle, *Dendroctonus pseudotsugae* (Coleoptera: Scolytidae)

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ABSTRACT

We compared pheromone-baited traps and trap trees for managing Douglas-fir beetle (DFB), *Dendroctonus pseudotsugae* Hopkins populations. Pheromone-baited traps caught significantly more DFB than did trap trees. More male DFB were caught in pheromone-baited traps than in trap trees, while significantly higher numbers of females were caught in the trap trees. Additional benefits of pheromone-baited traps include, easy deployment, less mortality of some beneficial insects, and low cost.

Key words: *Dendroctonus pseudotsugae*, Scolytidae, pheromones, trapping, trap trees

INTRODUCTION

The Douglas-fir beetle (DFB), *Dendroctonus pseudotsugae* Hopkins (Coleoptera: Scolytidae) is found throughout the range of Douglas-fir, *Pseudotsugae menziesii* (Mirbel). Although endemic populations of DFB usually inhabit dead, dying, downed, or injured trees, epidemic populations may also attack and kill large numbers of apparently healthy trees. Tree mortality caused by these beetles can lead to severe economic losses and interfere with management objectives in the infested area.

Pheromones of DFB are well known (Pitman and Vité 1970; Kinzer *et al.* 1971; Furniss *et al.* 1972; Rudinsky *et al.* 1974; Libbey *et al.* 1983) and several have been implemented in management strategies. Aerial application of the DFB anti-aggregation pheromone, 3-methylcyclohex-2-en-1-one (MCH), can effectively prevent the infestation of windthrown trees (McGregor *et al.* 1984). Strategies incorporating pheromone-baited traps and MCH (Ross and Daterman 1994), or MCH alone (Ross and Daterman 1995a), have significantly reduced DFB infestations in live trees in high-risk stands. Aggregation pheromones have been used to create trap trees in areas where DFB population levels are high (Knopf and Pitman 1972; Pitman 1973; Ringold *et al.* 1975). Trap trees concentrate DFB in selected trees that are subsequently harvested, thereby removing beetles from the local population. Aggregation and anti-aggregation pheromones can be used to selectively create tree snags, an important wildlife habitat component (Ross and Niwa 1997).

Pheromone-baited traps may be an alternative to trap trees in some situations (Ross and Daterman 1995b). While trap trees have been used for a number of years in operational programs (Patterson 1992), pheromone-baited traps have been used only to a limited extent by managers. This study was designed to compare the efficacy of trap trees and pheromone-baited traps in managing DFB.

MATERIALS AND METHODS

Field research was conducted in the Nezperce National Forest in central Idaho. The study area was a mixed-conifer stand composed primarily of Douglas-fir, with ponderosa pine (*Pinus ponderosa* Laws.) and grand fir (*Abies grandis* Lindl.) present at lower densities. Elevation of the study area ranged from 1524 to 1584 m and it was bisected by a forest road, with a recent clearcut on one side and a mature mixed-conifer stand on the other.

On 28 April 1997, before the onset of DFB flight, pheromone-baited traps were placed in the clearcut area adjacent to the Douglas-fir stand. Seven 16-unit multiple funnel traps (Lindgren 1983) were baited with 400 mg of frontalin (1,5-dimethyl-6,8-dioxabicyclo [3.2.1] octane) and 200 mg of seudenol (3-methylcyclohex-2-en-1-ol) in polyvinylchloride (PVC) formulations, and 15 ml of ethanol in a plastic pouch formulation. Release rates and chemical descriptions can be found in Ross and Daterman (1997). Traps were positioned in a line approximately 75 m apart. A piece of dichlorvos-impregnated plastic was added to each collection cup to kill captured insects. Captured insects were collected weekly from 15 May to 26 August. Samples were sorted to remove DFB and three primary bark beetle predators, *Thanasimus undatulus* (Say) (Coleoptera: Cleridae), *Temnochila chlorodia* (Mannerheim) (Coleoptera: Trogositidae), and *Enoclerus sphegeus* Fabricius (Coleoptera: Cleridae). All DFB in the samples were counted and sexed. Beetles captured in each trap were summed over the trapping period to determine the total number of beetles removed from the population by each trap.

When the traps were deployed, seven trees in the Douglas-fir stand adjacent to the clear cut were baited with pheromones to initiate DFB attack. These trees were spaced about 75 m apart in a line roughly parallel to the trap line. The line of trees and trap line were 150-200 m apart. A commercially available tree bait (Phero Tech Inc., Delta, BC, Canada) containing frontalin and α-pinene was stapled to each trap tree at a height of 2-3 m. In addition to the commercial tree bait, frontalin (20 mg) and seudenol (10 mg) in PVC formulations were attached to the tree boles. Mean diameter at breast height (dbh) of trap trees was 66 cm (SE ± 2.5), and mean height was 36.3 m (SE ± 1.2).

Trap trees were sampled on 28 July 1997, after the DFB flight had ended. Each tree was climbed to determine height at the top of the infestation, circumference at the top of the infestation, and to remove bark samples to estimate attack densities. In addition, height at the base of the infestation and circumference at the base of the infestation were measured. An axe was used to cut through the bark to determine if DFB galleries were present. This was continued until no DFB galleries were found at the top or bottom of trap trees. The average of the circumference at the base and top of the infestation was used along with length of the infested bole to estimate the amount of infested bark area for each tree based on the equation for the surface area of a cylinder. The areas surrounding trap trees were surveyed to determine if there were any spill-over attacks on adjacent trees.

At three heights along the infested tree bole, four 100 cm^2 circular bark samples were removed with an electric drill and hole saw. Sample heights were near the top, middle, and bottom of the infested portion of the bole. Samples were placed in plastic bags and stored in an ice chest until transported to the lab. In the lab, attack sites were determined for each sample. Attack sites were distinguished from ventilation holes or exit holes by their angle and the presence of packed frass.

To determine attack sites per tree, mean number of attack sites per cm^2 was multiplied by the surface area of the infested tree bole. Because DFB is monogamous, each attack site represents one pair of beetles that entered the trap tree. The total number of attack sites was multiplied by two to determine total number of DFB caught in each tree.

Catches of traps and trap trees were compared using a t-test. A square root transformation was used to meet assumptions of equal variances. All tests were performed with the statistical software JMP (ver 3.1.5, SAS Institute Inc., Cary, NC)

RESULTS

Mean infested tree bole surface area was 29.8 m^2 (SE ± 4.0) ranging from 19.2 to 48.9 m^2. Mean number of attack sites per tree was 3,320.8 (SE ± 607.0). Mean attack densities were 90 per m^2 and did not differ significantly by height ($P = 0.26$). No trees adjacent to trap trees were attacked by DFB.

The mean of the total number of beetles caught per trap over the season was 13,740.6 (SE ± 2813.5). In comparison, trap trees captured on average 6641.6 (SE ± 1213.9) beetles. Significantly more beetles were captured in the traps than in the trap trees ($P = 0.04$). Significantly more males were captured in traps than in trap trees ($P = 0.04$), assuming a 1:1 sex ratio in trap trees. In comparison, significantly more females were captured in trap trees than in traps ($P = 0.009$). Mean percent male beetles caught in traps was 80.8 (SE ± 0.66).

DISCUSSION

Pheromone-baited traps are used extensively to study the biology and behavior of many bark beetle species. In addition, pheromone-baited traps have been implemented in strategies to manage or monitor some pest species, or both (Lindgren and Borden 1983; Billings 1985; Shore and McLean 1985). However, trap trees have been used more commonly in the past to manage DFB populations than pheromone-baited traps. We could find no published data comparing the efficacy of trap trees and pheromone-baited traps in the management of DFB.

In our study, pheromone-baited traps were more effective at capturing DFB than trap trees. More beetles were removed from the population with pheromone-baited traps than trap trees. Because of damage to pheromone-baited traps, total trap catches were likely higher than our final results indicate. Throughout the study, ten trap collections were lost due to trap damage. Four of these occurred on 11 June when DFB activity was high. The average trap catch for the two undisturbed traps on that date was 1,307 beetles. We do not know exactly when the traps were damaged. If they were damaged immediately after they were last emptied then they likely caught few beetles. However, if they were damaged just before they were visited, then they may have caught as many as 5,228 additional beetles that were not included in our estimate of the total catch. In operational programs, damage to traps might be reduced by suspending them in non-host trees at a height where wildlife and livestock could not disturb them. However, deploying and maintaining suspended traps takes more time and, therefore, is more costly than for traps that are placed at ground level.

Although our estimate of captured beetles in traps is higher than in trap trees, it is possible that traps have an even greater impact on local beetle populations than suggested by a simple comparison of numbers of captured beetles. Because the brood sex ratio is 1:1 (Bedard 1937; Vité and Rudinsky 1957) and DFB is predominantly monogamous, removal of one beetle could actually represent the removal of a mated pair. Since we do not know what proportion of beetles collected in traps would have mated with one another if they had not been captured, we cannot determine the actual impact of trapping on local beetle populations. At one extreme, assuming that no beetles in the traps would have mated with each other, then the traps actually could have removed twice as many mated pairs from the population as indicated by the number of captured beetles.

There is evidence from laboratory studies that suggests some male DFB may mate with more than one female (Vité and Rudinsky 1957). However, there are no published data to indicate how often this occurs under natural conditions. If DFB males mate more than once under natural conditions, the removal of a single male beetle would not be equivalent to removal of a mated pair. Courtship in DFB is initially aggressive (Ryker 1984) and beetles may suffer significant damage during the mating process and gallery construction. Consequently, it is likely that many re-emerging male beetles are damaged and incapable of prolonged flights to locate new host trees and female beetles. With extended time searching for host trees and female beetles, DFB males would be exposed to higher levels of predation and other mortality factors. Until research is conducted to determine the sexual behavior of DFB under field conditions, we cannot be certain of the impact of removal of males from local breeding populations.

One possible reason that traps caught more DFB is that they continuously remove beetles from the population for the entire season. In comparison, trap trees have a finite capacity for trapping beetles. Once trees are fully colonized, MCH is released by adult DFB to deter other beetles from colonizing the tree. Consequently, beetles arriving at trap trees after they are fully colonized will attack nearby host trees if they are present, or they will disperse in search of suitable habitat.

Pheromone-baited traps removed a significantly higher number of male beetles from the population than trap trees. In comparison, trap trees removed a significantly higher number of female beetles than traps. It is possible that by manipulating trap lure components, a higher number of females could be captured. For example, addition of ethanol to the trap lure increases both total number of beetles and the proportion of females captured (Ross and Daterman 1995c). However, this may not be important, because DFB broods have a 1:1 sex ratio and the beetle is monogamous. Consequently, as discussed above, removing a male or a female theoretically removes a mating pair of beetles from the local population.

While a higher number of DFB are removed from local populations using traps compared to trap trees, impacts on beneficial insects are likely less. For example, when trap trees are harvested, beneficial insects inhabiting those trees are also removed from the local population. Beneficial insects, including predators and parasitoids, have been shown to cause high levels of mortality to several bark beetle species (Linit and Stephen 1983; Weslien 1994; Schroeder and Weslien 1994; Schroeder 1996) and some may have a regulating effect on populations (Reeve 1997; Turchin *et al.* 1999). Depending on timing of DFB infestation and removal of trap trees, beneficial insects including *Coeloides brunneri* Vierick (Hymenoptera: Braconidae), *Medetera aldrichii* Wheeler (Diptera: Dolichopidae), *Thanasimus undatulus*, *Enoclerus sphegeus*, *Temnochila chlorodia*, and possibly others could still be developing within or inhabiting host trees. Removal of these species may significantly impact natural controls in subsequent bark beetle generations.

While traps catch several predaceous beetle species, the impact on local populations is unknown. Many *T. undatulus* are often captured in traps. This beetle preys on DFB, but laboratory studies suggest that it prefers smaller species of *Scolytus* and *Pseudohylesinus* (Schmitz 1978). To minimize the possible impact of removing predators from the population, trap modifications can be employed to prevent their capture or provide for their escape (Ross and Daterman 1998). Additionally, traps do not capture parasitoids because they are not attracted to pheromones.

In addition to catching higher numbers of bark beetles, traps have several other advantages. First, traps are easily deployed and can be placed almost anywhere there is the threat of tree mortality. Traps, unlike trap trees, can be located in non-host stands or openings to minimize attacks on nearby host trees. Pheromones and traps are relatively inexpensive and traps can be used for several to many years depending upon their method of construction. Also, by using traps, no trees need be sacrificed.

Pheromone-baited traps are effective at capturing large numbers of DFB, thus removing beetles from the breeding population in local areas. Natural resource managers should consider substituting traps for trap trees in their management plans for DFB. By doing this, more beetles may be removed from local populations, while valuable trees need not be sacrificed.

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The Chrysopidae of Canada (Neuroptera): recent acquisitions chiefly in British Columbia and Yukon

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ABSTRACT

Chrysopidae collected since 1980 chiefly in British Columbia and Yukon, Canada, and some late additions collected before 1980, are reported. *Nineta gravida* (Banks) is reported for the first time in the last 90 years. This is the first supplement to the inventory of Chrysopidae in Canada.

Key words: Neuroptera, Chrysopidae, Canada

INTRODUCTION

The chrysopid fauna of Canada, as presently understood (Garland 1984, 1985), has been fully inventoried up to 1980 (Garland 1982). Since then, newly collected specimens in British Columbia and the Yukon, and some older-dated specimens not previously seen, have become available. The purpose of publishing these specimen label data is to supplement the already extensive inventory of label data on the Canadian chrysopid fauna, thereby extending it to the year 2000. Materials and methods appropriate to this study have been documented elsewhere (Garland 2000). All specimens reported here are deposited in the Spencer Entomological Museum, Department of Zoology, University of British Columbia. Acronyms used below: BC, British Columbia; SK, Saskatchewan; and YK, Yukon Territory.

FAMILY CHRYSOPIDAE Schneider, 1851
SUBFAMILY CHRYSOPINAE Schneider, 1851

A total of 57 specimens belonging to 10 recent species of Chrysopinae are reported here, as follows:

Chrysopa chi Fitch

BC: 1 ♀, Gavin L[ake], 25.v.1987 (R. Reich); 1 ♂, *id.*, 3.vi.1987 (R. Reich).

Chrysopa coloradensis Banks

BC: 1 ♂, Penticton, 23.viii.1983 (R.J. Cannings).

Chrysopa nigricornis Burmeister

BC: 1 ♂, Galiano I[sland], Spanish Hills, 26.vi.1987 (G.G.E. Scudder); 1 ♂, Osoyoos, 15.vii.1990 (G.G.E. Scudder); 4 ♂♂, *id.*, 16.vii.1990 (G.G.E. Scudder); 1 ♂, Osoyoos, East Bench, 30.viii.1997 (G.G.E. Scudder); 1 ♂, Penticton, 23.viii.1983 (R.J. Cannings); 1 ♂, Vanc[ouver], 4. 6 [vi]. [19]25, Permanent Loan from Vancouver City Museum.

Chrysopa oculata Say

YK: 1 ♀, Alaska Hwy, 29.vi.1974 (G.G.E. Scudder); 2 ♀♀, McCabe Cr[eek], 8 km S[outh], 30.vi.1985 (E. Krebs & J.J. Robinson); 1 ♀, Pelly Crossing, 30.vi.1985 (E. Krebs & J.J. Robinson); 1 ♀, Tatchun L[ake], 29.vi.1985 (E. Krebs & J.J. Robinson).

BC: 1 ♀, Dutch Cr[eek], 1 km N[orth], 31.viii.1998 (G.G.E. Scudder); 1 ♀, F[or]t Nelson, 1367 [collected in alcohol], 2.viii.1982 (G.G.E. Scudder); 1 ♀, Galiano I[sland], North end, 25.vi.1989 (G.G.E. Scudder); 1 ♀, Moyie, 1.ix.1998 (G.G.E. Scudder); 1 ♀, Osoyoos L[ake], Haynes Ecol[ogical] Res[erve], 27.vi.1981 (S.G. Cannings); 1 ♀, Sparwood, 20.vi.1982 (G.G.E. Scudder).

SK: 1 ♂, Regina, 18.vi.1943 (P. Larkin).

Chrysopa pleuralis Banks

BC: 1 ♂, Osoyoos, M[oun]t Kobau R[oa]d, km 17.1, 1720 m, IDFdk1,6VK:F/2DYd4/2RO, sweeping K3, 28.vii.1997 (G.G.E. Scudder).

Chrysoperla carnea (Stephens)

BC: 1 ♂, Alaska Hwy, km 670, Racing River, 1.viii.1982 (G.G.E. Scudder); 1 ♀, Alaska Hwy, 32.1 km E[ast of] Steamboat, 1.viii.1982 (G.G.E. Scudder); 1 ♀, Charlie L[ake], 25 km W[est], 5.viii.1982 (G.G.E. Scudder); 3 ♂♂, 10 ♀♀, F[or]t Nelson, 1367 [collected in alcohol], 2.viii.1982 (G.G.E. Scudder); 1 ♀, Galiano I[sland], Spanish Hills, 26.vi.1987 (G.G.E. Scudder); 1 ♀, Nanaimo, 7.v.1987 (G.G.E. Scudder); 1 ♂, Sonora I[sland], Owen Bay, 26.vii.1986 (G.G.E. Scudder); 1 ♂, 1 ♀, W[est] Vancouver, 12.viii.[19]34 (G.H. Larnder), Permanent Loan from Vancouver City Museum; 5 ♂♂, 2 ♀♀, Wood Creek, 2 km N[orth of] Toad River, 1361 [collected in alcohol], 1.viii.1982 (G.G.E. Scudder).

Meleoma dolicharthra (Navás)

BC: 1 ♂, Galiano I[sland], Spanish Hills, 26.vi.1987 (G.G.E. Scudder).

Meleoma emuncta (Fitch)

BC: 1 ♀, Penticton, 23.viii.1983 (R.J. Cannings).

Meleoma signoretti Fitch

BC: 1 ♀ [left FW & abdomen missing], W[est] Vancouver, 12.viii.[19]34 (G.H. Larnder), Permanent Loan from Vancouver City Museum.

Nineta gravida (Banks)

BC: 1 ♂, Gabriola Island, 19.vii.1999 (R.D. Kenner & G.S. Kenner).

DISCUSSION

For all ten species, the provincial and territorial distributions reported here were already known (Garland 1982, 1985; *cf.* Penny *et al.* 1997). However, for some of the species, the present data include important new locality records, *e.g.*, *Chrysopa pleuralis* in the South Okanagan just west of Osoyoos; for *Chrysoperla carnea*, all the specimens were yellow-green, characteristic of summer generations of this insect, which is thought to be bivoltine about the latitude of Whitehorse, Yukon and southward (Garland 1989); and, for *Nineta gravida*, the specimen reported here marks the first collecting record of the species for British Columbia in over 90 years, since 1908 in fact (Garland 2000).

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Comparison of α-pinene and myrcene on attraction of mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae) to pheromones in stands of western white pine

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ABSTRACT

Multiple-funnel traps baited with *exo*-brevicomin and a mixture of *cis*- and *trans*-verbenol were used to test the relative attractiveness of myrcene and (-)-α-pinene to the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, in a stand of western white pine, *Pinus monticola* Dougl. Traps baited with myrcene caught significantly more *D. ponderosae* than traps baited with (-)-α-pinene, irrespective of the presence of *exo*-brevicomin. *exo*-Brevicomin was attractive to *Thanasimus undatulus* (Say) (Coleoptera: Cleridae) whereas *Trypodendron lineatum* (Olivier) (Coleoptera: Scolytidae) was attracted to (-)-α-pinene. Our results support the use of myrcene in commercial trap lures and tree baits for *D. ponderosae* in stands of western white pine in British Columbia.

Key words: Scolytidae, *Dendroctonus ponderosae*, kairomones, *Pinus monticola*, *Trypodendron lineatum*, Cleridae, *Thanasimus undatulus*

INTRODUCTION

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae), has killed over 500 million lodgepole, *Pinus contorta* var. *latifolia* Engelm., ponderosa, *P. ponderosa* P. Laws. and western white pines, *P. monticola* Dougl. (Pinaceae) in British Columbia over the past 80 years (Unger 1993). The current integrated pest management program for *D. ponderosae* in BC (Maclauchlan and Brooks 1994) is cost-effective, with positive economic, social and environmental impacts (Miller *et al.* 1993).

Semiochemicals play an important role in several tactics within the program (Maclauchlan and Brooks 1994). Population levels and flight periods of *D. ponderosae* are monitored with multiple-funnel traps baited with commercial lures consisting of the pheromones, *exo*-brevicomin and *cis*- and *trans*-verbenol, and the kairomone, myrcene (Stock 1984; Maclauchlan and Brooks 1994). The spread of infestations has been curtailed by the application of commercial tree baits consisting of the same semiochemicals (Borden and Lacey 1985; Borden *et al.* 1986) or simply the pheromones, *exo*-brevicomin and *cis*- and *trans*-verbenol (Borden *et al.* 1993).

Semiochemical blends for these commercial lures and baits were developed in stands of lodgepole and ponderosa pine rather than western white pine, and discrepancies exist concerning the most appropriate kairomone. The host compound α-pinene was more effective than myrcene in enhancing attraction of *D. ponderosae* to *trans*-verbenol in stands of western white pine in Idaho (Pitman 1971). Myrcene was more effective than α-pinene in increasing attraction of *D. ponderosae* to pheromones in stands of ponderosa

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pine (Billings *et al.* 1976) and lodgepole pine (Borden *et al.* 1983; Conn *et al.* 1983). In lodgepole pine stands, catches of *D. ponderosae* in pheromone-baited traps exhibited a dose-dependent increase to both myrcene and 3-carene whereas α-pinene had no effect (Miller and Borden 2000).

Our objective was to verify the effectiveness of myrcene, relative to α-pinene, in commercial lures for *D. ponderosae* in stands of western white pine. Specifically we attempted to compare the response of beetles to pheromones in traps baited with α-pinene to those baited with myrcene. Our expectation was that myrcene would be as effective as α-pinene in attracting *D. ponderosae*.

MATERIALS AND METHODS

Semiochemical-Releasing Devices. Phero Tech Inc. (Delta, British Columbia) supplied polyethylene bubble-cap lures containing a 13:87 mixture of *trans*- and *cis*-verbenol [both chemical purities 98%; both enantiomeric compositions 83:17 (-):(+)], (±)-*exo*-brevicomin polyurethane flex lures (chemical purity >98%), and separate closed, low-density polyethylene bottles (15 mL) containing either α-pinene [chemical purity >98%; enantiomeric composition > 99% (-)] or β-myrcene (chemical purity > 98%). The verbenols were released at a combined rate of approximately 1.74 mg/d at 24 °C (determined by weight loss) whereas α-pinene and myrcene were released at approximately 413 mg/d and 281 mg/d at 24-28 °, respectively (determined by weight loss). *exo*-Brevicomin was released at approximately 0.1 mg/d at 24 °C (determined by collection of volatiles) (Phero Tech Inc.).

Experiments. Two experiments were conducted in a mature stand of western white pine with approximately 15% of live trees infested by *D. ponderosae* near Barriere, British Columbia (51°10'N, 120°8'W). In both experiments, forty 8-unit multiple-funnel traps (Lindgren 1983) (Phero Tech Inc.) were set 10-15 m apart, and ≥ 2m from any tree, along two parallel transect lines spaced approximately 20 m apart. Each trap was suspended between trees by rope such that the top funnel of each trap was 1.3–1.5 m above ground.
In Experiment 1, the effect of α-pinene and myrcene on the attraction of *D. ponderosae* to traps baited with the verbenol mix was determined, with and without *exo*-brevicomin. All traps, baited with the verbenol mix, were set on 1 August 1990. The following treatments were randomly assigned to 10 traps each: (1) α-pinene; (2) myrcene; (3) α-pinene and *exo*-brevicomin; and (4) myrcene and *exo*-brevicomin. Experiment 1 was terminated on 25 August 1990.

Experiment 2 tested the interaction between α-pinene and myrcene on the attraction of *D. ponderosae* to traps baited with *exo*-brevicomin and the verbenol mix. All traps, baited with the verbenol mix and *exo*-brevicomin, were set on 25 August 1990. The following treatments were randomly assigned to 10 traps each: (1) no kairomone control; (2) α-pinene; (3) myrcene; and (4) α-pinene and myrcene. Experiment 2 was terminated on 12 September 1990.

Catches of *D. ponderosae* and serendipitous catches of *Trypodendron lineatum* (Olivier) (Coleoptera:Scolytidae) and *Thanasimus undatulus* (Say) (Coleoptera: Cleridae) were tallied for each treatment. Sexes of *D. ponderosae* captured in Experiment 2 were determined by dissection and examination of genitalia. Voucher specimens were deposited at the Entomology Museum, Simon Fraser University, Burnaby, BC.

Statistical Analyses. Trap catch data were analysed by 2-way ANOVA using the SYSTAT statistical package version 8.0 (SPSS 1998). The model factors in Experiment 1 were *exo*-brevicomin, monoterpenes (α-pinene or myrcene), and the interaction between *exo*-brevicomin and monoterpenes. In Experiment 2, the model factors were α-pinene, myrcene and the interaction of α-pinene and myrcene. Catches of *D. ponderosae* were transformed by ln(Y) to remove heteroscedasticity whereas catches of *Thanasimus undatulus* and *Trypodendron lineatum* were transformed by ln(Y+1) due to zero catches in some treatments. Sex ratio data, expressed as percentage of males in catches, from Experiment 2 were transformed by arcsine(Y). Fisher's least significant difference (LSD) multiple range tests were performed when $P < 0.05$.

RESULTS AND DISCUSSION

Our results clearly support the retention of myrcene in commercial lures for *D. ponderosae* in stands of western white pine. Catches of *D. ponderosae* were significantly higher in traps baited with myrcene than in traps baited with α-pinene (Figs. 1,2). *exo*-Brevicomin did not affect the preference of beetles for myrcene over α-pinene ($F_{1,36}$ = 0.605, P = 0.442) in Experiment 1 nor was there any interaction between α-pinene and myrcene on catches of *D. ponderosae* ($F_{1,36}$ = 0.018, P = 0.894) in Experiment 2. There was no significant difference in sex ratio among the treatments in Experiment 2 ($F_{3,19}$ = 2.232, P = 0.121) with the mean (± SE) percentage of males in catches at 55 ± 3 %.

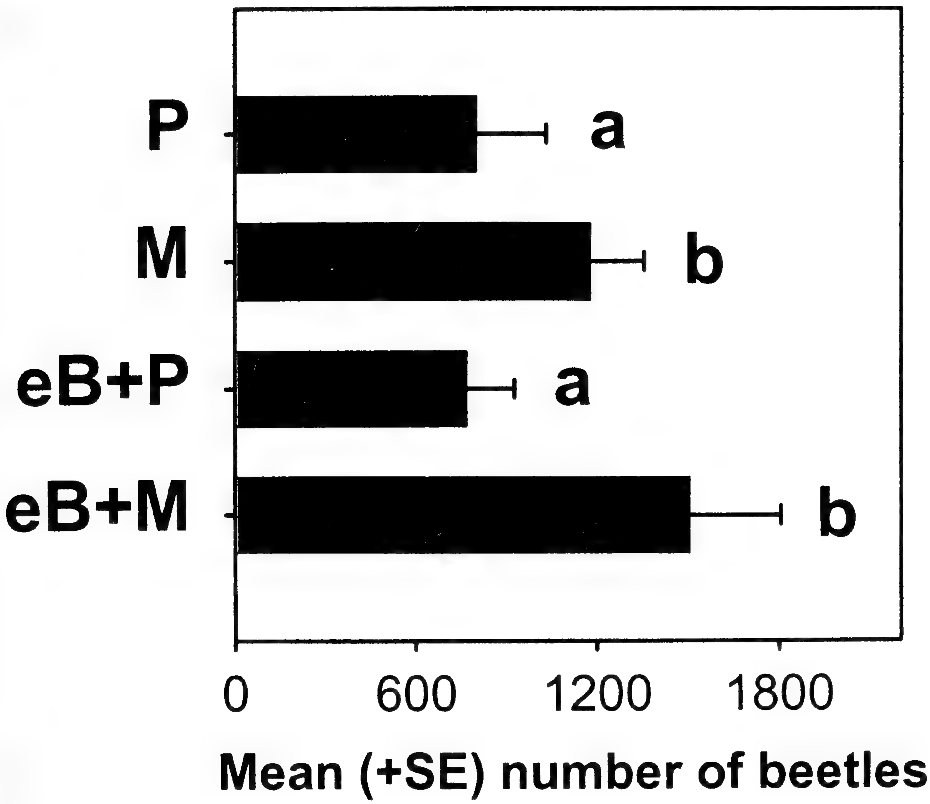

Figure 1. Effect of *exo*-brevicomin (eB), α-pinene (P) and myrcene (M) on the attraction of *Dendroctonus ponderosae* to verbenol-baited multiple-funnel traps from 1 August to 25 August 1990 (n = 10). Means followed by different letters are significantly different at $P <$ 0.05 (LSD test).

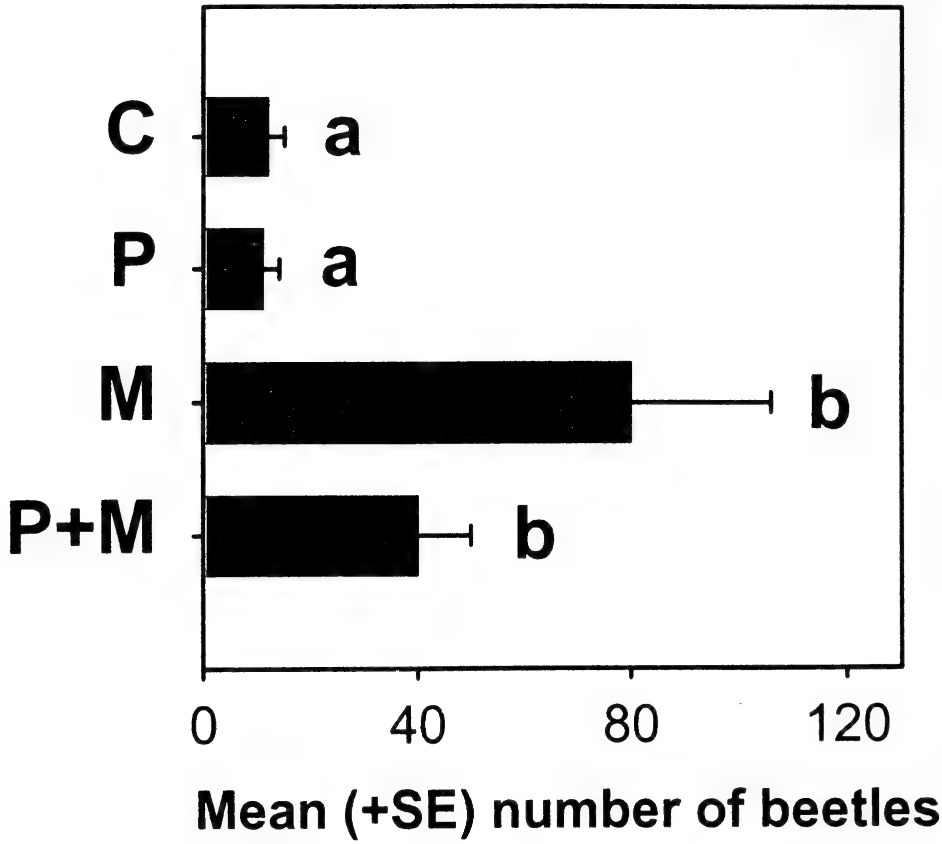

Figure 2. Effect of α-pinene (P) and myrcene (M) on the attraction of *Dendroctonus ponderosae* to multiple-funnel traps baited with verbenols and *exo*-brevicomin from 25 August to 12 September 1990 (n = 10). Means followed by different letters are significantly different at $P < 0.05$ (LSD test); control (c).

Our results are inconsistent with those of Pitman (1971) who demonstrated that α-pinene was more effective than myrcene in attracting *D. ponderosae* in stands of western white pine and are surprising since α-pinene is the most common monoterpene in the resin of western white pine, which has low amounts of myrcene (Mirov 1961). The relative proportion of myrcene is higher in the resin of lodgepole and ponderosa pines with amounts of myrcene greater than or equal to amounts of α-pinene (Mirov 1961; Shrimpton 1973). Geographic variation in semiochemical responses, similar to that in *Ips pini* (Say) (Miller *et al.* 1997), may explain some of these results.

Finally, research by Pitman (1971), Billings *et al.* (1976), Borden *et al.* (1983) and Conn *et al.* (1983) were conducted before the importance of the enantiomeric composition of α-pinene was widely recognised. It is likely, but not certain, that they used either (±)- or (-)-α-pinene due to the high costs associated with (+)-α-pinene. We used (-)-α-pinene in our trials since it is the predominant enantiomer in the resin of western white pine phloem tissue (Mirov 1961).

In Experiment 1, catches of *Trypodendron lineatum* were lowest in traps baited with myrcene alone, and highest in traps baited with either α-pinene or *exo*-brevicomin (Table 1). α-Pinene significantly increases the attraction of *T. lineatum* to ethanol and the pheromone lineatin (Borden *et al.* 1982; Schroeder and Lindelöw 1989). No *T. lineatum* were caught in Experiment 2.

Table 1

Mean (± SE) catches of *Trypodendron lineatum* (Scolytidae) and *Thanasimus undatulus* (Cleridae) in verbenol-baited multiple-funnel traps from 1 August to 25 August 1990 [a].

Treatment	*Trypodendron lineatum*	*Thanasimus undatulus*
(-)-α-Pinene	11 ± 5 b	1 ± 1 a
Myrcene	3 ± 1 a	1 ± 1 a
(-)-α-Pinene + (±)-*exo*-brevicomin	12 ± 2 b	28 ± 5 c
Myrcene + (±)-*exo*-brevicomin	9 ± 2 b	16 ± 3 b

[a] Means within the same column followed by the same letter are not significantly different, $P < 0.05$ (LSD multiple comparison test).

The predator, *Thanasimus undatulus,* showed a preference for traps baited with *exo*-brevicomin in combination with myrcene or α-pinene, particularly the latter (Table 1). As might be expected for a generalist predator, similar results with *T. undatulus* have been reported with the following bark beetle pheromones: frontalin, *exo*- and *endo*-brevicomin, ipsdienol, ipsenol, and *cis*-verbenol (Kline *et al.* 1974; Dyer 1975; Chatelain and Schenk 1984; Miller *et al.* 1987; Miller and Borden 1990; Miller *et al.* 1991; Miller *et al.* 1997; Poland and Borden 1997). Usually, *T. undatulus* are not attracted to host tree compounds (Furniss and Schmitz 1971; Miller and Borden 1990) although Macías-Sámano *et al.* (1998) demonstrated attraction of *T. undatulus* to host blends from grand fir, *Abies grandis* (Dougl.) Lindl. No *T. undatulus* were caught in Experiment 2.

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Somatochlora kennedyi (Odonata: Corduliidae): a new species for British Columbia, with notes on geographic variation in size and wing venation

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ABSTRACT

The first confirmed record for *Somatochlora kennedyi* Walker in British Columbia is reported. Specimens of this species from the northern Yukon are smaller than those from elsewhere in its range and have a reduced number of cells in certain parts of the wings. The reduced number of cells may cause some keys to yield ambiguous results.

Keywords: *Somatochlora*, Corduliidae, Odonata, British Columbia, geographic variation

INTRODUCTION

In the summer of 1997, the Conservation Data Centre (Ministry of Environment, Lands and Parks) sponsored two expeditions to northeastern British Columbia to survey the odonate fauna of that region. During the first, Leah Ramsay and I made a number of interesting discoveries among which was the capture of a female *Somatochlora kennedyi* Walker near Fort Nelson. This is the first confirmed record for this species in British Columbia. While comparing this specimen to named *S. kennedyi* specimens in the collection of the Spencer Entomological Museum (SEM), certain anomolies were noted in the size and wing venation of specimens from the Yukon. That information is presented here.

Somatochlora kennedyi is a southern boreal species with a distribution which extends from the northern Yukon east to Newfoundland, south to Minnesota, Wisconsin, Michigan; and east to Ohio, New York and Massachusetts (Walker and Corbet 1975; Cannings *et al.* 1991; Bick and Mauffray 2000). The distribution is poorly known, especially in the west; Cannings and Cannings (1994) noted that it is "unusual for a southern boreal species to be unknown in British Columbia and Alberta". The records for the Yukon, Manitoba and the Northwest Territories are from late June and July (Walker and Corbet 1975; Cannings *et al.* 1991). *Somatochlora kennedyi* has been reported from "sedge/rush and polygon sedge fens" and "deep sedge/moss marsh" in the Yukon (Cannings and Cannings 1994) and "a shallow pond in a swampy wood" in New Brunswick (Walker 1925).

MATERIAL EXAMINED

All specimens of *S. kennedyi* examined are deposited in the SEM, Department of Zoology, University of British Columbia. All specimens were dried in acetone and are stored in clear envelopes. The collection data for the BC specimen are 1 ♀, Andy Bailly Lake, S of Fort Nelson, 25 June 1997, R. D. Kenner. The details for the 20 Yukon specimens are given in Cannings *et al.* (1991): 1 ♂, 1 ♀, Loon Lake (60° 02' N 127° 35' W) and 15 ♂, 3 ♀, Old Crow area (2 separate sites).

RESULTS AND DISCUSSION

The specimen from Andy Bailly Lake is a young female, caught while it was resting on the road beside our vehicle. We saw no other individuals. Due to its teneral nature, the abdomen partially collapsed during treatment with acetone for preservation. I determined it to be *S. kennedyi* using the keys in Walker and Corbet (1975) and by comparison with named specimens in the collection of the SEM. The specimen was also examined by R. A. Cannings and S. G. Cannings who have previous experience with this species and they confirmed the determination. The occurrence of *S. kennedyi* in BC was expected (Cannings and Stuart 1977), especially since it has been collected in the southeastern Yukon not far from the BC-Yukon border (Cannings *et al.* 1991).

Although this is the first confirmed record for BC, it may not be the first time *S. kennedyi* has been collected in BC. There is in the SEM, a previously unidentified final stadium larval specimen which keys out as *S. kennedyi.* It was collected in sweeps of the "moss/rush/sedge" in the fen at the south end of Eddontenajon Lake on 17 June 1987 by S. G. Cannings. Separating the larvae of *S. kennedyi* from those of *S. franklini* (Selys) depends on differences in the arrangement of setae on the dorsum of the abdominal segments (Walker 1925; Walker and Corbet 1975). Some of these setae may break off during capture and storage and it is difficult for me to be completely certain of the identification without named material for direct comparison.

In keys for adult female *Somatochlora* sp. (Walker 1925; Walker and Corbet 1975) the number of cells "in the fork of R_2" is one of several characters used for separating *S. kennedyi* and *S. franklini*; *S. kennedyi* has 11–20 cells and *S. franklini* has 6–9 cells. This character is also used in the key in Needham and Westfall (1955). The data in Table 1 show that the number of cells in the fork of R_2 is not a reliable character for separating *S. kennedyi* and *S. franklini* in the northern Yukon. A more useful character appears to be the colour of the lateral lobes of the postclypeus (brown in *S. kennedyi* but black in *S. franklini*).

Table 1

Latitudinal variation in morphological characteristics of *Somatochlora kennedyi* from British Columbia and the Yukon.

	Andy Bailly L. 58°49'N	Loon L. 60°02'N		Old Crow Area 67°35'N		Walker and Corbet (1975)	
	1 ♀	1 ♂	1 ♀	15 ♂	3 ♀	♂	♀
Total length (mm)	43.5	47	49	41-45 (42.5)	40-43 (42)	51.5-55	47-55
Hind wing length (mm)	30	29.5	33	25.5-28 (26.7)	26.5-28 (27.5)	29.5-32	29.5-33.5
# cells in R_2 fore wing	12/14	12/13	13/15	5-15 (10.8)	7-11 (9.2)	13-19	11-18
# cells in R_2 hind wing	12/14	13/13	18/19	9-15 (11.9)	9-12 (10)	12-19	12-20

Numbers in parentheses are mean values.

The data in Table 1 also show that both total length and hind wing length for the specimens from the Old Crow area are smaller than the lower limit given in Walker and Corbet (1975). The partial collapse of the abdomen of the BC specimen may have contributed to its apparent small size.

The literature contains a number of references to geographical variations in size. Walker (1925) briefly discusses geographical variations in *Somatochlora* spp. and reports that *S. franklini* is "larger towards the southern limit of its range" and *S. albicincta* (Burmeister) is smaller in the far north and on the Labrador coast. Although Tennessen (1977) states that a decrease in size with latitude is common in North American odonates, there are a number of references which show either increases or decreases in size with increasing latitude for both odonates and non-odonate insects (see, for examples, citations in Stewart 1982 and Corbet 1999). Cannings (1982) showed that the larvae of *Sympetrum illotum* Hagen increase in size with increasing latitude. It is clear that factors other than latitude need to be taken into account in developing an understanding of the observed size variations.

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Heteroptera (Hemiptera: Prosorrhyncha) new to Canada. Part 1

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ABSTRACT

The occurrence of 34 species of true bugs newly recognized in Canada is documented.

INTRODUCTION

In preparing the recently published checklist of the Hemiptera of Canada and Alaska (Maw *et al.* 2000), various collections across Canada were examined to document the distribution of the species. In the process, 34 species new to Canada were identified. The locality and collection records for these new discoveries are published herein, so as to validate the inclusion of the species in the above mentioned checklist. Additional species will be published in Part 2 when all determinations have been confirmed. The records of new Miridae to Canada are being published elsewhere (Schwartz and Scudder 2000).

The arrangement in the list below is according to the checklist (Maw *et al.* 2000), and in general follows the catalogue by Henry and Froeschner (1988). The latter publication provides references to the descriptions of the various species and associated literature. References to keys for identification are included in Henry and Froeschner (1988) and Maw *et al.* (2000). Where data label uses common name of host, the scientific name has been added in parentheses.

Museum abbreviations used in the text are as follows (curators in parentheses):

APM: Alberta Provincial Museum, Edmonton, AB (A.T. Finnamore).
CNC: Canadian Collection of Insects, Agriculture and Agri-Food, Ottawa, ON (R.G. Foottit).
LEMQ: Lyman Entomological Museum, McGill University, Macdonald College Campus, St.-Ann-de-Bellevue, QC (T.A. Wheeler).
RBCM: Royal British Columbia Museum, Victoria, BC (R.A. Cannings).
ROM: Royal Ontario Museum, Toronto, ON (D. Currie).
UBC: Spencer Entomological Museum, Department of Zoology, University of British Columbia, Vancouver, BC (K.M. Needham).
UG: Department of Environmental Biology, University of Guelph, Guelph, ON (S.A. Marshall).

SPECIES NEW TO CANADA

Infraorder NEPOMORPHA
Family CORIXIDAE
Ramphocorixa acuminata (Uhler)
ON: 2♂ 1♀, Essex Co., South Gosfield Tp., Wigle Creek Sta. 2, 42°03.3'N 82°46.5'W, MNR Lot No. 8282-028, 2.xi.1982 (J. Blackburn; H. Tardif) [ROM].

Trichocorixa kanza Sailer

ON: 1♂, Greeley, gravel pit, 2.xi.1983 (D.J. Larson) [CNC].

Trichocorixa louisianae Jaczewski

NS: 1♀, Sable Is., 8.vi.1966 (W.R.M. Mason) [CNC]; 3♀, Sable Is., West end, 1.vii.1967 (H.F. Howden) [CNC]; 47♂ 40♀, Sable Is., 11-15.ix.1967 (J.E.H. Martin) [CNC].

Trichocorixa verticalis verticalis (Fieber)

PE: 1♂ 1♀, Queens Co., Mount Steward, 21.viii.1971 [CNC].

Infraorder GERROMORPHA

Family HEBRIDAE

Hebrus buenoi Drake & Harris

ON: 1♂, Arkell, 20.iv.1976 (W.J. Moolenbeck) [UG]; 2♂, Damascus, 2.vi.1976 (S.A. Marshall) [UG]; 1♂, Guelph, 23.v.1977 (Kevin Barber) [UG]; 1♀, Guelph, 18.vii.1977 (W.A. Attwater) [UG]; 1♂, *id.*, 21.vii.1977 [UG].

Merragata brunnea Drake

ON: 1♀, Arkell, pond #2 (B.S. Heming) [UG]; 1♀, Guelph, 22.ix.1983 (Nancy R. Ennis) [UG]; 1♂, Guelph, 22.ix.1983 (Edward Hippert) [UG]; 1♂, Walpole I., 11.vii.1977 (E.A. Inns) [UG].

Family VELIIDAE

Microvelia hinei Drake

NS: 2♂, 7♀, Falmouth, pond #1, pH 6.1, 20.v.1984 (G.G.E. Scudder) [CNC, UBC].

ON: 1♀, Walpole I., 27.vi.1985 (G.G.E. Scudder) [CNC].
This Ontario record was included in a tabulation in Scudder (1987), but without a locality record.

Steinovelia stagnalis (Burmeister)

ON: 1♀, Rondeau Pr. Pk., Marsh Trail, treading *Typha* in marsh, 2.vi.1985 (A. Davies, J.M. Campbell) [CNC].

Infraorder LEPTOPODOMORPHA

Family SALDIDAE

Chiloxanthus arcticus (Sahlberg)

NT: 1♂ 1♀, Richards Is., Kidluit Bay, 30.viii.1948 (W.J. Brown) [CNC].

Saldula balli Drake

BC: 1♀, Vernon, vii.1920 (N.L. Cutler) [UBC].

Infraorder CIMICOMORPHA

Family TINGIDAE

Corythucha bellula Gibson

MB: 7♂ 7♀, Aweme, *Ribes*, 19.v.1919 (N. Criddle) [CNC]; 1♀, Aweme, *Corylus*, 30.v.1919 (N. Criddle) [CNC]; 4♂ 1♀, Aweme, *Alnus incarna*, 13.viii.1930 (R.M. White) [CNC]; 1♀, Darlington, swept from saskatoons (*Amelanchier* sp.), 24.v.1930 (R.M. White) [CNC]; 2♂, Lake Audy, alder (*Alnus* sp.), 1.vi.1941 (R.D. Bird) [CNC].

ON: 4♀, Bothwell, 29.v.1929 (G.S. Walley) [CNC]; 7♂ 12♀, Haggersville, on *Crataegus*, 9.vii.1962 (Kelton & Thorpe) [CNC].

Corythucha obliqua Osborn & Drake

BC: 3♂ 4♀, Summerland, *Ceanothus*, 7.vii.1975 (L.A. Kelton) [CNC].

Gargaphia angulata Heidemann

ON: 1♀, Belle River, 7.vi.1961 (Kelton & Brumpton) [CNC]; 12♂ 15♀, Grand Bend, 7.ix.1961 (L.A. Kelton) [CNC]; 4♂ 5♀, Grand Bend, 15.vi.1962 (Kelton & Thorpe) [CNC]; 1♂ 1♀, Pinery Pt. Pk., 8.ix.1961 (J. Brumpton) [CNC].

Hesperotingis antennata Parshley

BC: 2♂, Cranbrook, Ponderosa pine (*Pinus ponderosa*), 23.vii.1959 (L.A. Kelton) [CNC].

MB: 1♀, Aweme, 25.viii.1922 (R.M. White) [CNC].

SK: 1♀, Cypress Hills, S. Maple Cr. (117), 20.vii.1956 (Lindroth) [CNC]; 2♂, Saskatoon, 4.viii.1925 (Kenneth M. King) [CNC].

Hesperotingis fuscata Parshley

AB: 1♂ 1♀, Brocket, 18 km NNW, 49°41'N 113°54'W, 1350m., pantrap, 18-22.vii.1998 (K. White) [CNC]; 4♂ 1♀, *id.*, pitfall trap [CNC; Scudder Coll; White Coll.]; 2♂ 1♀, *id.*, 6-10.viii.1998 [CNC]; 2♂ 1♀, *id.*, 10-14.viii.1998 [CNC]; 1♂, *id.*, 14-18.viii.1998 [CNC]; 1♂ 1♀, CFB Suffield, NWA, 50°37.678'N 110°18.371'W, pan trap, 16-28.vii.1994 (A.T. Finnamore) [APM]; 1♂ 1♀, *id.*, 16-29.vii.1994 [APM]; 1♂ 1♀, *id.*, 16-28.vii.1994 [APM]; 1♂ 2♀, *id.*, 50°23.466'N 110°36.768'W, 16-28.vii.1994 [APM].

BC: 1♂, Fairview, White L., BGxh1, SWm, pan trap P-2, 20.vi-27.vi.1995 (J. Jarrett) [UBC]; 2♂, *id.*, pan trap P-9, 27.vi-4.vii.1995 [UBC]; 1♀, Kilpoola L., PPxh1, pitfall trap KL3-4, 15.vii-6.viii.1996 (J. Jarrett & G.G.E. Scudder) [UBC]; 1♂, *id.*, pitfall trap KL3-5 [UBC]; 1♂, *id.*, pitfall trap KL1-5, 23.vi-28.vii.1997 (J. Jarrett) [UBC].

Hesperotingis occidentalis Drake

AB: 2♀, Kananaskis, 20.vii.1974 (L.A. Kelton) [CNC]; 1♂, Lundbreck, 7.vii.1970 (L.A. Kelton) [CNC].

BC: 2♀, Fernie, 1.vii.1934 (Hugh B. Leech) [CNC].

Leptopharsa heidemanni (Osborne & Drake)

ON: 5♂ 12♀, Ojibway, 6-7.vi.1961 (Kelton & Brumpton) [CNC].

Family REDUVIIDAE

Emesaya brevipennis brevipennis (Say)

ON: 1(?), Chatham, 24.ix.1927 (C.W. Smith) [CNC]; 1♂, Essex Co., 10.ix.1955 (W. Kendrick) [UG]; 1♀, Freelton, Malaise, 28.viii.1984 (M.T. Kasserra) [UG]; 1♂, Harrow, 10.ix.1950 (A.H. Kichi) [UG]; 1♂,London, 1958 [CNC]; 1♀ 2 immature, Pt. Pelee, 28.vii.1920 (N.K. Bigelow) [CNC]; 1♀, Pt. Pelee, 16.ix.1932 (G.M. Stirrett) [CNC]; 2♂, Pt. Pelee, 8.ix.1954 (R. Lambert) [CNC]; 1♀, Pt. Pelee, 9.ix.1954 (C.D. Miller) [CNC]; 2♀, Pt. Pelee, 13.ix.1961 (G. Brumpton) [CNC]; 1(?), Sarnia, 5.x.1907 (W.A. Dent) [CNC]; 1♀, *id.*, 14.xi.1913 [CNC]; 1♂ 1♀, *id.*, x.1914 [CNC]; 2♂, S. School, 1937 (E.A. Watts, M. Fletcher) [UG]; 1♂ 1♀, St. Thomas, x.1920 (H.G. Crawford) [CNC]; 1♂, Windsor, Malaise, 24.vii.1984 (M.T. Kasserra) [UG]; 1♀,Yarmouth, 1946 [CNC].

Empicoris culiciformis (DeGeer)

BC: 1♀, Chilliwack, 1.vi.1924 [RBCM]; 6♂ 3♀, Victoria, 24.v.1921 (W. Downes) [CNC].

ON: 1♀, Chatham, 29.vi.1928 (G.J. Spencer) [CNC]; 1♂ 1♀, Don Mills, in home with pinned insects infested with carpet beetles, x.1959 (G.B. Wiggins) [ROM]; 1♀, Toronto, 12.viii.1964 (B. Pulley) [ROM].

Empicoris parshleyi (Bergroth)

QC: 4♂ 5♀, Brome, under bark on maple (*Acer* sp.), 9.vi.1936 (G.S. Walley) [CNC]; 1♀, Covey Hill, 8.vii.1937 (G.S. Walley) [CNC]; 1♂, Rigaud, 25.vi.1906 (Beaulieu) [CNC].

Infraorder PENTATOMOMORPHA

Family ARADIDAE

Aradus basalis Parshley

NB: 1♀, Bathurst, vi.1930 (J.N. Knull) [CNC].

QC: 1♀, Mt. Jacques Cartier, 5.vii.1954 (W.J. Brown) [CNC].

Family COREIDAE

Acanthocephala terminalis (Dallas)

ON: 1♂, Kent Co., 28.viii.1955 (G. McDonald) [UG]; 1♂, Kent Co., Forest at Hwy. 401, 12.x.1997 (S.A. Marshall) [UG]; 1♂, Lambton Co., North Lambton, 30.vii.1996 (J. Skevington) [UG]; 1♀, Lambton Co., Pinery Prov. Pk., 21.vii.1992 (J. Carmichel) [UG]; 1♂ 5♀, Leamington, 29.v.1937 (G.S. Walley) [CNC]; 3♀, *id.*, 31.v.1937 [CNC]; 3♀, *id.*, 1.vi.1937 [CNC]; 1♂, *id.*, 9.vi.1937 [CNC]; 1♀, *id.*, 11.vi.1937 [CNC]; 1♀, Simcoe, 6.vi.1939 (G.E. Shewell) [CNC]; 1♀, Simcoe, 24.vi.1939 (T.N. Freeman) [CNC].

Catorhintha mendica Stål

MB: 1♀, Aweme, 11.vi.1922 (R.M. White) [CNC].

ON: 1♂, St. Catharines, goldenrod (*Solidago* sp.), 13.ix.1964 [ROM].

Family RHOPALIDAE

Arhyssus crassus Harris

BC: 1♂, Osoyoos, 26.viii.1986 (G.G.E. Scudder) [UBC]; 1♂ 2♀, Osoyoos, Mt. Kobau, 1525m., 26.viii.1986 (G.G.E. Scudder) [UBC]; 1♂, Osoyoos, Mt. Kobau Rd., km 6.7, on flowers of *Holodiscus discolor*, 10.vii.1994 (G.G.E. Scudder) [UBC]; 1♀, Osoyoos, Mt. Kobau Rd., km 1.8, PPxh1, WAw, pitfall trap, 23.vi-28.vii.1997 (J. Jarrett) [UBC].

Aufeius impressicollis Stål

BC: 1♂, Osoyoos IR, nr. Mud L., 49°13'N 119°31'W, *Purshia* assoc., BGxh1, AN, pitfall trap, 4.x.1994-10.iv.1995 (G.G.E. Scudder) [UBC].

Family ARTHENIDAE

Chilacis typhae (Perris)

BC: 2♀, Osoyoos, 7.7 km N, jct. Hwy. 97/Rd. 22, 49°05'23"N 119°32'49"W, on *Typha latifolia*, 8.x.1999 (G.G.E. Scudder) [UBC]; 7♂ 10♀, *id.*, 16.x.1999 [UBC]; 40♂ 38♀, Osoyoos, 8 km N, 49°05'32"N 119°32'18"W, on *Typha latifolia*, 16.x.1999 (G.G.E. Scudder) [CNC, RBCM, UBC].

ON: 1♂, Nepean, Piney Forest, Lafontaine House, ex MV lite, 18.vii.1991 (M.D. Schwartz) [CNC]; 2♂, *id.*, 27.vii.1991 [CNC].

Family LYGAEIDAE
Kleidocerys modestus Barber
BC: 4♂ 1♀, Vernon, BX Range, 610m [2000'], 4.vii.1979 (R.A. Cannings) [UBC].

Family CYDNIDAE
Macroporus repetitus Uhler
BC: 2♂ 1♀, Vaseux Cr., 'CWS Bench', 49°16'N 119°30'W, *Purshia* assoc., BGxh1, AN, pitfall trap, 9.v-3.vi.1994 (G.G.E. Scudder [UBC]; 2♂ 3♀, *id.*, 3.vi-8.vii.1994 [UBC]; 2♂, *id.*, 8.vi-5.vii.1995 [UBC].
Melanaethus robustus Uhler
ON: 1♀, Pelee I., Fish Point, 28.vi.1985 (G.G.E. Scudder) [CNC].
Microporus obliquus Uhler
AB: 3♂, CFB Suffield, NWA, 50°37.678'N 110°18.371'W, 16.vi.1995 (A.T. Finnamore) [APM]; 1♂ 2♀, *id.*, 16-28.vii.1994 [APM]; 1♂ 2♀, *id.*, 16-29.vi.1994 [APM]; 1♂, *id.*, 28.vii-16.viii.1994 [APM]; 2♂ 1♀, *id.*, 16.viii-7.ix.1994 [APM].
BC: 2♀, Oliver, IRI, 'Watertower', 49°10'N 119°31'W, *Purshia* assoc., BGxh1, AN, pitfall trap, 3.v-7.vi.1995 (G.G.E. Scudder) [UBC]; 1♀, Osoyoos, Haynes Ecol. Res., BGxh1, AN recovery after fire, pitfall trap, 9.vii-7.viii.1994 (G.G.E. Scudder) [UBC]; 1♂, *id.*, 9.viii-3.ix.1995 [UBC]; 1♂ 2♀, *id.*, 14.v-9.vi.1996 [UBC]; 1♀, *id.*, 9.vi-9.vii.1996 [UBC]; 2♂ 1♀, *id.*, 9.viii-20.ix.1996 [UBC]; 1♀, *id.*, 19.vi-18.vii.1997 [UBC]; 2♀, *id.*, 12.v-28.vi.1998 [UBC].

Family PENTATOMIDAE
Murgantia histrionica (Hahn)
ON: 4♂ 5♀, Southampton, on *Brassica*, 15.ix.1956 (P.N. Vroom) [CNC].

Family SCUTELLERIDAE
Euptychodera corrugata (Van Duzee)
AB: 1♀, Manyberries, 19 km S, jct. 501-502, 13.viii.1982 (S.G. & R.A. Cannings) [UBC].

Family THYREOCORIDAE
Corimelaena alpina (McAtee & Malloch)
NB: 1♀, Fredericton, French Lake, 12.vi.1931 (C.W. Maxwell) [LEMQ].
QC: 1♀, Laval, 7.viii.1938 [LEMQ].
Corimelaena obscura McPherson & Sailer
ON: 2♂, Kingsville, 8.vii.1977 (A.A. Konecny) [UG].

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Pheromone interruption of pine engraver, *Ips pini*, by pheromones of mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae)

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ABSTRACT

The effect of pheromones of *Dendroctonus ponderosae* Hopkins on the attraction of *Ips pini* (Say) to its pheromone, ipsdienol, was investigated in stands of lodgepole pine. The mixture of *cis*- and *trans*-verbenol significantly reduced catches of *I. pini* in traps baited with ipsdienol at three locations in British Columbia. *exo*-Brevicomin had no effect on catches of *I. pini*, irrespective of the enantiomeric composition of *exo*-brevicomin. Ipsdienol did not significantly reduce the attraction of *D. ponderosae* to traps baited with *cis*- and *trans*-verbenol, and (±)-*exo*-brevicomin.

Key Words: Coleoptera, Scolytidae, *Ips pini*, *Dendroctonus ponderosae*, pheromone interruption, synomone, *exo*-brevicomin, *cis*-verbenol, *trans*-verbenol, ipsdienol

INTRODUCTION

The pine engraver, *Ips pini* (Say), and the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae), are common bark beetle species in stands of lodgepole pine, *Pinus contorta* var. *latifolia* Engelmann (Pinaceae), in western North America (Furniss and Carolin 1980). *Ips pini* breeds in the phloem tissue of dead, dying or downed lodgepole pines (Furniss and Carolin 1980). *Dendroctonus ponderosae* breeds in the healthy phloem tissue of live, standing pine trees (Unger 1993). During the past 80 years, *D. ponderosae* has killed more than 500 million pine trees in British Columbia alone (Unger 1993). Densities of *D. ponderosae* galleries on infested material range from 10 – 261/m^2 with optimal brood production densities of 75 – 85/m^2 (Safranyik and Linton 1998). Population levels of *I. pini* can build up during drought conditions, or following catastrophic events such as logging, fire, windthrow, or epidemics of *D. ponderosae*, with attack densities reaching 200-300/m^2 (Safranyik *et al.* 1996). At times, populations of *I. pini* may be sufficiently large that they initiate attacks on live, standing trees. Two years after the 1988 fire in the greater Yellowstone Park area, 44 % of the lodgepole pines were infested by *I. pini* (Amman and Ryan 1991).

In spite of their abundance and similarity in phloem resource requirements, these two species maintain ecological and reproductive isolation by assembling on host material in large non-overlapping, single-species aggregations. *Dendroctonus ponderosae* generally infests the lower bole of standing trees whereas *I. pini* attacks mid- and upper-bole regions, or the entire tree bole in the absence of *D. ponderosae* (Furniss and Carolin 1980). Separation of aggregations seems to be facilitated by semiochemicals. *Ips pini* uses ipsdienol (2-methyl-6-methylene-2,7-octadien-4-ol) as an aggregation pheromone (Birch *et al.* 1980; Lanier *et al.* 1980) with both sexes preferring a racemic blend throughout most

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of British Columbia (Miller *et al.* 1996). *Dendroctonus ponderosae* produces various semiochemicals and responds optimally to the combination of *exo*-brevicomin (*exo*-7-ethyl-5-methyl-6,8-dioxabicyclo[3.2.1]octane) and *cis*- and *trans*-verbenol (*cis*- and *trans*-4,6,6-trimethylbicyclo[3.1.1]hept-3-en-2-ol) (Borden *et al.* 1987; Miller and Lafontaine 1991).

Mutual interruption of pheromone attraction can enhance specificity in bark beetle aggregations (Byers 1989). Ipsdienol, produced by male *I. pini*, interrupts the attraction of *D. ponderosae* to the semiochemical blend of myrcene, (±)-*exo*-brevicomin, and *cis*- and *trans*-verbenol (Hunt and Borden 1988). The pheromone blend of (±)-*exo*-brevicomin and *cis*- and *trans*-verbenol, produced by *D. ponderosae*, interrupts the attraction of *I. pini* to its pheromone ipsdienol (Hunt and Borden 1988). The effects of individual components are not known. Therefore, our study assessed the effects of (+)-, (-)-, and (±)-*exo*-brevicomin, and the mix of *cis*- and *trans*-verbenol, separately and in combination, on the attraction of *I. pini* to ipsdienol. Specifically, we expected that all these compounds would reduce trap catches of male and female *I. pini* to ipsdienol-baited multiple-funnel traps.

MATERIALS AND METHODS

Chemicals and Release Devices. Phero Tech Inc. (Delta, British Columbia) supplied polyethylene bubble-cap lures containing a 13:87 mixture of *trans*- and *cis*-verbenol [both chemical purities 98%; both enantiomeric compositions 83:17 (-):(+)]. The verbenols were released at a combined rate of ca. 1.74 mg/d at 24 °C (determined by weight loss). In 1986, Phero Tech Inc. supplied laminar (±)-*exo*-brevicomin lures (chemical purity 98%). In 1987, each *exo*-brevicomin lure consisted of an open polyethylene microcentrifuge tube (400 mL) (Evergreen Scientific, Los Angeles, California) containing one 3-cm-long glass capillary tube (i.d. 13 mm; o.d. 15 mm) filled with *exo*-brevicomin. Phero Tech Inc. supplied (±)-*exo*-brevicomin (chemical purity 98%) and B.D. Johnston (Department of Chemistry, Simon Fraser University, Burnaby, British Columbia) supplied (+)-*exo*-brevicomin [chemical purity >99%; enantiomeric composition 97:3 (+):(-)] and (-)-*exo*-brevicomin [chemical purity >99%; enantiomeric composition 2:98 (+):(-)]. The release rates of *exo*-brevicomin were approximately 0.12 mg/d at 25 °C in 1986 (determined by collection of volatiles on Porapak-Q) and approximately 0.15 mg/d at 20 °C in 1987 (determined by weight loss).

(±)-Ipsdienol (chemical purity >98%) was obtained from Bedoukian Research Inc. (Danbury, Connecticut). In 1986, each ipsdienol lure consisted of eight Microcap® disposable pipettes (2μL) (Drummond Scientific Co., Broomall, Pennsylvania), each pipette sealed at one end, filled with (±)-ipsdienol and placed in an open polyethylene, microcentrifuge tube (1.8 mL) (Evergreen Scientific). In 1987, each ipsdienol lure consisted of a 10-cm length of C-flex® tubing (i.d. 1.6 mm; o.d. 3.2 mm) (Concept Inc., Clearwater, Florida), filled with an ethanol solution of (±)-ipsdienol, and heat-pressure sealed at both ends. The release rates of ipsdienol were approximately 0.08 mg/day at 24 °C in 1986 (determined by weight loss) and approximately 0.6 mg/day at 24 °C in 1987 (determined by collection of volatiles on Porapak-Q). Ethanol, used in the formulation to reduce the risk of polymerization of ipsdienol, is not attractive to *I. pini* (Miller 1990).

Experiments. Three experiments were conducted in 1986-1987. In all experiments, replicates of 8-unit Lindgren multiple-funnel traps (Phero Tech Inc.) were set in mature stands of lodgepole pine. Replicates were spaced at least 100 m apart, and traps were spaced 10-15 m apart within each replicate. Each trap was suspended by rope between trees such that the top of each trap was 1.3-1.5 m above ground level. No trap was within 2 m of any tree.

Experiment 1 tested the effect of ipsdienol, (±)-*exo*-brevicomin and verbenols on the attraction of *I. pini* and *D. ponderosae*. Ten replicates of five traps/replicate were set on 4 August, 1986, in regular pentagon formations near Princeton, British Columbia. The following treatments were randomly assigned within each replicate: (1) ipsdienol alone; (2) ipsdienol and (±)-*exo*-brevicomin; (3) ipsdienol and verbenols; (4) ipsdienol, (±)-*exo*-brevicomin and verbenols; and (5) (±)-*exo*-brevicomin and verbenols. The experiment was terminated on 3 September, 1986.

In 1987, experiment 2 tested the effect of (±)-*exo*-brevicomin and verbenols on the attraction of *I. pini* to ipsdienol at three sites in British Columbia: Princeton, Williams Lake and Radium. At each site, five replicates of four traps/replicate were set in grids of 2 X 2 on 16 July, 7 September, and 9 September, respectively. The following treatments were randomly assigned within each replicate: (1) ipsdienol alone; (2) ipsdienol and (±)-*exo*-brevicomin; (3) ipsdienol and verbenols; and (4) ipsdienol, (±)-*exo*-brevicomin and verbenols. Trapping was terminated at the three sites on 29 September, 3 October, and 1 October, 1987, respectively.

In 1987, experiment 3 tested the effect of enantiomeric composition of *exo*-brevicomin on the attraction of *I. pini* to ipsdienol. Five replicates of five traps/replicate were set on 20 August, each in a regular pentagon formation near Princeton, British Columbia. The following treatments were randomly assigned within each replicate: (1) ipsdienol alone; (2) ipsdienol and (-)-*exo*-brevicomin; (3) ipsdienol and (+)-*exo*-brevicomin; (4) ipsdienol and (±)-*exo*-brevicomin; and (5) ipsdienol and double (±)-*exo*-brevicomin. The separate release rates of (-)- and (+)-*exo*-brevicomin in treatments 2, 3 and 5 were identical whereas the combined release rate of both enantiomers in treatments 2, 3 and 4 were identical. The total release rate of *exo*-brevicomin in treatment 5 was twice that of *exo*-brevicomin in treatment 4. The experiment was terminated on 29 September, 1987.

Sexes of *I. pini* were determined using declivital characters (Wood 1982) whereas those of *D. ponderosae* were determined by dissection and examination of genitalia. Voucher specimens were deposited at the Entomology Museum, Simon Fraser University.

Statistical Analyses. The data were analyzed with the SYSTAT statistical package (version 8.0) (SPSS 1998). Trap catch data from all experiments were transformed by ln(Y+1) whereas sex ratio data (for catches > 5) were transformed by arcsine$\sqrt{(Y)}$. All data were analyzed by one-way ANOVA, followed by Fisher's least-significant-difference (LSD) multiple comparison test when $P < 0.05$. In addition, data from experiment 2 were analyzed by full-factorial three-way ANOVA using location, verbenol mix and *exo*-brevicomin as the model factors.

RESULTS

The treatments in experiment 1 had a significant effect on catches of *I. pini* ($F_{4,44}$ = 15.85, $P < 0.001$) and *D. ponderosae* ($F_{4,29}$ = 4.48, P = 0.006). Three replicates were excluded in the analyses for *D. ponderosae* because no beetles were captured in these replicates. The combination of (±)-*exo*-brevicomin and *cis*- and *trans*-verbenol significantly interrupted the attraction of *I. pini* to its pheromone ipsdienol, reducing mean catches of *I. pini* to levels similar to those in traps baited only with (±)-*exo*-brevicomin and *cis*- and *trans*-verbenol (Fig. 1). Mean catches in traps baited with either ipsdienol and (±)-*exo*-brevicomin or ipsdienol and the verbenol mixture were not significantly different from mean catches in traps baited only with ipsdienol. The response of *D. ponderosae* was the converse of *I. pini* with the highest catches in all traps baited with the verbenol mixture (Fig. 1). There was no significant effect of treatment on sex ratios for either *I. pini* ($F_{2,21}$ = 0.36, P = 0.705) or *D. ponderosae* ($F_{3,16}$ = 2.47, P = 0.099). The mean percentages (±SE) of male *I. pini* and *D. ponderosae* in trap catches were 33 (± 3) % and 47 (± 3) %, respectively.

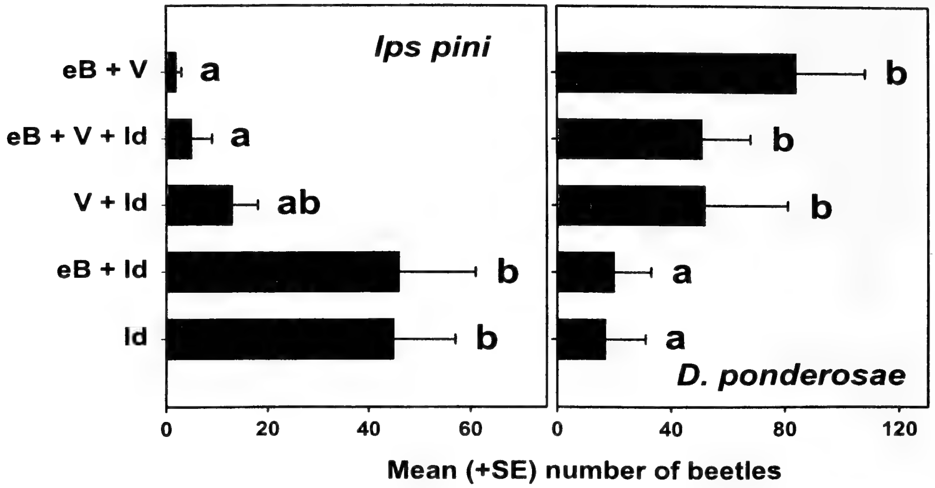

Figure 1. Effect of ipsdienol (Id), (±)-*exo*-brevicomin (eB), and *cis*- and *trans*-verbenol mixture (V) on the attraction of *Ips pini* and *Dendroctonus ponderosae* to multiple-funnel traps in experiment 1 in 1986 (N = 10). Mean trap catches, within the same figure, followed by the same letter are not significantly different at $P = 0.05$ (Fisher's LSD test).

In experiment 2, the verbenol mixture had a significant effect on catches of *I. pini* (Table 1). The effect was consistent for all three regions since no interaction term was significant. Catches of *I. pini* to ipsdienol-baited traps were significantly reduced by the verbenol mixture, with or without (±)-*exo*-brevicomin (Fig. 2). There was no significant effect of (±)-*exo*-brevicomin on trap catches (Table 1). In all three regions, catches of *I. pini* in traps baited with ipsdienol and (±)-*exo*-brevicomin were not significantly different from those in traps baited with ipsdienol alone (Fig. 2). There was no effect of treatment on sex ratios of *I. pini* in trap catches (Table 1). The mean (±SE) percentage of males in trap catches was 25 (± 1) %.

Table 1

Analysis of variance on effects of location (Princeton, Williams Lake, and Radium, BC), verbenol mixture, and (±)-*exo*-brevicomin on number and sex ratio of *Ips pini* responding to ipsdienol-baited multiple-funnel traps in 1987 (Experiment 2).

	Trap catch [a]			Proportion of males [b]		
Source	df	F	P	df	F	P
Location (A)	2	24.26	<0.001	2	0.63	0.539
Verbenol mix (B)	1	27.73	<0.001	1	0.06	0.809
(±)-*exo*-Brevicomin (C)	1	0.04	0.833	1	0.19	0.669
A * B	2	0.15	0.862	2	0.57	0.567
A * C	2	0.92	0.406	2	0.31	0.733
B * C	1	0.26	0.610	1	1.08	0.304
A * B * C	2	0.35	0.703	2	1.26	0.293
Error	48			47		

[a] Data transformed by ln(Y + 1).

[b] Data transformed by arcsine√(Y).

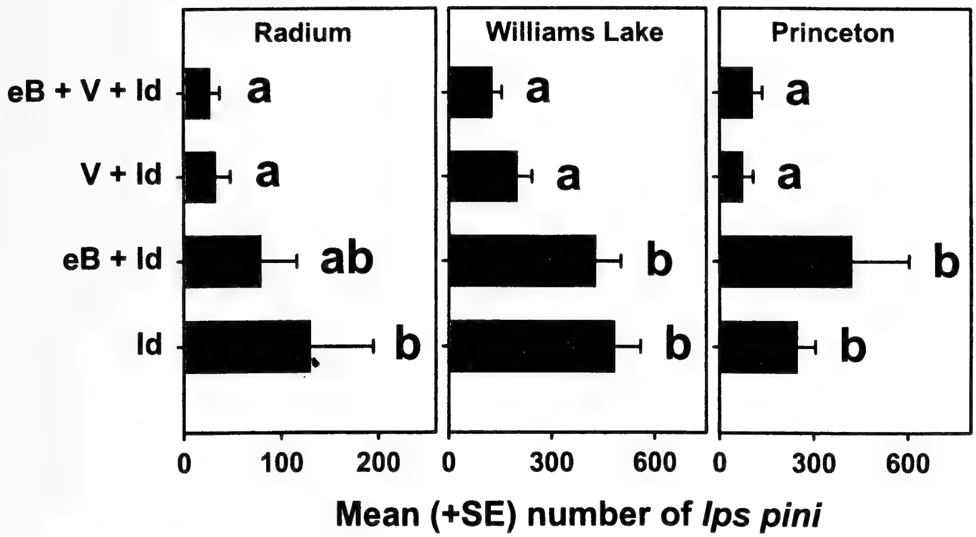

Figure 2. Effect of (±)-*exo*-brevicomin (eB) and *cis*- and *trans*-verbenol mixture (V) on the attraction of *Ips pini* to ipsdienol (Id) - baited multiple-funnel traps in experiment 2 in 1987 ($N = 5$). Mean trap catches, within the same figure, followed by the same letter are not significantly different at $P = 0.05$ (Fisher's LSD test).

In experiment 3, the enantiomeric composition of *exo*-brevicomin had no significant effect on trap catches of *I. pini* ($F_{4,20} = 0.54$, $P = 0.707$) or sex ratio of captured *I. pini* ($F_{4,20} = 1.65$, $P = 0.202$) (Fig. 3). The mean (±SE) percentage of males in trap catches was 27 (± 2) %.

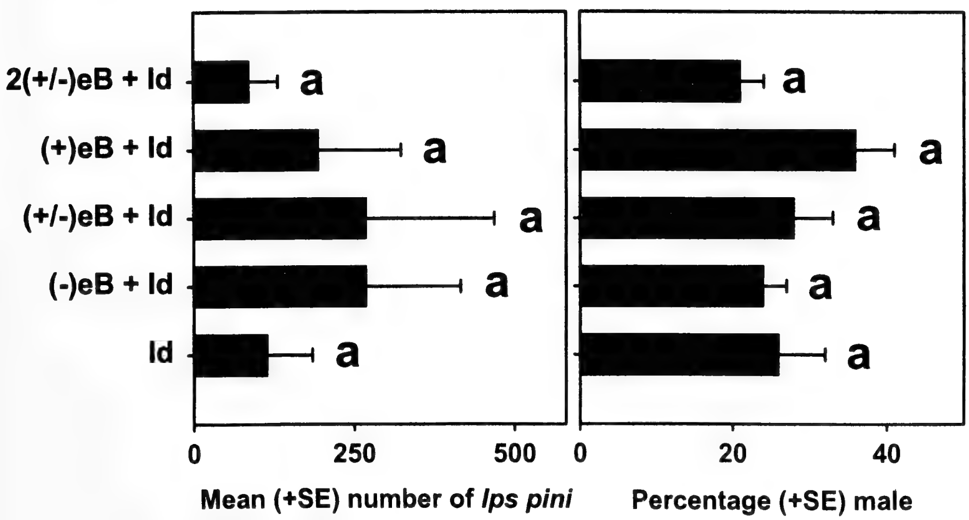

Figure 3. Effect of enantiomeric composition of *exo*-brevicomin (eB) on the attraction of *Ips pini* to ipsdienol (Id) - baited multiple-funnel traps in experiment 3 in 1987 ($N = 5$). Mean trap catches, within the same figure, followed by the same letter are not significantly different at $P = 0.05$ (Fisher's LSD test).

DISCUSSION

Bark beetles use semiochemicals to ensure ecological and reproductive isolation (Byers 1989). Host partitioning within the southern pine bark beetle guild of five species occurs through pheromone specificity and mutual interruption of pheromone attraction (Smith *et al.* 1993). The principal pheromones and synomones are ipsenol, ipsdienol, frontalin, verbenone, brevicomins and verbenols (Smith *et al.* 1993). Similarly in Europe, separation among six species of *Ips* DeGeer is maintained by pheromone blends of ipsenol, ipsdienol, amitinol, myrtenol, and verbenols (Kohnle *et al.* 1988, 1993).

The same phenomenon is apparent among western species of bark beetles in North America as well. Mutual interruption of pheromone response occurs between *I. pini* and *D. ponderosae* in stands of lodgepole pine in British Columbia. Our results substantiate prior work by Hunt and Borden (1988) demonstrating that the attraction of *I. pini* to its pheromone is interrupted by pheromones of *D. ponderosae.* Specifically, we found that attraction of *I. pini* to (±)-ipsdienol was clearly interrupted by the combination of *cis-* and *trans*-verbenol (Figs. 1-2).

Additional work is required to separate the effects of *cis*-verbenol and *trans*-verbenol, and their enantiomeric compositions, on the interruption of pheromone attraction by *I. pini.* Our work employed a 13:87 mix of *cis-* and *trans*-verbenol with an overall enantiomeric composition of 83:17 (-):(+), due to the lack of availability of pure compounds. Both *cis-* and *trans*-verbenol are used by *D. ponderosae* as aggregation pheromones (Miller and Lafontaine 1991) and likely have similar effects on the response of *I. pini* to its pheromone.

Exo-brevicomin had no effect on the attraction of *I. pini* to ipsdienol (Figs. 1-2). Pureswaran *et al.* (2000) demonstrated that *exo*-brevicomin significantly decreased catches of male *I. pini* to (±)-ipsdienol-baited multiple-funnel traps near Princeton, BC. There was no significant effect on catches of female *I. pini* (Pureswaran *et al.* 2000). It is possible that our results with *exo*-brevicomin were due to an inappropriate dose range. We used devices, which released *exo*-brevicomin at rates of 0.12-0.15 mg/d at 20-25 °C whereas Pureswaran *et al.* (2000) used devices, which released *exo*-brevicomin at a rate of ca. 3.1 mg/d at 25 °C.

The enantiomeric composition of *exo*-brevicomin had no effect on trap catches of *I. pini* (Fig. 3). Pureswaran *et al.* (2000) demonstrated antennal responses of male and female *I. pini* to (+)-*exo*-brevicomin and (+)-*endo*-brevicomin. The antipodes, (-)-*exo*-brevicomin and (-)-*endo*-brevicomin, elicited no response from *I. pini.* Further trials with *exo*-brevicomin should be conducted with higher release rates of the (+)-enantiomer since the lack of antennal activity with the (-)-enantiomer should correlate with a lack of field activity.

In contrast to Hunt and Borden (1988), ipsdienol had no effect on the attraction of *D. ponderosae* to the female-produced pheromones, *cis-* and *trans*-verbenol (Fig. 1). All our experiments were conducted in late summer (August and September) whereas Hunt and Borden (1988) demonstrated significant interruption in pheromone response in experiments conducted in July. Their experiments conducted in early August failed to demonstrate interruption of attraction of *D. ponderosae* to the blend of myrcene, *exo*-brevicomin, and *cis-* and *trans*-verbenol by ipsdienol. It is possible that discrimination by *D. ponderosae* differs during the season, possibly due to differential costs and benefits related to the onset of colder temperatures (Reid 1962). Since the egg and early larval stages are susceptible to high mortality from cold temperatures, beetles need to ensure that eggs hatch and develop to the cold-tolerant 3-rd and 4-th larval stages prior to the arrival of winter temperatures (Safranyik and Linton 1998). Additional work should be conducted on the effect of another *I. pini* pheromone, lanierone (2-hydroxy-4,4,6-trimethyl-2,5-cyclohexadien1-one), as an interruptant for *D. ponderosae.* Lanierone produced by male

I. pini (Teale *et al.* 1991) significantly increases catches of *I. pini* to ipsdienol-baited traps in British Columbia (Miller *et al.* 1997).

Semiochemical specificity and mutual interruption of pheromones in western pine forests is not limited to *I. pini* and *D. ponderosae*. More than 50 species of bark beetles have been reported on lodgepole pine, many of which are phloeophagous and maintain ecological and reproductive separation (Wood 1982). Attraction of *I. latidens* (LeConte) to its pheromone, ipsenol (2-methyl-6-methylene-7-octen-4-ol), is interrupted by (+)-ipsdienol (Miller and Borden 1992) whereas attraction of *I. pini* is interrupted by the pheromone of *I. latidens*, ipsenol (Borden *et al.* 1992). The attraction of *I. integer* (Eichhoff) to lanierone is interrupted by ipsdienol whereas the attraction of *I. pini* to ipsdienol is enhanced by lanierone (Miller *et al.* 1997). Mutual interruption of pheromone attraction also occurs between *I. pini* and *I. paraconfusus* Lanier (Birch and Wood 1975; Birch *et al.* 1980) and between *I. paraconfusus* and *D. brevicomis* LeConte (Byers and Wood 1980, 1981).

Semiochemical interruptants will play an important role in future integrated pest management programs for bark beetles (Borden *et al.* 1992). For example, interruptants can be used to minimize the likelihood that populations of *I. pini* build up in slash generated by thinning operations to such levels that they successfully attack and kill standing trees (Borden *et al.* 1992). Verbenone (4,6,6-trimethylbicyclo[3.1.1]hept-3-en-2-one), an antiaggregation pheromone produced by *D. ponderosae* (Borden *et al.* 1987), and ipsenol, a pheromone produced by *I. latidens* (Miller *et al.* 1991), interrupt the attraction of *I. pini* to its pheromone (Borden *et al.* 1992). The combination of verbenone and ipsenol resulted in a 67% reduction in the number of downed lodgepole pines attacked by *I. pini* and a 99% reduction in attack density (Borden *et al.* 1992).

A complete understanding of the role and impact of the various pheromones and kairomones is required to develop effective management programs. For example, the combination of the interruptants for *D. frontalis* Zimmermann, verbenone and *endo*- and *exo*-brevicomin, reduced the landings of *D. frontalis* on live loblolly pine by 84% with a 84% reduction in eggs laid (Payne and Richerson 1979). However, the treatment failed to prevent tree mortality due to an increase in attacks by another bark beetle, *I. avulsus* (Eichhoff).

The risks and consequences of interruptants should be carefully considered in management programs that facilitate interspecific competition to reduce the reproductive potential of a pest species. Significant reductions in survivorship of *D. frontalis* can occur by the practice of simply falling infested trees and abandoning them (Billings 1980). This fall-and-leave practice apparently increases levels of competition by secondary bark beetles, predation and parasitism (Billings 1980). Other researchers have used semiochemicals to induce similar levels of competition with bark beetles in western North America. Rankin and Borden (1991) used ipsdienol to induce attacks by *I. pini* on logs previously infested with *D. ponderosae*, resulting in a 73% reduction in progeny of *D. ponderosae*. Safranyik *et al.* (1998) obtained a 49% reduction in progeny of *D. ponderosae* by baiting standing lodgepole pine with *I. pini* pheromones, ipsdienol and lanierone, when baiting was conducted in September. In both studies, the attack densities of *D. ponderosae* between control and treated trees were not significantly different. However, Safranyik *et al.* (1998) found that baiting standing trees with *I. pini* pheromones in August resulted in a 53% reduction in attack density of *D. ponderosae* with no difference in mean progeny production between treated and control trees. Attractants used to initiate competition against a pest species such as *D. ponderosae* should be applied with due consideration to timing of application and appropriate combinations of semiochemicals.

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Gyrinus cavatus and *G. minutus* (Coleoptera: Gyrinidae) in British Columbia with comments on their nearctic distributions

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ABSTRACT

The distributions of *Gyrinus cavatus* Atton and *G. minutus* Fabricius in British Columbia (BC) were determined by examining adult specimens from a number of museum collections. *Gyrinus cavatus* appears to be restricted to the eastern half of the province except in the far north; *G. minutus* is more widespread. Outside BC, *G. cavatus* is widely distributed with a range extending from Newfoundland to Alaska and south as far as Kansas, with an apparently isolated population in southern Utah. *Gyrinus minutus*, although generally more northern in distribution, extends south along the Rocky Mountains as far as Colorado.

Key words: Gyrinidae, *Gyrinulus*, *Gyrinus*, *cavatus*, *minutus*, *rockinghamensis*, British Columbia, Yukon, Alaska, nearctic, distribution

INTRODUCTION

The Gyrinidae are a small family of distinctive beetles that are superbly adapted to their aquatic lifestyle (Ferkinhoff and Gundersen 1983, Hilsenhoff 1990). North American Gyrinidae are classified in four genera, two of which, *Dineutus* MacLeay and *Gyrinus* Müller, occur in British Columbia (BC) (Roughley 1991). *Dineutus* is represented by a single species, *Dineutus assimilis* (Kirby), whose status in BC is questionable (Hatch 1953). The genus *Gyrinus* is represented in British Columbia by 17 species (Roughley 1991; Oygur and Wolfe 1991). One subgenus, *Gyrinulus* Zaitzev, includes three species in North America: *Gyrinus minutus* Fabricius, *G. cavatus* Atton and *G. rockinghamensis* LeConte. The former two species occur in BC and their distribution forms the subject of this study. *Gyrinus rockinghamensis* is known from the east coast of North America (Fall 1922; Oygur and Wolfe 1991).

Atton (1990) showed that what was called *G. minutus* in North America was in fact two species: *G. minutus,* with a relatively northern holarctic distribution, and *G. cavatus,* with a more southerly distribution. Atton gave only Canadian localities for the two species and he listed only two localities in BC for *G. cavatus*: Windermere and Mile 744 on the Alaska Highway. Oygur and Wolfe (1991) did not recognize *G. cavatus*, thus their distribution map for *G. minutus* includes possible *G. cavatus* records. To better understand the status of *G. cavatus* in BC, I have collected locality information by examining specimens from a number of museums.

MATERIALS AND METHODS

During the course of this investigation, several thousand *Gyrinus* spp. specimens from 20 museums and a private collection were examined, including 799 *G. minutus* and *G. cavatus*, and several hundred *G. rockinghamensis*. In addition, G.G.E. Scudder (University of British Columbia) supplied a list of records based on the specimens in the Canadian National Collection in Ottawa (CNC), which I did not examine. No particular effort was made to be comprehensive in coverage of eastern North America. The following museums and collectors kindly loaned material for this investigation:

American Museum of Natural History, L. Herman
W. F. Barr Entomological Museum, University of Idaho, F. W. Merickel
California Academy of Sciences, D. H. Kavanaugh
Carnegie Museum of Natural History, R. L. Davidson
Entomology Section, Oregon Department of Agriculture, R. L. Westcott
Essig Museum of Entomology, University of California, Berkeley, C. Barr
W. T. James Entomological Collection, Washington State University, R. S. Zack
Lyman Entomological Museum, McGill University, C. C. Hsiung
Museum of Zoology, University of Michigan, M. F. O'Brien
National Museum of Natural History, P. J. Spangler
Natural History Museum of Los Angeles County, B. V. Brown
Oregon State Arthropod Collection, Oregon State University, D. Judd
A. B. Richards, Lakewood, Colorado
Royal British Columbia Museum, R. A. Cannings
Royal Ontario Museum, D. Currie
Snow Entomological Museum, University of Kansas, R. W. Brooks
Spencer Entomological Museum, University of British Columbia, K. Needham
Strickland Museum, University of Alberta, D. Shpeley
University of Nebraska State Museum, G. Hall
University of Wyoming Insect Museum, S. R. Shaw
J. B. Wallis Museum, University of Manitoba, R. E. Roughley.

Gyrinus cavatus, *G. minutus* and *G. rockinghamensis* were separated using the characters given in Fall (1922), Atton (1990) and Oygur and Wolfe (1991). *Gyrinus cavatus* has dark abdominal sterna and a pale mesosternum with a medial sulcus and deep right-triangular anterolateral depressions. *Gyrinus minutus* is completely dark ventrally with a sulcate mesosternum having shallow oblique-triangular anterolateral depressions. *Gyrinus rockinghamensis* is completely pale ventrally and has a mesosternum with only a very shallow or no medial sulcus and very shallow or no anterolateral depressions. Body length is also useful in separating *G. cavatus* and *G. minutus;* it was measured as specified by Atton (1990), using an eyepiece graticule on a stereomicroscope and is reported as mean ±SE with *n* being the number of specimens. A detailed list of the specimens examined can be obtained from the author and should eventually be available on the Internet.

RESULTS AND DISCUSSION

Based on the specimens examined during this study, along with the records from the CNC and Atton (1990), the distribution of *G. cavatus* extends from Newfoundland to Alaska. The following jurisdictions should be added to the distribution given in the "Checklist of Beetles of Canada and Alaska" (Roughley 1991): AK, ON, PQ and NF (SK, the type locality, was also omitted). In the contiguous United States, it occurs from Maine to New Jersey on the east coast, then west from Indiana and Michigan through Illinois, Iowa, Nebraska and Kansas, north to the Canadian border (Wisconsin, Minnesota, South and North Dakota and Wyoming). I have no records for Montana or Idaho but I have seen one specimen labelled simply "Wash" and eight specimens labelled "Was. T."or "W. T." (Washington Territory, an older designation for the Pacific Northwest, P.J. Spangler, National Museum of Natural History, personal communication) which may imply its occurrence in Washington. In addition, there is an apparently disjunct population in Utah.

In spite of its broad range, *G. cavatus* is relatively uniform morphologically with no obvious regional variation other than the exception discussed below. Some individual variability in ventral color was apparent but some of that may be due to differences in preservation and treatment. Many specimens of *G. cavatus* have a slight convexity in the sides of the median sulcus of the mesosternum that results in a slightly oval widening of the sulcus near its mid-point. In a few specimens, that convexity is exaggerated to the point where a flat-bottomed oval depression is formed in the medial sulcus. This occurs in a majority of the specimens from the Aquarius Plateau in south-central Utah but also occurs in a few specimens from other areas. The specimens from Utah are larger than elsewhere (Table 1). This larger size is not simply a matter of increasing size with decreasing latitude as the specimens from Kansas, at about the same latitude as Utah, are similar in size to those from northern Canada.

Table 1

Body length (BL) of three *Gyrinulus* species by location: range, mean ± SE and sample size (*n*).

Locality	Species	BL (♂) (mm)	BL (♀) (mm)
all areas except Utah	*G. cavatus*	3.00 – 4.00 3.67 ± 0.012 (151)	3.50 – 4.35 3.99 ± 0.012 (140)
Utah	*G. cavatus*	3.85 – 4.10 3.96 ± 0.038 (9)	4.2 (1)
Canada and Alaska	*G. minutus*	3.75 – 4.45 4.11 ± 0.013 (144)	4.00 – 4.85 4.48 ± 0.015 (127)
Wyoming	*G. minutus*	4.00 – 4.45 4.28 ± 0.035 (15)	4.35 – 4.95 4.55 ± 0.035 (17)
Colorado	*G. minutus*	4.3 (1)	-
all areas	*G. rockinghamensis*	3.45 – 4.05 3.69 ± 0.015 (70)	3.55 – 4.30 3.98 ± 0.023 (47)

The distribution of *G. minutus* also stretches across Canada and Alaska although I have very few records from the eastern provinces: one record from Newfoundland, three from Quebec and one labelled "H. B." (Hudson Bay, R.L. Davidson, Carnegie Museum of Natural History, personal communication). It is restricted to the more northerly parts of Manitoba and Saskatchewan and is widespread in the Northwest and Yukon Territories and Alaska. In Alberta, it is found as far south as Edmonton, except in the Rocky Mountains, where it is found at least as far south as Jasper. Its distribution appears to extend south along the Rocky Mountains with records from Wyoming and Colorado. It seems likely that it will be found in the southern Canadian Rockies and Montana.

Gyrinus minutus is also relatively uniform in appearance over its large range in North America; Atton (1990) found no difference between nearctic and palearctic specimens. The male specimens from Wyoming and Colorado are slightly larger than those from Canada although the females are little different (Table 1).

The distributions of *G. cavatus* and *G. minutus* in BC, Yukon Territory and Alaska, based on this work and the sources cited above, are shown in Figure 1. In BC, *G. cavatus* appears to be restricted to the eastern half of the province except in the far north; *G. minutus* is more widespread but is not found west of the Coast Mountains. The few records for these species in BC suggest that either they are relatively uncommon or that limited collecting was done in the appropriate habitat or season. The lack of data precludes any possibility of determining habitat preferences which dictate the distributions. I have two sites in BC at which both species were collected, Barkerville and Summit Lake at mile 392 on the Alaska Highway. In addition, there are four such

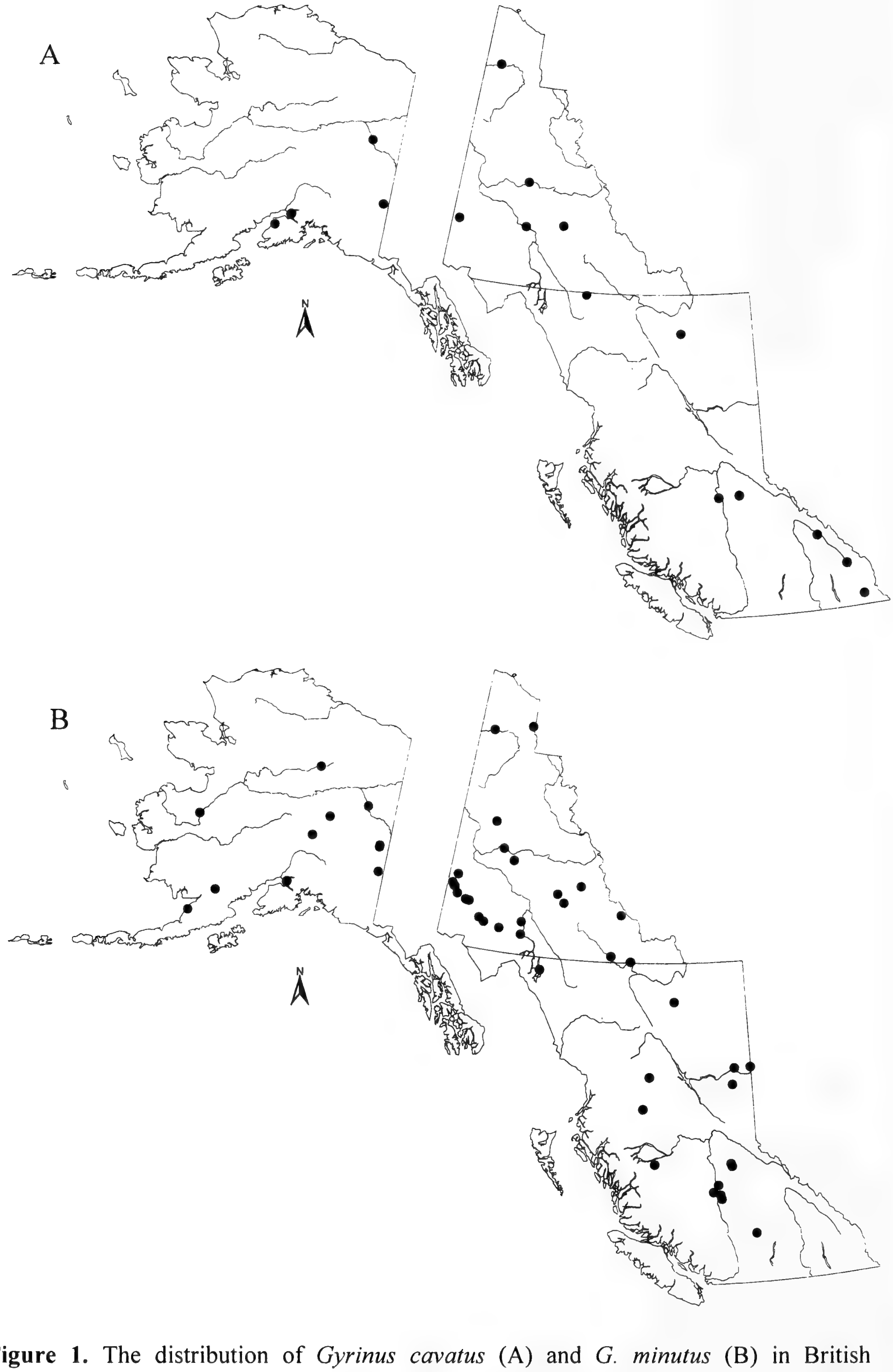

Figure 1. The distribution of *Gyrinus cavatus* (A) and *G. minutus* (B) in British Columbia, Yukon Territory and Alaska based on the data on the labels of the specimens I examined, the data on the labels of the specimens in the Canadian National Collection (Ottawa) and localities given in Atton (1990). Alaska is plotted on a smaller scale than British Columbia and Yukon Territory.

sites in Alaska, three in the Yukon, four in the Northwest Territories and three in Alberta.

I have records for both *Gyrinus cavatus* and *G. rockinghamensis* in New Jersey but the overlap in their ranges is probably more extensive. The two species are superficially very similar, being almost identical in size (Table 1) and both have pale mesosterna. I have seen several examples of *G. cavatus* specimens which were misidentified as *G. rockinghamensis* (see, for example, Figure 5 in Oygur and Wolfe (1991) which is clearly a male *G. cavatus*). The characters discussed above should be adequate to reliably separate the two species.

Studies such as the one reported here can only give a general sense of the overall distribution for the species concerned. The locality labels on most specimens, especially the older ones, give only the general location and carry no information on the habitat in which the collection was made. Even so, one can look for correlations between the ranges and geographic features or ecological zones. Although this study accomplished what it set out to do, it generates several new questions. For example, what is the southern limit for *G. minutus* across the prairie provinces and in eastern North America? Roughley (1991) indicates that *G. minutus* occurs in every province and territory in Canada except Prince Edward Island, but Roughley (1991) is based in part on data that predate the description of *G. cavatus*. Do some of these records actually refer to *G. cavatus*? Another question concerns the apparent gap in the distribution of *G. cavatus* between New Jersey and Indiana. Does *G. cavatus* not occur in the intervening states? Another study similar to this one but with a more eastern geographical focus would probably answer such questions.

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Occurrence and inheritance of a colour pattern dimorphism in adults of *Hyalophora euryalus* (Lepidoptera: Saturniidae)

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ABSTRACT

A white prothoracic collar and white abdominal rings are among the characters used to distinguish adults in the genus *Hyalophora* Duncan (Lepidoptera: Saturniidae) from those in the related genera *Callosamia* Packard and *Eupackardia* Cockerell. However, some adults of *H. euryalus* (Boisduval) on southern Vancouver Island, British Columbia, were found to lack these white body markings. Controlled rearing indicated that the "brown" phenotype is produced by a recessive allele at a single autosomal locus, and examination of museum specimens showed that it is fairly common on southern Vancouver Island and has been present there for at least half a century.

INTRODUCTION

Adults in the genus *Hyalophora* Duncan (Lepidoptera: Saturniidae) are large reddish brown moths with white crescent-shaped discal spots, a white prothoracic collar, and white segmental rings on the abdomen; these white markings are the key characters used to separate this genus from the related genera *Callosamia* Packard and *Eupackardia* Cockerell (Ferguson 1972; Lemaire 1978). In the course of other studies (Morewood 1991a, 1991b) an atypical adult phenotype, characterized by the absence of the white prothoracic collar and abdominal rings (Fig. 1), was discovered in *Hyalophora euryalus* (Boisduval) on southern Vancouver Island, British Columbia. This phenotype appears to be unique in the genus *Hyalophora* and has not been reported previously; for example, Tuskes *et al.* (1996) made no mention of the white prothoracic collar or abdominal rings in their discussion of adult variation for any of the taxa within the genus. The objectives of the current study were to document this adult colour pattern dimorphism, determine its pattern of inheritance, and provide preliminary estimates of its prevalence and distribution.

MATERIALS AND METHODS

A small colony of *H. euryalus* was established from eggs laid by wild adult females captured in Saanich, BC, one female on 16 May 1991 and one female on 6 May 1992 (Fig. 2). Larvae were reared indoors on cuttings of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco ssp. *menziesii*, in large plastic buckets with screened lids. Pupae were overwintered in small cages outdoors, and in the spring, adults were mated using two different methods. In most cases mating cages constructed from coffee cans, as described by Miller and Cooper (1976), were used to mate reared females to wild males to reduce inbreeding. In some cases matings were obtained between reared adults by keeping them together in a larger cage outdoors overnight. Each spring the phenotypes of all reared adults, as well as wild males attracted by the caged females, were recorded as either "normal" (having a white prothoracic collar and abdominal rings) or, for simplicity, "brown" (lacking the "normal" white body markings such that the body appeared brown overall). Twenty-two

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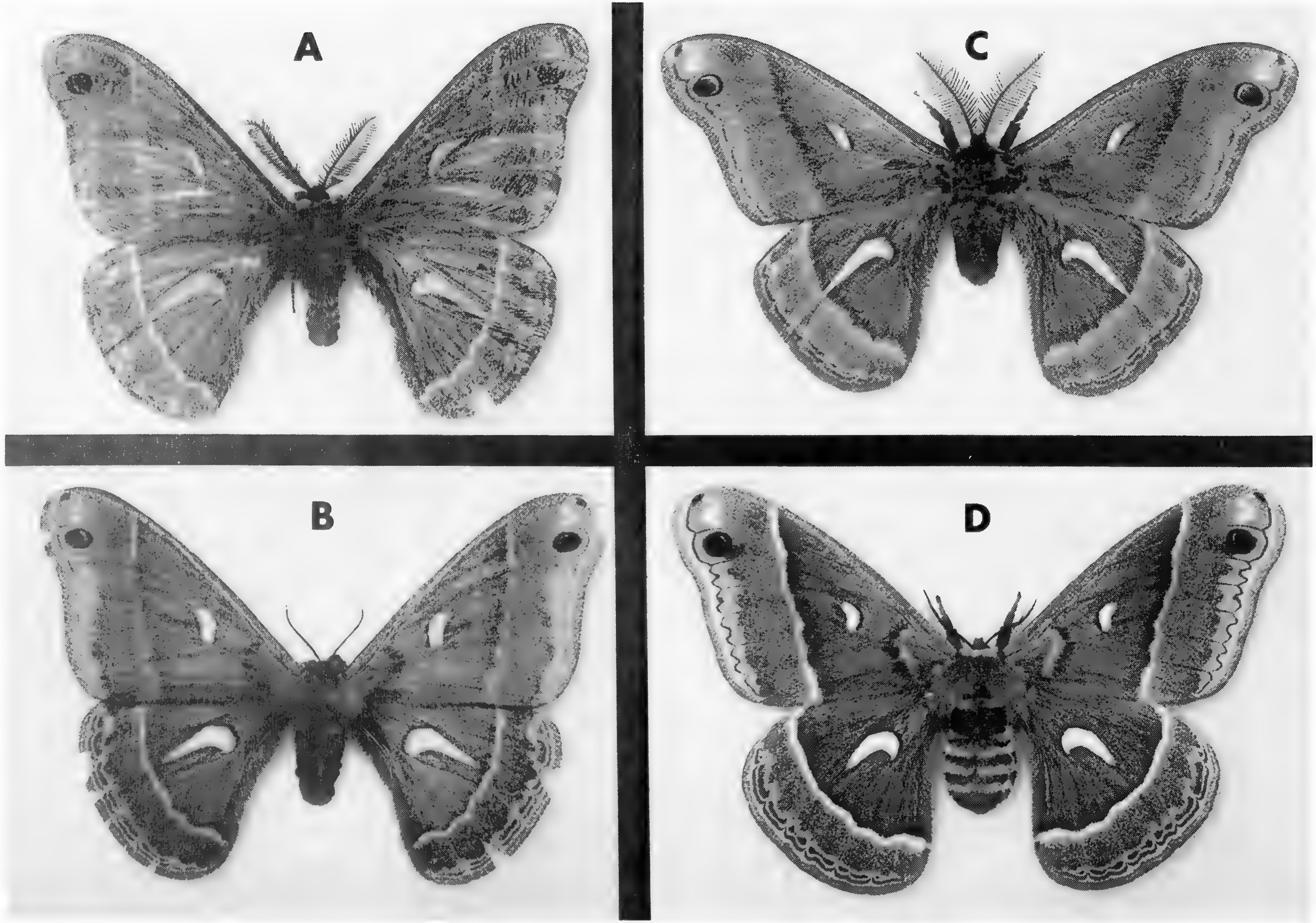

Figure 1. Phenotypically "normal" and "brown" adults of *Hyalophora euryalus* illustrated by specimens from Vancouver Island in the Royal British Columbia Museum collection [catalogue number is given for each specimen]. (A) Normal (very greasy) male, Nanoose, 24 May 1995 [ENT996-006508]. (B) Brown female, Nanoose, 24 May 1995 [ENT996-006511]. (C) Brown male, Saanich, 1959 [ENT991-154531]. (D) Normal female, Victoria, 1958 [ENT991-154526].

different broods were reared between 1991 and 1999, and the study was terminated when in the summer of 1999 all larvae were lost to disease. Due to logistic constraints, only small numbers of larvae were reared from most broods, making analysis of the distribution of adult phenotypes within individual broods unlikely to yield meaningful results. Therefore, broods representing crosses of apparently equivalent genotypes were grouped together and the overall distribution of phenotypes for each type of cross was used to evaluate the pattern of inheritance.

To provide a broader estimate of the prevalence and distribution of the brown phenotype, all of the adult specimens of *H. euryalus* were examined in three major insect collections in southwestern BC, namely those in the Spencer Entomological Museum at the University of British Columbia in Vancouver and in the Pacific Forestry Centre and the Royal British Columbia Museum in Victoria.

RESULTS

Adults were easily classified as having either the normal or the brown phenotype, with no intermediate forms, and both phenotypes were common in both sexes (Figs. 1, 2). The normal pattern of white body markings, in particular the location of the white prothoracic collar, was often detectable as a faint greyish "smudge" in adults with the brown phenotype; however, in no case was there any difficulty in assigning an individual to one phenotype or the other. Crosses in which both parents were brown produced only brown progeny (Brood numbers 3, 5, 9, 16, and 18 in Fig. 2 and Table 1) but crosses in which both parents were normal had the potential to produce progeny of both phenotypes (Brood number 4 in Fig. 2 and Table 1). Crosses in which one parent was brown and the other was heterozygous normal (Brood numbers 2, 6, 7, 8, 10, 11, 12, 13, 14, and 20) produced progeny in almost exactly the expected 1:1 ratio overall (Table 1), including both phenotypes in progeny of each sex (Fig. 2).

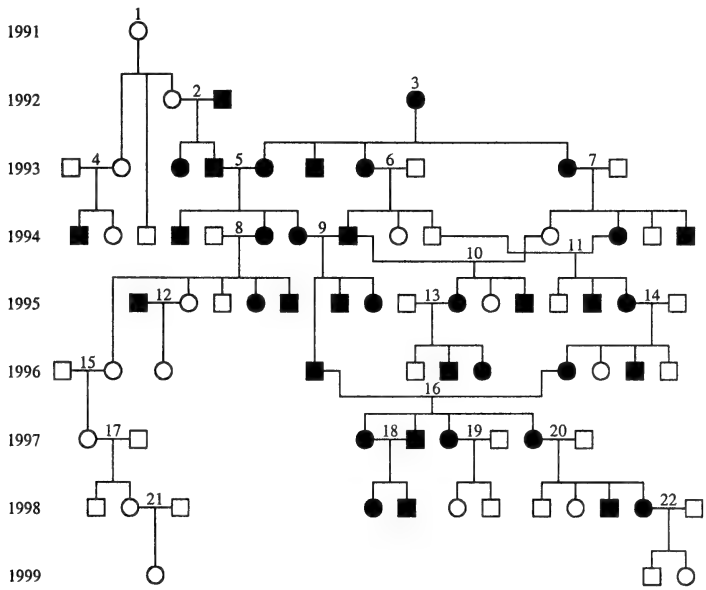

Figure 2. Pedigree for the adults of *Hyalophora euryalus* reared during the course of this study. Circles represent females, squares represent males; open symbols indicate the "normal" phenotype, filled symbols indicate the "brown" phenotype. Numbers above matings, and above the two founding females, are the "Brood numbers" in Table 1.

Table 1

Observed and expected adult phenotypes of *Hyalophora euryalus* reared in Saanich, British Columbia, between 1991 and 1999.

Type of cross (parental genotypes)	Brood numbers[1] (see Fig. 2)	Observed phenotypes Normal	Observed phenotypes Brown	Expected phenotypes Normal	Expected phenotypes Brown
Normal x Brown	2	0	7		
(Bb x bb)	6	4	2		
	7	2	4		
	8	11	4		
	10	2	5		
	11	3	3		
	12	1	0		
	13	5	7		
	14	6	4		
	20	6	8		
	Total:	40	44	42	42
Brown x Brown	3	0	22		
(bb x bb)	5	0	5		
	9	0	15		
	16	0	31		
	18	0	4		
	Total:	0	77	0	77
Normal x Normal	4	4	2		
(Bb x Bb)	Total:	4	2	3	1

[1]Excluding broods 1, 15, 17, 19, 21, and 22, for which both parental genotypes could not be conclusively determined.

The phenotypes of 28 wild males attracted by reared females caged in Saanich were recorded during the course of this study; of these, seven (25%) had the brown phenotype. A total of 40 adult specimens of *H. euryalus* were examined at the Spencer Entomological Museum, approximately one-third of these being from southern Vancouver Island and the adjacent Gulf Islands and the remainder from various localities in the southern interior of BC as far north as Riske Creek and as far east as Cranbrook. Only three of these specimens (7.5% of the total) had the brown phenotype, one from Nanaimo (1951), one from Langford (no collection date), and one from Salmon Arm (1961). At the Pacific Forestry Centre 18 adult specimens of *H. euryalus* were examined, over half of these being from southern Vancouver Island and the remainder from the northern Okanagan region of the southern interior, and no brown phenotypes were found. A total of 52 adult specimens of *H. euryalus* were examined at the Royal British Columbia Museum, almost half being from southern Vancouver Island and the Gulf Islands and the remainder of those with locality data being from the southern interior of BC as far north as Williams Lake and as far east as Cranbrook. Six of these specimens (11.5% of the total) had the brown phenotype, two from Saanich (1959 and 1990), one from Nanoose (1995), one from Galiano Island (1989), and two with no locality data (and no collection dates). Overall, of 50 museum specimens from southern Vancouver Island and the Gulf Islands, six (12%) had the brown phenotype and of 40 museum specimens from the mainland (all but one from the interior) of BC, only one (2.5%) had the brown phenotype (the remaining 20 museum specimens had no locality data).

DISCUSSION

The overall distribution of phenotypes was consistent with a simple Mendelian pattern of inheritance. Specifically, the presence or absence of the white prothoracic collar and abdominal rings appears to be controlled by a single autosomal gene with two alleles, a dominant allele ("B") producing the normal phenotype and a recessive allele ("b") producing the brown phenotype (Table 1). The distribution of phenotypes among the progeny of crosses in which the parental female was normal and the parental male was brown indicates that the brown phenotype is not sex-linked. Considering that the female is the heterogametic sex in Lepidoptera, such crosses (Brood numbers 2, 10, and 12) should produce only normal males and brown females if the trait is sex-linked, but that was not the case (Fig. 2).

Other atypical phenotypes with similar patterns of inheritance have been reported previously for various Lepidoptera in the context of biochemistry or evolution or both. Waldbauer and Sternburg (1972) reported that a "blue" larval phenotype arose in their laboratory colony of *Hyalophora cecropia* (L.) and was inherited as a simple autosomal recessive. Based on the work of Clark (1971), they suggested that it was produced by a mutation affecting the biochemical pathway that produces cuticular pigments from dietary carotenoids. Stimson and Meyers (1984) reported that a "white" adult phenotype known since 1965 in the Monarch butterfly, *Danaus plexippus* (L.) (Nymphalidae), in Hawaii is inherited as a simple autosomal recessive. They presented evidence that it might be increasing in frequency due to a lack of natural predators in Hawaii compared to North America where predators would selectively remove adults lacking the normal aposematic colour pattern. Adult females of the Eastern Tiger Swallowtail, *Papilio glaucus* L. (Papilionidae), have either the black and yellow phenotype typical of the species or a melanic phenotype that is thought to mimic the distasteful Pipevine Swallowtail, *Battus philenor* (L.) (Papilionidae) (Brower and Brower 1962). Clarke and Sheppard (1962) presented evidence that the melanic phenotype is completely sex-linked and Koch *et al.* (1998) proposed a biochemical mechanism by which it could be controlled through a single locus on the Y chromosome.

The museum specimens and wild individuals of *H. euryalus* observed during the current study indicate that the brown phenotype has existed for at least half a century and is fairly common on southern Vancouver Island, which suggests that the trait arose in this region and that it offers some selective advantage or at least is not deleterious. The single brown specimen from Salmon Arm indicates that this phenotype may also occur more rarely in the interior of BC in *Hyalophora "kasloensis"* - a population of hybrid origin and uncertain taxonomic standing (Tuskes *et al.* 1996; Collins 1997) which formerly was considered to be a subspecies of *H. euryalus* (Morewood 1991a) - and suggests that there might be gene flow between populations of *Hyalophora* in the interior and on the coast.

Among the colour patterns on the wings of various Lepidoptera, including many Saturniidae, are well-developed "eyespots" that are thought to provide some protection from vertebrate predators. The discal spots of *Hyalophora* can hardly be considered to resemble typical eyes, however. The discal spots of *H. euryalus* are white, more-or-less crescent-shaped, and much larger and more elongate on the hindwings than on the forewings (Fig. 1). In the normal posture of living moths (as opposed to spread museum specimens), the discal spots on the forewings and hindwings, respectively, of *H. euryalus* might be imagined to resemble the narrowed eyes and bared canine teeth of a small feline predator. Such a resemblance might provide some protection against predation by birds and perhaps this resemblance is disrupted by the presence of the white body markings typical of adults of *Hyalophora*.

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Aphid (Homoptera: Aphididae) accumulation and distribution near fences designed for cabbage fly (Diptera: Anthomyiidae) exclusion

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ABSTRACT

Aphids accumulate near exclusion fences designed to intercept *Delia radicum* (L.) movement into fields. Aphid accumulations increase with increasing fence height, but are not affected by fence overhang length. Overall aphid levels are higher in small (4.3 m square) enclosed plots than in unenclosed plots. Enclosing large (38 m square) plots does not alter overall aphid catches, but does alter aphid distribution within enclosures. In large enclosures aphid accumulations are higher at enclosure perimeters than interiors, with the highest accumulations near enclosure corners. This concentric distribution is not observed in unfenced areas, and is not altered by the addition of a trap crop outside an enclosure.

Key words: *Myzus persicae*, *Delia radicum*, physical control

INTRODUCTION

The brassica pest *Delia radicum* (L.) (Diptera:Anthomyiidae) tends to fly close to the ground (Vernon and MacKenzie 1998), where it can be intercepted by mesh exclusion fences erected around brassica plantings to reduce crop damage (Vernon and MacKenzie 1998; Päts and Vernon 1999; Bomford *et al.* 2000). In contrast, aphids (Homoptera: Aphididae) commonly migrate at altitudes between 10 and 2,000 m (Isard *et al.* 1990). Exclusion fences are unlikely to intercept aphid movement due to aphids' tendancy to move close to the ground only when making short, local flights or preparing to alight. Aphids are known to alight in areas where wind speeds are low, perhaps due to passive deposition (Lewis and Dibley 1970), or active behaviour (Kennedy and Thomas 1973). Since an exclusion fence may act as a partial windbreak, aphid accumulations may occur inside the fence, which could be a concern to growers wishing to adopt this pest management tool. This paper reports observations of aphid distribution inside fenced enclosures during several experiments initially conducted to test *D. radicum* exclusion by mesh fences.

MATERIALS AND METHODS

Fence height study. Exclusion fences consisted of wooden frameworks covered with 1-mm-mesh nylon window screening (Stollco Industries Ltd., Port Coquitlam, BC), enclosing 5 m square plots. At the top of each fence, the vertical screen was bent over a horizontal wooden sill (5 cm wide) along the top of the fence posts, to form a 22 cm outward overhang, angled downward at 30-35° along triangular pieces of plywood secured to the fence posts. There was no screen overhang projecting into the inside of the enclosures. Fence heights (from ground level to the bottom of the outward overhang) of 30, 60, and 90 cm were tested. The open check plots had the same structure as the 30-cm fence, but without the vertically oriented nylon screen. The trial was arranged as a four by four Latin square, with adjacent blocks 4 m apart.

Fences were installed by 26 April 1991 in a 50 by 55 m field located at Abbotsford, BC. The field had been planted in raspberries for the 3 years previous, and had been kept virtually weed free during the previous growing season. To prevent weed growth, soil on the inside of the enclosures was covered with landscape fabric (Lumite 994, Division of Synthetic Ind., Norcross, Georgia), and soil in a 1 m strip centred along the fence perimeter was covered with black plastic. On 29 April, 1991, twenty 2-week-old rutabagas, *Brassica campestris* var. *napobrassica* (L.) 'Laurentian,' were transplanted into the plots along each of five parallel rows cut into the landscape fabric. Exposed soil around rutabagas was weeded weekly.

On 4 July 1991, counts of aphids, aphids parasitized by aphidiid wasps (Hymenoptera: Aphidiidae), and syrphid fly larvae (Diptera: Syrphidae) were recorded for 15-23 rutabaga leaves from each of the five crop rows of each plot. The mean number of insects per leaf was calculated for each insect in each treatment. Data were analyzed by ANOVA, and treatment means were separated using Tukey's test.

Standard fence design. A modified version of the fence used in the previous study was used in all remaining studies. Aluminum framed window screens of 1 mm black nylon mesh (210 cm long by 120 cm high) (Stollco Industries, Port Coquitlam, BC) were supported between wooden fence posts (7.5 cm by 9 cm wide by 120 cm high) to form vertical panels. At the top of each panel a wooden fence top (2 cm high by 8 cm wide by 210 cm long) rested on the top edge of the aluminum frame. From this wooden top, separate strips of 1-mm-mesh nylon screen were attached to form collection overhangs of specified lengths angled downward at 45° on both sides of the fence, and held in place by plywood triangles attached to the tops of the fence posts. All exposed fence components were black.

Sticky trap design. Sticky traps were used to monitor winged aphid populations in all remaining studies. Traps were made from sheets of white cardboard (4-ply Railroad Board; Domtar Fine Papers, Toronto, ON) painted on both sides with yellow, semigloss enamel paint (Yellow 776, Cloverdale Paint and Chemicals, Surrey, BC), cut into 10 by 14 cm rectangles and dipped in a commercial insect adhesive (Stiky Stuff, Olson Products, Medina, OH). Traps were attached to wooden stakes, with the bottom edge (14 cm long) 15 cm above the ground, and were oriented to face north-south.

Overhang length studies. The experimental site was a regularly mowed field of mixed grass near Abbotsford, BC. The trials were arranged in a randomized complete block design with four replicates, 30 m apart. Each replicate contained three 7 x 7 m square treatment plots, 10 m apart, covered with black woven landscape fabric to prevent the growth of weeds. The three treatment plots in each block were as follows: (1) an unfenced control plot, (2) a plot enclosed by a fence with a 25-cm-long collection overhang, and (3) a plot enclosed by a fence without an overhang (trial 1: 13 July – 10 August, 1994), a fence with a 12.5 cm collection overhang (trial 2: 12-30 August, 1994) or a fence with a 50 cm collection overhang (trial 3: 23 August – 14 September, 1995). The positions of plots in each block were randomized at the start of each trial. Fences enclosed a 4.3 x 4.3 m square in the centre of each plot.

At the beginning of each trial, black plastic flats of 50 6- to 15-d-old radish, *Raphanus sativus* (L.) 'Cavalrondo,' seedlings were evenly spaced throughout a 3.5 x 3.5 m square in the centre of each plot. Radishes were watered daily for the duration of each trial.

Winged aphid catches on sticky traps placed 1.5 m north-east and south-west of the center of each plot were recorded every 2-6 d throughout each trial, following trap replacement. Data were transformed (square root ($x + 0.5$)) to correct for heterogeneity of variance. For each trial, mean aphids per trap were calculated for each 2-6 d trapping session for each treatment, and the effect of treatment and block on mean aphids per trap for each 2-6 d trapping session was tested by ANOVA and means separated using Tukey's test (Zar 1984). Data from all 2-6 d trapping sessions in each trial were then pooled, the effect of treatment and block on mean aphids per trap tested by ANOVA, and means separated using Tukey's test.

Concentric enclosure study. A 41 x 41 m square in a regularly mowed field of mixed grass near Abbotsford, BC was covered with black landscape fabric to prevent weed invasion, and to provide a uniform environment throughout the experimental area. Four concentric enclosures were constructed in the centre of the experimental area using standard exclusion fences. The innermost enclosure was a 4.5 x 4.5 m square; the next a 13.5 x 13.5 m square; the next a 22.5 x 22.5 m square; and the outermost a 31.5 x 31.5 m square.

On 23 June 1994, 324 flats of 50 7-d-old radish seedlings were arranged in a 1 m grid (18 rows and columns) throughout the experimental area. Eighty-one sticky traps were arranged throughout the experimental area in a 9 row and 9 column grid, with 4.5 m between consecutive traps. All traps were replaced at 3-7 (mean 5) d intervals, until 17 August 1994 – a total of 10 trapping sessions. Winged aphid catches on each trap were recorded for each trapping session.

Traps were grouped into one of five levels, according to their location (Table 1). Mean aphid catches for each level were calculated and ranked for each trapping session. Trapping sessions were treated as replicates in time. Friedman's test (Zar 1984) was used to test the null hypothesis that mean aphid catches were equivalent for each level; rankings were separated using a variation of Tukey's test for multiple comparisons of nonparametric data (Zar 1984). Cumulative aphid distribution throughout the experimental area was mapped using 3-dimensional graphing software (MSGraph 8.0, Microsoft 1997).

Table 1

Trap locations by level in concentric enclosure study.

Level	Distance from outer fence (m)	Traps	Trap location in relation to fenced enclosure(s)
1	+2.50	32	Outside 31.5 m enclosure
2	-2.50	24	Between 22.5 and 31.5 m enclosures
3	-6.75	16	Between 13.5 and 22.5 m enclosures
4	-11.25	8	Between 4.5 and 13.5 m enclosures
5	-15.75	1	Inside 4.5 m enclosure

Large enclosure studies. Three 38 x 38 m squares in a regularly mowed field of mixed grass near Abbotsford, BC were covered with black landscape fabric. Treatment areas were arranged in a line oriented roughly perpendicular to the main southwest wind direction, with adjacent plots ~20 m apart. Sticky traps and flats of 10-d-old radishes were evenly spaced throughout each experimental area, according to the design of the previous experiment.

Experimental areas were randomly assigned to one of three treatments: (1) no fence (Control); (2) a 38 by 38 m square standard fence, enclosing all of the radish plants (Fence); and (3) a 30 by 30 m square standard fence, with radish plants also encircling the fence to act as a trap crop (Fence + Trap crop). Due to the large size of the treatment plots, replication was conducted over time in 1995. The treatments were initially established on 29 May 1995, and were subsequently re-randomized on three additional occasions (11 July, 15 August, 12 September) to allow four replicated blocks. Traps were changed every 3-7 d (mean, 4 d) for a period of 21-28 d (mean, 24 d). Cumulative aphid distributions for each treatment were mapped using 3-dimensional graphing software (MSGraph 8.0, Microsoft 1997). ANOVA was used to test for effects of treatment and block (time) on overall aphid catches. The average aphid catch for each enclosure treatment and block (time) on sticky traps immediately inside the enclosure was compared to that on the remaining traps using the Wilkoxon paired-sample test (Zar 1984).

RESULTS

All studies. Aphids caught in all studies were predominantly *Myzus persicae* (Sulzer), but the proportion was not quantified. Total aphid catches varied considerably from one trapping session to another, following no apparent trends. Differences between treatments tended to be most pronounced for trapping sessions with relatively high aphid catches.

Fence height study. A total of 3,637 aphids were found on the 1,244 leaves sampled. More aphids were found in plots enclosed by 90-cm-high fences than in plots without fences or plots with 30-cm-high fences (P=0.008) (Fig. 1A). Aphid accumulations increased with increasing fence height over the range of fence heights tested, but were not significantly higher inside plots surrounded by 30- and 60-cm-high fences than in unfenced control plots (Fig. 1A). No block effect was detected.

A total of 127 aphids were parasitized by aphidiid wasps and 35 syrphid fly larvae were found on the leaves sampled. Both of these aphid biocontrols were more numerous inside plots enclosed by 90-cm-high fences than in other experimental plots (P=0.007, aphidius; P=0.002, syrphid) (Fig. 1A,B). No block effect was detected.

Overhang length studies. A total of 18,526 winged aphids were caught on sticky traps over the course of the three overhang length trials. Significant (P<0.05) treatment, block, and trapping date effects were detected in all trials. A significant interaction between treatment and trapping date was attributed to a positive correlation between total aphid catch and strength of the treatment effect. More winged aphids were caught on sticky traps inside the fenced enclosures than in unfenced check plots in each of the trials (Table 2). The presence of overhangs, and overhang length had no effect on aphid catches (Table 2).

Concentric enclosure study. A total of 37,894 winged aphids were caught on sticky traps over the course of this study, averaging 468 aphids per trap and 46.8 aphids per trap for each trapping session. Aphid catches varied tremendously between trapping sessions, ranging from 0.6 aphids per trap on 5 July, to 237.0 aphids per trap on 11 August.

Trap location had a significant (P<0.001) effect on aphid catches, with traps within the outer two enclosures (levels 2 and 3) catching the most aphids (Table 3; Fig. 2). Traps in level 2 caught more aphids than those in levels 1, 4, or 5; traps in level 3 caught more than those in level 4 (Table 3). Aphid catches peaked near the inner corners of the largest enclosure (Fig. 2). Catches were below average around the outer perimeters and towards the center of the study area (Fig. 2).

Large enclosure study. A total of 25,419 aphids were caught throughout this study, averaging 26 aphids per trap for each block (time). The mean aphid catches (± SE), were 2006 ± 1098, 2085 ± 802, and 2264 ± 1148 in the Check, Fence, and Fence + Trap Crop treatments, respectively. No significant difference in mean aphid catches were detected between treatments. The block effect was highly significant ($P<0.0001$), indicating variation in aphid catches over time.

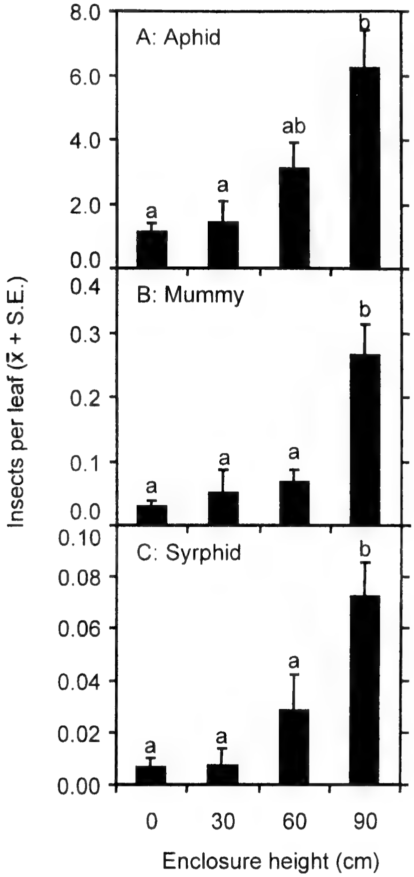

Figure 1. Counts of living aphids (A), aphids parasitized by aphidiid wasps (B), and syrphid larvae (C) on leaves of rutabagas growing inside exclusion fences ranging from 0-90 cm in height (n=4). Bars with the same letter are not significantly different, Tukey's test, $P<0.05$.

Table 2

Average aphid catch on sticky traps in unfenced plots of radish and plots of radish enclosed by 120-cm-high exclusion fences with varying overhang lengths.

Treatment	Mean aphid catch by trial, n=4[a]		
	Trial 1 (13/7/94 -10/8/94)	Trial 2 (12/8/94 -30/8/94)	Trial 3 (23/8/95 -14/9/95)
No fence	97.9 *a*	292.7 *a*	154.0 *a*
Fence without overhang	364.7 *b*	-	-
Fence with 12.5 cm overhang	-	930.2 *b*	-
Fence with 25 cm overhang	494.2 *b*	923.9 *b*	715.9 *b*
Fence with 50 cm overhang	-	-	658.1 *b*

[a]Means within a column followed by the same letter are not significantly different, Tukey's test, $P<0.05$.

Aphid catches were above average near the outer edges of fenced enclosures particularly near the enclosure corners (Fig. 3B,C). This pattern was not observed in the unfenced control plots (Fig. 3A). Aphid catches on traps immediately inside the enclosure fences were higher (P<0.001) than for the remaining traps inside both the Fence and Fence + Trap Crop treatments. This concentric distribution was not observed in the control plots.

Table 3

Winged aphid catches, by level, in five levels of a concentric enclosure study. Rank sum is the sum of aphid catch ranking for each of 10 trapping sessions, according to Friedman's analysis of variance by ranks.

Level	Total traps	Aphids per trap per session, n=10 ($\bar{x}$ ± S.E.)	Rank sum, n=10[a]
1 (outer traps)	32	36.8 ± 18.2	21.5 *ab*
2	24	60.5 ± 30.5	45.0 *c*
3	16	50.0 ± 24.7	40.0 *bc*
4	8	40.3 ± 21.4	20.5 *a*
5 (center trap)	1	43.3 ± 25.3	23.0 *ab*

[a]Rank sums followed by the same letter are not significantly different, Tukey's test, P<0.05.

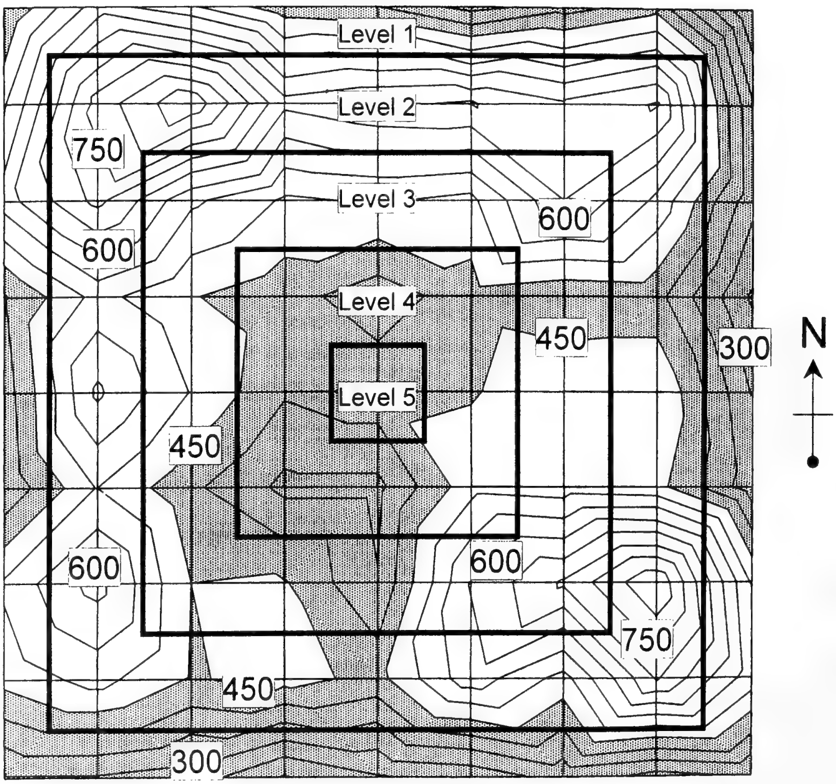

Figure 2. Contour map showing aphid distribution in an experimental area with concentric exclusion fences (heavy lines). Sticky traps were placed at grid nodes. Contour lines show total aphid catch per trap after 10 trapping sessions ($\bar{x}$ = 468), at intervals of 50, and are labeled at intervals of 150. Areas with total catches below 450 aphids per trap (approximate average) are shaded gray. One square = 4.5 by 4.5 m.

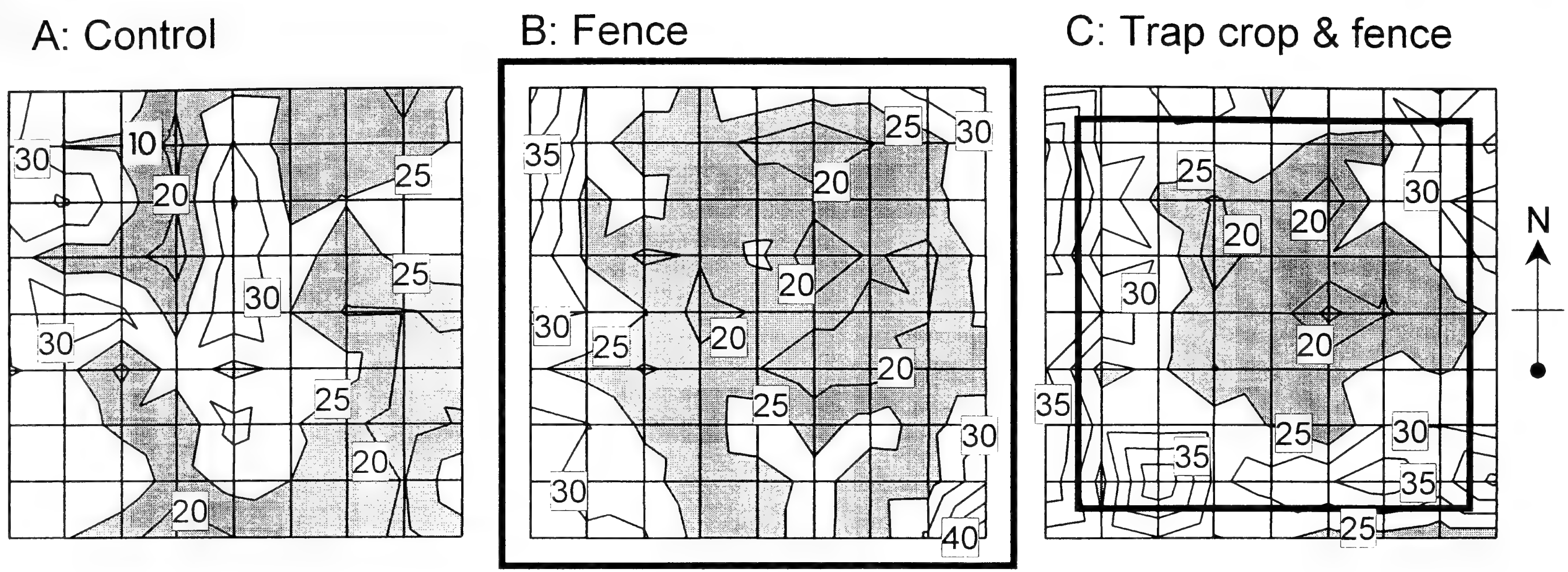

Figure 3. Contour map showing aphid distribution in unfenced control plots (A), plots entirely surrounded by exclusion fences (B), and plots surrounded by a trap crop and exclusion fence (C). Heavy lines denote exclusion fences. Sticky traps were placed at grid nodes. Contour lines show average aphid catch per trap (n = 4; $\overline{x}_A = 25$, $\overline{x}_B = 26$, $\overline{x}_C = 28$), at intervals of 5. Areas with average catches below 25 aphids per trap (approximate average) are shaded gray. One square = 4.5 by 4.5 m.

DISCUSSION

We conclude that exclusion fences trigger aphid accumulations near enclosure perimeters. Inside small enclosures, where all enclosed areas are relatively near the enclosure perimeter, exclusion fences increase aphid numbers overall. In large enclosures higher aphid catches near enclosure edges are counterbalanced by comparatively low aphid catches far from enclosure edges, resulting in an altered aphid distribution within enclosures, but no overall change in aphid catches.

Aphid accumulations inside exclusion fences are affected by fence height, but not overhang length. In small enclosures 30 - 90-cm-high, aphid accumulations increase with fence height. Lewis and Dibley (1970) hypothesized that small insects, such as aphids, are passively carried by wind currents, and deposited in the lee of windbreaks by swirling eddies, which are larger for taller windbreaks, assuming constant windbreak permeability. Kennedy and Thomas (1973) agreed that aphids accumulate in areas where windspeeds are low, but argued that this was an effect of aphid behaviour rather than passive deposition. Whether due to active behaviour or passive deposition, both authors agree that aphid accumulations will be highest where windspeed is reduced, as we observed near exclusion fences.

At our study locations the prevailing daytime wind blew from the southwest. Prevailing night winds blew from the northeast. The regular reversals in the local prevailing wind direction made it difficult to establish any relationships between the location of aphid accumulations within enclosures and wind direction, particularly since we made no observations of the time of day when winged aphids were caught.

Our observation that overhang length has no effect on aphid accumulations conflicts with the finding that overhangs reduce cabbage fly movement into fenced enclosures (Bomford *et al.* 2000). This may be because exclusion fences intercept the low-flying cabbage flies, but not aphids, which maintain a higher altitude before alighting. Overhangs will only reduce insect movement into enclosures if insects fly into the exclusion fence, then encounter the overhang as they attempt to move up and over the fence.

More syrphid fly larvae, which feed on aphids, and aphids parasitized by aphidiid wasps were found inside 60-cm-high fences than in control plots. These insects may have been attracted to the higher concentrations of their aphid hosts within the small enclosures, or they may accumulate in the same low windspeed areas where aphids tend to alight. The fact that the exclusion fences did not reduce immigration of these predators and parasites suggests that this physical control tactic could compliment efforts to use these beneficial insects for the biological control of aphids.

The highest aphid accumulations in large enclosures occurred near enclosure corners. Corner traps likely catch aphids moving from two directions, whereas traps near the middle of an edge likely catch only aphids coming from one direction. Traps placed inside small enclosures catch aphids coming from all directions, resulting in the marked increase in aphid catches observed in small enclosures relative to control plots.

Positioning an exclusion fence between a perimeter trap crop and the main crop had no effect on overall aphid accumulations, as compared to control plots without a fence, or plots entirely enclosed by a fence. Plot size was held constant in these experiments, such that allowing room for a trap crop required a reduced enclosure size. The area of reduced aphid accumulations in the interior of the Fence + Trap Crop plots was correspondingly smaller than the area of reduced aphid accumulations in the fully enclosed plots.

In our concentric enclosure study all traps were the same distance from a mesh fence, yet traps towards the outer edge of the study areas caught more aphids than traps towards the center of the study area. This was the same distribution pattern observed in our large enclosure study, suggesting that local aphid distributions are better predicted by the distance from the outer edge of an enclosed area than distance from a fence.

Extrapolating from our observations in experimental plots, we would expect aphids to accumulate near the outer edges of fields enclosed by exclusion fences. By comparison, fields without exclusion fences should have similar overall aphid levels, but aphids will be more randomly distributed throughout the field area. The more predictable aphid distribution within fields surrounded by exclusion fences could allow producers to target field edges for insecticide applications intended for aphid control, reducing control costs, insecticide use, and soil compaction, while preserving an area of refuge for biological control organisms in field interiors.

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Parasitism of the eggs of *Lygus shulli* and *Lygus elisus* (Heteroptera: Miridae) by *Anaphes iole* (Hymenoptera: Mymaridae)

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ABSTRACT

Females of the egg parasitoid *Anaphes iole* Girault (Hymenoptera: Myrmaridae) accepted and oviposited in eggs of both *Lygus shulli* Knight and *L. elisus* Van Duzee (Heteroptera: Miridae) when presented on sections of green bean pod in the laboratory. Resulting *A. iole* larvae developed normally on eggs of both host species and emerged as adults. The wings of *A. iole* emerging from *L. shulli* eggs were significantly larger than those from *L. elisus* probably because the eggs of *L. shulli* were larger. *Anaphes iole* females parasitized only approximately 50% of the eggs available of either host species. This may indicate that 50% of the hosts were suitable and rejected, that 50% were unsuitable for oviposition, or that the structure of bean pods prevents females from finding or ovipositing in 50% of hosts. *Anaphes iole* has potential for biological control of *Lygus* spp. on greenhouse vegetables in southwestern British Columbia.

Key words: *Anaphes iole*, Mymaridae, *Lygus shulli*, *Lygus elisus*, *Lygus hesperus*, Miridae, egg parasitoids, biological control, greenhouse vegetables

INTRODUCTION

Plant bugs in the genus *Lygus* (Heteroptera: Miridae) feed on a wide variety of native plant species and agricultural crops throughout North America (Schwartz and Footit 1992; Schwartz and Footit 1998). Sequential migration among different seasonally-occurring host-plant species is typical of the biology of *Lygus* (Schwartz and Footit 1992). As a consequence, *Lygus* species migrate into, and feed upon, acceptable agricultural crops. Economic damage occurs when *Lygus* nymphs or adults feed on reproductive tissues or apical meristems (Schwartz and Footit 1992). Damage has been reported on cotton (Leigh *et al.* 1988), alfalfa (Sorenson 1936), canola (Butts and Lamb 1991; Wise and Lamb 1998), strawberries (Norton and Welter 1996) and conifer seedlings (Schowalter 1987). In southwestern British Columbia (BC), *Lygus* bugs are sporadically-occurring pests of greenhouse vegetable crops like cucumber and sweet pepper (Gillespie *et al.* 1999). Here, we report on parasitism of the eggs of *L. shulli* Knight and *L. elisus* Van Duzee by the egg parasitoid *Anaphes iole* Girault (Hymenoptera: Mymaridae), and discuss the potential of *A. iole* for biological control of *Lygus* species in BC vegetable greenhouses.

Lygus hesperus Knight, *L. shulli* and *L. elisus* are the three most common species of *Lygus* in the Fraser Valley of southwestern BC (Gillespie *et al.* 1999). *Lygus shulli* and *L. elisus* are sporadically found in vegetable greenhouses throughout the growing season, and their feeding damages both cucumbers and peppers (Gillespie *et al.* 1999). *Lygus hesperus* occurs only on late-season pepper crops, and there is no definitive evidence, at present, that

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this species causes economic damage (Gillespie *et al.* 1999). Invasion of greenhouses probably occurs when *Lygus* bugs disperse from surrounding weedy habitat (Gillespie *et al.* 1999).

Augmentative releases of the egg parasitoid *Anaphes iole* have been used to manage populations of *L. hesperus* in field plantings of strawberries in California (Norton *et al.* 1992; Norton and Welter 1996; Udayagiri and Welter 2000). Although *A. iole* is available commercially (Biotactics Inc., Riverside, California) and could potentially be used for biological control of *Lygus* spp. in BC, no information is currently available regarding parasitism of *L. shulli* and *L. elisus* by this parasitoid. In this paper, we report on the acceptance and suitability of *L. shulli* and *L. elisus* eggs as hosts for *A. iole*.

MATERIALS AND METHODS

Host eggs for parasitism bioassays. Adults of *L. shulli* and *L. elisus* were collected at field sites near the Pacific Agri-Food Research Centre in Agassiz, BC in July 1999. *Lygus* adults were identified to species using Henry and Froeschner (1988). Adults of each species were held at ambient conditions in the laboratory in groups of 5-10 in cylindrical 500-ml plastic containers with screened lids. *Lygus* adults were provided with 5-10 sections of green bean (3 to 5 cm in length) for feeding and oviposition. Bean sections were inspected daily for *Lygus* eggs and those with two or more eggs present were removed from the containers and stored in a refrigerator at 10°C until used in parasitism bioassays. Bean sections were replaced in oviposition containers when removed (as above) or when their condition deteriorated (*e.g.* showing signs of fungal growth).

Parasitism bioassays. Adult Anaphes iole of unknown age were obtained directly from a commercial supplier (Biotactics Inc., Riverside, California). Female *A. iole* were selected for use in oviposition bioassays by examining abdominal morphology under a dissecting microscope to determine sex. Individual female *A. iole* were introduced using a moistened fine paintbrush into 62-ml plastic cups (Solo Cup No. P200, Solo Cup Company, Urbana, Illinois) each containing a single section of green bean with eggs of either *L. shulli* (91 cups) or *L. elisus* (82 cups). The number of eggs available for parasitism on each bean section ranged from 2 to 36 for *L. elisus* and from 2 to 68 for *L. shulli*. The cups were held in a growth chamber for 24 h to allow *A. iole* to oviposit (L:D 16:8 h photoperiod and temperatures of 23.0 ± 0.2°C (±SD) during photophase and 18.0 ± 0.2°C (±SD) during scotophase; relative humidity was not controlled). After 24 h, the female *A. iole* were removed with a moistened paintbrush and the cups were returned to the growth chamber and checked every second day for emergence of *Lygus* nymphs or *A. iole* adults until no further emergence occurred. Emerging *Lygus* nymphs were removed, counted and discarded. Emerging *A. iole* adults in each cup were removed and stored separately, as families, in 70% (w/v) ethanol. The total numbers of *Lygus* nymphs and *A. iole* males and females that emerged from each bean section were recorded.

Wing size of *A. iole* adults. The right wing of *A. iole* adults that emerged from bean sections was measured as an index of body size. From the offspring stored in ethanol, we selected at random, one male and one female adult from each of 32 randomly-selected families reared on *L. shulli* and 31-32 families reared on *L. elisus*. The length (from the point of attachment to the tip of the wing) and width (at the widest point) of each right forewing were measured and recorded.

Size of *Lygus* eggs. Adults of *L. shulli* and *L. elisus* were collected at field sites near the Pacific Agri-Food Research Centre at Agassiz, BC in July of 2000. The ovaries of 10 adult females of each species were dissected. The length (from tip to tip) and width (at the widest point) of all mature, fully chorionated eggs for each female were measured and recorded.

Data analysis. Total number of viable host eggs in parasitism bioassays was calculated as the totals of *Lygus* and *A. iole* emerging from each bean section. This calculation gives a conservative estimate of the original number of *Lygus* eggs per bean section as it assumes that no *Lygus* or *Anaphes* eggs died during the test. The proportion of eggs parasitized per female was calculated as the number of *A. iole* emerging divided by the total number of host eggs. The proportion of female *A. iole* emerging from each bean section (sex ratio) was calculated as the number of females emerging divided by the total of both sexes (F/(F+M)). Proportion of *Lygus* eggs parasitized, number of *A. iole* emergents, number of *Lygus* emergents, total number of host eggs and sex ratio of *A. iole* emergents (all per bean section) were compared between *L. shulli* and *L. elisus* using Mann-Whitney tests. Proportional data were arcsin-square root transformed before analysis. The length and width of the wings of male and female wasps emerging from *L. shulli* and *L. elisus* were compared using Mann-Whitney tests. The length and width of the eggs of *L. shulli* and *L. elisus* were compared using Mann-Whitney tests. All statistical analyses were conducted using Systat (Wilkinson *et al.* 1997) and Sigmastat (Fox *et al.* 1995).

RESULTS

Parasitism bioassays. Female *A. iole* oviposited in eggs of both *Lygus* species, and both species were suitable for the development of *A. iole* from larva to adult. There was no significant difference in the proportion of eggs parasitized per *A. iole* female for either *L. elisus* or *L. shulli* (Table 1). The number of *A. iole* and *Lygus* emerging and the total number of host eggs per bean section were significantly higher for *L. shulli* than for *L. elisus* (Table 1). Previous observations indicate that *L. shulli* is more likely to oviposit on green beans than *L. elisus* (D.M.J. Quiring, personal observation). There was no significant difference in the sex ratio of *A. iole* emerging from *L. shulli* compared to *L. elisus* eggs (Table 1).

Table 1

Proportion of *Lygus* eggs parasitized, number of *Anaphes* and *Lygus* emerging, number of *Lygus* host eggs, and sex ratio (Means ± SE) of *A. iole* emerging per bean section containing host eggs of *L. shulli* and *L. elisus*.

Variable	*L. shulli*	*L. elisus*	Mann-Whitney test U	*P*
Proportion of eggs parasitized	0.46 ± 0.04 (n=91)	0.49 ± 0.04 (n=82)	3952	0.50
Number of *Anaphes* emerging	10.4 ± 1.1 (n=91)	5.1 ± 0.5 (n=82)	2986	0.01
Number of *Lygus* emerging	10.9 ± 1.0 (n=91)	6.0 ± 0.6 (n=82)	2549	< 0.001
Total number of host eggs	21.2 ± 1.3 (n=91)	11.1 ± 0.8 (n=82)	1791	< 0.001
Sex ratio (F/(F+M))	0.55 ± 0.03 (n=64)	0.52 ± 0.04 (n=67)	1991	0.48

Wing size of *A. iole* adults. The mean length and width of the right forewings of both male and female *A. iole* emerging from the eggs of *L. shulli* were significantly greater than those emerging from the eggs of *L. elisus* (Table 2).

Table 2

Length and width (Mean ± SE) of right forewings of *Anaphes iole* males and females reared on the eggs of *Lygus shulli* and *Lygus elisus*.

Variable	*L. shulli*	*L. elisus*	Mann-Whitney test U	*P*
Female wing length (mm)	0.75 ± 0.01 (n=32)	0.71 ± 0.01 (n=32)	204	< 0.001
Female wing width (mm)	0.17 ± < 0.005 (n=32)	0.15 ± < 0.005 (n=32)	202	< 0.001
Male wing length (mm)	0.79 ± < 0.005 (n=32)	0.75 ± 0.01 (n=31)	133	< 0.001
Male wing width (mm)	0.18 ± < 0.005 (n=32)	0.17 ± < 0.005 (n=31)	343	0.033

Size of *Lygus* eggs. The mean length of *L. shulli* eggs (0.99 ± 0.01 mm) was significantly greater than that of *L. elisus* eggs (0.91 ± 0.01 mm; Mann Whitney test: U = 132, *P*<0.001), as was the mean width of *L. shulli* eggs (0.26 ± 0.00 mm) compared to *L. elisus* eggs (0.23 ± 0.00 mm; Mann Whitney test: U = 224, *P*<0.001).

DISCUSSSION

Anaphes iole females readily accepted, and oviposited in, eggs of both *L. shulli* and *L. elisus*. Their offspring developed successfully in both species of host eggs and emerged as adults. *Anaphes iole* are available commercially and readily parasitize all three *Lygus* spp. (*L. shulli*, *L. elisus*, and *L. hesperus*) found in greenhouses in the Fraser Valley of southwestern BC. *Anaphes iole* thus has a strong potential for biological control of *Lygus* spp. in BC vegetable greenhouses.

No significant differences were found between the two host species in the proportion of available eggs parasitized by *A. iole* females. The proportion of eggs parasitized was approximately 50% for both species despite the fact that, on average, nearly twice the number of host eggs were oviposited on bean sections by *L. shulli* compared with *L. elisus*. *Anaphes iole* females typically carry between 30 and 40 mature eggs in their abdomens, and an individual female can parasitize approximately 30 *Lygus* eggs per day (S. Udayagiri, University of California, personal communication). Assuming that no *A. iole* eggs died after oviposition in our experiments, the *A. iole* females in this study oviposited substantially fewer eggs (on either host species) during 24 h than they had available (5 eggs on average on bean sections with *L. elisus* eggs and 10 eggs on average on those with *L. shulli* eggs). It is possible that 50% of the eggs of both species were either suitable hosts that were rejected by females, or unacceptable hosts for oviposition. Alternatively, 50% of *Lygus* eggs could have been inaccessible for oviposition, or impossible to locate, by *A. iole* on bean sections. Recently, it has been shown that plant structure can influence the oviposition success of *A. iole*. A lower proportion of *Lygus* eggs were parasitized by *A. iole* females on strawberry fruits than on petioles, leaflets or calyx tissue (Udayagiri and Welter 2000). Achenes (one-seeded fruitlets) on strawberry fruits apparently hinder access by *A. iole* females to *Lygus* eggs present on fruits (Udayagiri and Welter 2000). If *A. iole* is to be used for biological control of *Lygus* spp. in BC greenhouses, it will be critical to determine whether plant structure affects the ability of *A. iole* females to locate and parasitize eggs on cucumbers and peppers.

Anaphes iole adults that emerged from *L. shulli* eggs had larger wings than adults from *L. elisus* eggs. Assuming that wing size correlates with body size, *L. shulli* eggs may be of higher quality for development of *A. iole* than *L. elisus* eggs. This is likely a consequence of the larger size of *L. shulli* eggs compared to *L. elisus* eggs. Alternatively, the difference in wing size we observed may be caused by some influence of the host not related to egg size. Host-induced variation in antennal morphology unrelated to host size was found in *A. iole* by Huber and Rajakulendran (1988). Determining whether wing-size variation between hosts reflects differences in host-egg size or other effects will require further research.

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Early records of alien species of Heteroptera (Hemiptera: Prosorrhyncha) in Canada

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ABSTRACT

Early records for 45 alien species of Heteroptera in the provinces across Canada are reported. Nine of the records constitute new provincial records, with 69 others documenting published records of occurrence in detail for the first time. There are also 51 reported occurrences in provinces prior to published literature records.

INTRODUCTION

Many alien Heteroptera have become important agricultural crop pests in Canada (Beirne 1972), and more can be expected. The potential invasion appears greatest for those bug species that either overwinter as adults, or oviposit in plant tissue (Lattin and Oman 1983).

Research has thus been initiated on the origins, distribution patterns, pathways of spread, and ecological impact of alien Heteroptera in Canada (Scudder and Foottit 2000). It is important to understand not only the history of alien species occurrence and impact in the past, but also to undertake future pest risk assessment and the potential effects of impending climate change. New evidence suggests that invasive species share traits that will allow them to capitalize on the various elements of the forthcoming global change (Dukes and Mooney 1999)

Hence, over the past few years, most of the major collections of insects across Canada have been visited, specimens of alien species of Heteroptera examined and named, the capture information databased and the locality data georeferenced. These data have been combined with published records to document the distribution of species in Canada, their probable place of introduction, and their subsequent dispersal.

In the process, many new provincial records were discovered. Most of these have been tabulated by Maw *et al.* (2000), but the voucher data for these records have not been published. For 45 of the total 79 alien Heteroptera in Canada, we thus document 9 new provincial records (indicated by an asterisk) that are not included in Maw *et al.* (2000), plus 69 others that document published records of occurrence in detail for the first time. We cite only the earliest records for the provinces.

Our research on collections also shows that some of the alien species have been collected in provinces earlier than published records currently indicate. Since early records are important for tracing the spread of these species, we document also 51 reported occurrences prior to the literature records.

The order of species in the text follows Maw *et al.* (2000). Provinces (by acronym) are arranged in alphabetical order.

Collection abbreviations are as follows:

CNC: Canadian National Collection, Agriculture and Agri-Food, Ottawa, ON.
FRNF: Department of Forest Resources and Lands, Corner Brook, NF.
LEMQ: Lyman Entomological Museum, Macdonald College, McGill University, Ste-Anne-de Bellevue, QC.
MU: Department of Biology, Memorial University, St. John's, NF.
NSM: Nova Scotia Museum, Halifax, NS.
ROM: Royal Ontario Museum, Toronto, ON.
UBC: Spencer Entomological Museum, University of British Columbia, Vancouver, BC.
UG: Department of Environmental Biology, University of Guelph, Guelph, ON.
USNM: National Museum of Natural History, Smithsonian Institution, Washington, DC.

Infraorder CIMICOMORPHA

Family ANTHOCORIDAE

Anthocoris confusus Reuter

NS: Kentville, 15-17.vii.1966 (L.A. Kelton) [CNC]. Reported from Nova Scotia without date by Kelton (1978).

Orius minutus (Linnaeus)

BC: Abbotsford, 7.ix.1950 [CNC]. Previously reported from British Columbia in 1951 by Tonks (1953) and Downes (1957).

Family MIRIDAE

Tribe MIRINI

Adelphocoris lineolatus (Goeze)

AB: Elkwater Park, 28.vii.1952 (L.A. Konotopetz) [CNC]. *BC*: no data, 1964 (J.R. Hill) [LEMQ]. *ON*: Vineland Station, 1.ix.1942 (W.L.Putman) [CNC]. *PE*: Wood Island, 9.viii.1929 (R.P. Gorham) [CNC]. *QC*: Mont Royal, 26.viii.1944 [LEMQ]. Recorded from Alberta in 1968 (Craig 1971), Ontario in 1949 (Phillips 1951) and Quebec (Moore 1950; Larochelle 1984) without dates.

Camptozygum aequale (Villers)

QC: Saint-Antoine-Abbé, 3.vi.1983 (Larochelle & Larivière) [LEMQ].

Capsus ater (Linnaeus)

NB: Nashwaak Bridge, 22.vi.1934 (C.E. Atwood) [ROM]. *PE*: Woods Island, 11.vii.1966 (L.A. Kelton) [CNC]. Kelton collected this species at 9 localities throughout New Brunswick in late June to early July of 1966.

Closterotomus norwegicus (Gmelin)

BC: Royal Oak, 24.vii.1917 (W. Downes) [CNC]. *NB*: Fredericton, 22.viii.1940 (R.P. Gorham) [CNC]. *PE*: Brackley Beach, 24.vii.1940 (J. McDunnough) [CNC]. Recorded from British Columbia (Kelton 1959) and Prince Edward Island (Kelton 1982a) without dates.

Phytocoris populi (Linnaeus)

**MB*: Bald Head Hills (20.9 km (13 mi) n of Glenboro), 8.viii.1958 (J.G. Chillcott) [CNC]. *NS*: Halifax, 7-8.viii.1966 (L.A. Kelton) [CNC]. **ON*: Gull L., 6.viii.1918 (H.S. Parish) [CNC].

Phytocoris tiliae (Fabricius)
NS: Halifax, 7-8.viii.1966 (L.A. Kelton) [CNC].

Stenotus binotatus (Fabricius)
MB: Falcon Lake, 25.vi.1972 (L.A. Kelton) [CNC]. *NS*: Kings Co., 15.vii.1948 (Ralph J. Day) [NSM]. *ON*: Trenton, 26.vi.1911 (Evans) [CNC]. *PE*: Cavendish National Park, 9.vii.1966 (L.A. Kelton) [CNC]. *QC*: Aylmer, 27.vi.1924 (C.H. Curran) [CNC]. Recorded from Ontario by Gibson (1912) without year, and Manitoba (Kelton 1980), Ontario and Quebec (Carvalho 1959) without dates.

Tribe STENODEMINI

Leptopterna dolabrata (Linnaeus)
**AB*: Highwood River Picnic Area, Hwy. 541, 24.vii.1994 (M.D. Schwartz) [CNC]. *MB*: Moose Lake, 25.vi.1972 (L.A. Kelton) [CNC]. *NS*: Halifax, 1899 [CNC]. Osborn (1918) and Parshley (1923) recorded specimens from Nova Scotia collected in 1915; recorded from Manitoba (Kelton 1980) without dates.

Megaloceroea recticornis (Geoffroy)
**AB*: Waterton Park, 3.viii.1994 (M.D. Schwartz) [CNC]. *NB*: Fredericton, 23.vi.1966 (L.A. Kelton) [CNC]. *NS*: Bible Hill, 12.vii.1966 (L.A. Kelton) [CNC]. *PE*: Cavendish National Park, 9.vii.1966 (L.A. Kelton) [CNC]. *QC*: North Hatley, 25.vii.1929 (G.S. Walley) [CNC]. Recorded from Quebec by Larochelle (1984) without date, and Wheeler and Henry (1992) recorded collections from Nova Scotia in 1971.

Pithanus maerkeli ((Herrich-Schaeffer)
AB: Elkwater, 16.vii.1952 (A.R. Brooks) [CNC]. *NB*: Fundy National Park, 6.vii.1966 (L.A. Kelton) [CNC]. *ON*: Rondeau Park, 13.vi.1929 (G.S. Walley) [CNC]. *PE*: Cavendish National Park, 9.vii.1966 (L.A. Kelton) [CNC]. *QC*: Laniel, 10-11.vii.1963 (L.A. Kelton) [CNC]. Previously recorded from Alberta, New Brunswick, Ontario, Prince Edward Island and Quebec, but without dates (Kelton 1966).

Subfamily ORTHOTYLINAE

Tribe HALTICINI

Halticus apterus (Linnaeus)
NB: Fredericton, 192[9?] [CNC]. *NF*: Pasadena, 24.viii-3.ix.1985 (B. 4820) [CNC; FRNF]. *PE*: Rustico, 4.viii.1966 (L.A. Kelton) [CNC].

Orthocephalus coriaceus (Fabricius)
BC: Galiano Island (north end), 1.vii.1976 (G.G.E. Scudder) [UBC]. *NB*: Woodstock, 22.vi.1966 (L.A. Kelton) [CNC]. *NF*: Baie D'Espoir, low vegetation in field, 11.vii.1985 (L.H. Hollett) [FRNF]. *NS*: Lockeport, 2.viii.1958 (J.R. Vockeroth) [CNC]. *ON*: Niagara Falls, 7.vii.1955 (L.A. Kelton) [CNC]. *PE*: Cavendish National Park, 9.vii.1966 (L.A. Kelton) [CNC]. *QC*: Georgeville, 27.vi.1936 (G.S. Walley) [CNC]. Reported in 1973 from Ontario (Reid *et al.* 1976). Kelton collected this species from 9 localities throughout New Brunswick in late June 1966.

Orthocephalus saltator (Hahn)
NF: Carbonear, 2.viii.1925 (J.M. Swaine) [CNC]. *QC*: L'Anse-Pleureuse, 29.vii.1984 (Larochelle & Larivière) [LEMQ].

Tribe ORTHOTYLINI

Blepharidopterus angulatus (Fallén)
NB: Saint John (Rockwood Park), 4.viii.1954 (J.F. Brimley) [CNC]. *NF*: Pasadena, 18.viii.1984 (D. Langor) [FRNF]. *PE*: Cavendish National Park, 3-5.vii.1966 (L.A. Kelton) [CNC]. Reported from Prince Edward Island without date (Kelton 1982a).

Heterotoma planicornis (Pallas)
BC: Victoria, 6.viii.1923 (W. Downes) [CNC]. *NS*: Halifax, 10.viii.1980 (L.A. Kelton) [CNC]. Recorded from British Columbia in 1933 (Downes 1957), and Nova Scotia without date (Kelton 1982a).

Melanotrichus concolor (Kirschbaum)
NS: Shelburne, 2.viii.1958 (J.R. Vockeroth) [CNC].

Melanotrichus flavosparsus (Sahlberg)
AB: Manyberries (Experimental Range), 4.viii.1951 (D.F. Hardwick) [CNC]. *BC*: Vernon, 22.ix.1923 (D.G. Gillespie) [CNC]. *MB*: Aweme, 19.vi.1930 (R.M. White) [CNC]. *NB*: Fredericton (Experimental Station), 18.vi.1925 [CNC]. *NT*: Fort Simpson, 19.vi.1950 (D.P. Whillans) [CNC]. *ON*: Trenton, 16.ix.1903 (Evans) [CNC]. *PE*: Cavendish National Park, 9.vii.1966 (L.A. Kelton) [CNC]. *SK*: Estevan, 27.viii.1929 (P.C. Brown) [CNC]. Previously reported from Ontario in 1914 (Gibson 1917), and Alberta, Manitoba and Saskatchewan (Kelton 1980) without dates.

Melanotrichus virescens (Douglas & Scott)
NS: Shelburne, 2.viii.1958 (J.R. Vockeroth) [CNC].

Orthotylus nassatus (Fabricius)
ON: Niagara, 25.vii.1963 (L.A. Kelton) [CNC].

Subfamily PHYLINAE

Tribe PHYLINI

Amblytylus nasutus (Kirshbaum)
BC: Saanich District, 6.vii.1950 (B.P. Beirne) [CNC]. *ON*: Marmora, 13.vi.1952 (J.C. Mitchell) [CNC].

Asciodema obsoletum (Fieber)
BC: Vancouver (UBC), 6.vii.1959 (G.G.E. Scudder) [UBC]. Recorded from British Columbia in 1963 (Waloff 1966).

Atractotomus magnicornis (Fallén)
NF: St. John's, 2.x.1980 (D. Northcott) [MU]. *NS*: Halifax, 22.vii.1976 (L.A. Kelton) [CNC]. *ON*: Aldershot, 6.vii.1955 (L.A. Kelton) [CNC].

Atractotomus mali (Meyer-Dür)
BC: Oliver, 19.vii.1970 (L.A. Kelton) [CNC]. *PE*: Charlottetown, 7-10.viii.1976 (L.A. Kelton) [CNC]. Reported from Prince Edward Island without date by Kelton (1982a).

Campylomma verbasci (Meyer-Dür)
NS: Kentville, 19.vii.1923 (R.P. Gorham) [CNC]. *ON*: Jordan, 27.viii.1915 (W.A. Ross) [UG]. *PE*: Dalvay House, 13.viii.1940 (G.S. Walley) [CNC]. Previously reported from Ontario in 1950 (Phillips 1951) and Nova Scotia in 1931 by Gilliatt (1935).

Compsidolon salicellum ((Herrich-Schaeffer)
ON: Presque Isle Provincial Park, 14.viii.1991 (M.D. Schwartz) [CNC]. *PE*: Burlington, 4.viii.1966 (L.A. Kelton) [CNC]. Previously recorded from Prince Edward Island in 1976 by Kelton (1982b).

Lepidargyrus ancorifer (Fieber)
BC: Langley, 17.vii.1959 (L.A. Kelton) [CNC]. *ON*: Rainy River District, 30.vi.1924 (J.F. Brimley) [CNC].

Lopus decolor (Fallén)
BC: Saltspring Island, 30.vii.1981 (G.G.E. Scudder) [UBC]. *NB*: Fredericton, 192[9?] [CNC]. *NF*: Pasadena, 3.vii.1984 (D. Langor) [FRNF]. *ON*: Norway Point (Lake of Bays), 15.vii.1922 (J. McDunnough) [CNC]. *PE*: Brackley Beach, 29.vii.1940 (G.S. Walley) [CNC]. Recorded from Ontario (Carvelho 1958) without date.

Megalocoleus molliculus (Fallén)
NB: Grey Mills [?=Grey Hills], 13.vii.1921 (R.P. G[orham]) [CNC]. *NF*: Silverdale, 31.vii.1980 (L.A. Kelton) [CNC]. *NS*: Parrsboro (Ottawa House), 9.viii.1943 (J. McDunnough) [CNC]. *ON*: Strathroy, 12.vii.1936 [CNC]. *PE*: Wood Island, ix.1929 [CNC]. *QC*: Forestville, 8.viii.1950 (R. de Ruette) [CNC]. Previously recorded from Ontario in 1972 by Reid *et al.* (1976), Nova Scotia in 1967 by Wheeler and Henry (1992) and Quebec (Larochelle 1984) without date.

Parapsallus vitellinus (Scholtz)
**NS*: Kentville, 3-6.vii.1976 (L.A. Kelton) [CNC]. *ON*: Saint Catharines, 22.vi.1961 (Kelton & Brumpton) [CNC]. Previously recorded from Ontario in 1978 (Henry and Wheeler 1979).

Plagiognathus arbustorum (Fabricius)
BC: Lulu Is., 23.viii.1954 (W. Downes) [UBC]. *NF*: St. John's, Pippy Park, 14.ix.1982 [FRNF]. Previously recorded from British Columbia in 1959 (Kelton 1982c) and 1963 (Waloff 1966).

Plagiognathus chrysanthemi (Wolff)
**AB*: Waterton Park, 3.viii.1994 (M.D. Schwartz) [CNC]. *BC*: Creston, 7.viii.1948 (D.B. Waddell) [CNC]. *NB*: Fredericton, 1.viii.1919 (R.P. Gorham) [CNC]. *NF*: Carbonear, 2.viii.1925 (J.M. Swaine) [CNC]. **SK*: Melville 5 km E, Rt. 16, 18.vii.1990 (M.D. Schwartz) [CNC]. Previously reported from British Columbia in 1951 (Tonks 1953), Newfoundland in 1949 (Lindberg 1958), and New Brunswick (Kelton 1982a) without date.

Sthenarus rotermundi (Scholtz)
**QC*: St-Jean-Baptiste[-de-]Rouville, 22.vi.1992 (J. F. Roch) [CNC].

Tribe PILOPHORINI

Pilophorus perplexus Douglas & Scott
BC: Victoria, 3.viii.1927 (W. Downes) [UBC]. *ON*: Guelph, 15.vii.1916 [CNC; UG]. *PE*: Cavendish, 13-19.viii.1976 (L.A. Kelton) [CNC]. Reported from Ontario by Knight (1941) and from Ontario and Prince Edward Island by Schuh and Schwartz (1988) without dates.

Family TINGIDAE

Dictyla echii (Schrank)
QC: Mont Royal, ex. *Echium vulgare* L., 14.vii.1997 (J.F.R.) [CNC; USNM].

Dictynota fuliginosa Costa
BC: Victoria, 29.vii.1957 (N.H. Anderson) [CNC]. Previously reported from British Columbia in 1959 (Scudder 1960).

Stephanitis rhododendri Horváth
NB: Saint John (Rockwood Park), 12.viii.1953 (J.F. Brimley) [CNC]. *NF*: Miguels Lake, 28.ix.1983 (L.H. Hollett) [CNC]. *ON*: Vineland Station, 16.vii.1963 (W.L. Putnam) [CNC]. *QC*: Mount Lyall, 12.viii.1933 (W.J. Brown) [CNC].

Family REDUVIIDAE

Empicoris pilosus (Fieber)
NS: Halifax, 22.vii.1976 (L.A. Kelton) [CNC]. *ON*: DeGrassi Point, 14.viii.1915 (E.M. Walker) [ROM]. *QC*: Brome, 9.vi.1948 (G.S. Walley) [CNC].

Empicoris vagabundus (Linnaeus)
NF: Crooked Lake, 19.viii.1984 (L.H. Hollett) [CNC]. *NS*: Halifax, 8.viii.1966 (L.A. Kelton) [CNC]. *ON*: Prince Edward County, 1.viii.1940 (J.F. Brimley) [CNC]. *PE*: Rustico, 4.viii.1966 (L.A. Kelton) [CNC]. *QC*: Québec, 24.viii.1959 (A.E. Strasby) [CNC].

Family BERYTIDAE

Berytinus minor ((Herrich-Schaeffer)
QC: Ste-Anne-de-Bellevue, 24.v.1947 (G.A. Moore) [LEMQ]. Previously reported in Quebec without date (Moore 1950).

Family RHYPAROCHROMIDAE

Megalonotus sabulicola (Thomson)
ON: Prince Edward County, 9.v.1965 (J.F. Brimley) [CNC].

Stygnocoris rusticus (Fallén)
AB: Millet, 11.viii.1993 (A.S. McClay) [CNC]. **NB*: Saint Andrews , 30.ix.1984 (G.G.E. Scudder) [CNC]. *NF*: St. John's, Long Pond, 12.viii.1977 (D. Larson) [CNC]. *QC*: Mont Royal, 27.viii.1907 [CNC]. Previously reported from Quebec in 1916 (Criddle 1922).

Stygnocoris sabulosus (Schilling)
AB: Brocket, 19 km N, 49°43'N 113°45'W, 1410 m, pan trap, 10-14.viii.1998 (K. White) [CNC]. *NB*: Fredericton, 30.viii.1949 (D.G. Cameron) [CNC]. *ON*: Guelph, 10.ix.1971 (C.D. Rollo) [UG]. *PE*: Charlottetown, 7-10.viii.1976 (L.A. Kelton) [CNC].

Family PENTATOMIDAE
Picromerus bidens (Linnaeus)
NB: Kouchibouguac National Park, 21.vii.1977 (S.J. Miller) [CNC]. *NS*: Amherst Shore, 11.viii.1980 (J. Gilhen) [NSM]. *ON*: York Co., Whitchurch, 8.viii.1974 (Antonucci) [ROM]. *PE*: Charlottetown, 7-10.viii.1976 (L.A. Kelton) [CNC]. Reported from New Brunswick, Nova Scotia, Ontario and Prince Edward Island (Larivière and Larochelle 1989) without dates, but recorded from Quebec in 1968 by Kelton (1972).

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The ambrosia beetle, *Gnathotrichus retusus* (Coleoptera: Scolytidae) breeding in red alder, *Alnus rubra* (Betulaceae)

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ABSTRACT

Brood adult ambrosia beetles recovered from well established galleries in a wind-thrown red alder, *Alnus rubra* Bongard, on Burnaby Mountain, Burnaby, British Columbia, were identified as *Gnathotrichus retusus* LeConte. The tree was attacked to a height of 25.8 m. Galleries penetrated up to 17.5 cm into the wood. The mean density of gallery entrance holes (± SE) was 120 ± 31.9 per m^2 of the bark surface. The mean production of brood in five completely dissected galleries was 13.2 ± 5.5. These results show conclusively that *G. retusus* in British Columbia can breed successfully in an angiosperm host.

Key Words: *Gnathotrichus retusus*, *Alnus rubra*, ambrosia beetle

INTRODUCTION

The ambrosia beetle, *Gnathotrichus retusus* LeConte, is widely distributed throughout western North America, from Alaska to Baja California (Bright 1976; Wood 1982). This monogamous, univoltine species commonly attacks dying, standing, or recently cut or fallen coniferous trees in the genera *Picea*, *Pinus*, *Pseudotsuga*, *Tsuga* and *Abies*, but is also recorded as attacking angiosperm trees, specifically alders, *Alnus* spp. and *Populus trichocarpa* Torrey (Nijholt 1981; Wood 1982). Wood (1982) synonymized *G. alni* Blackman (Blackman 1931) and *G. retusus*, because he failed to see distinguishing characteristics. The reproductive biology and the breeding success of *G. retusus* in angiosperm trees are not well documented, although Nijholt (1981) reported live striped ambrosia beetles, *Trypodenron lineatum* Olivier, and *G. retusus* and their progeny in red alder, *Alnus rubra* Bongard, that had been killed with 2,4-D. We describe and verify the successful attack and brood production by *Gnathotrichus retusus* in red alder.

OBSERVATIONS

Two large red alder trees of similar size were found fallen over a trail on the south slope of Burnaby Mountain Park in Burnaby, British Columbia, Canada, at the beginning of August 1998. The trees were partially rooted and were most likely wind-thrown in a severe storm in January of 1997, and attacked in the spring of 1998. No evidence of root rot or other disease was apparent, but reddish-brown frass on the bark was observed around the gallery entrances of the alder bark beetle, *Alniphagus aspericollis* LeConte, a common bark beetle in this locale (Borden 1969). Creamy-white frass occurred at the entrance to

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ambrosia beetle galleries, later identified, using beetles recovered from the galleries, to be those of *G. retusus*.

One of the trees was measured in detail. The tree was 30 m high, 43.9 cm in diameter at 1 m height from the root collar, and had major branches at 17, 19.3, 21.8, and 22 m. Attack by *G. retusus* occurred from the root collar to a height of 25.8 m (8.7 cm diam.). On 16 August 1998, three disks ca. 20 cm long were cut from the tree with a chain saw at 2, 8.5, and 15 m up the bole. The densities of *G. retusus* gallery entrances on these disks ranged from 36 to199 per m^2, representing a mean attack density (±SE) of 120 ± 32 per m^2 of bark surface. With the first cut into the tree at 3 m height the trunk shattered lengthwise and revealed extensive gallery systems, from which numerous living callow and mature adult beetles emerged. These galleries penetrated the wood to a depth of 17.5 cm, and were stained dark brown, very similar to *G. retusus* galleries in conifers. They contained adults, callow adults, larvae, and eggs, samples of each life stage were collected in 70% ethanol. Voucher specimens of mature adults have been deposited in the collection of the Pacific Forestry Centre, Canadian Forest Service, Victoria, BC.

From the cut discs, 11 galleries were dissected, revealing all life stages. One gallery dissected in February 1999, from a disk that had been left outside in the shade, contained egg niches, larvae, pupae, and both callow and mature adults, indicating that as in conifers (Prebble and Graham 1957; Chamberlin 1958) *G. retusus* in red alder can overwinter in any life stage. Galleries were typically forked two to four times, and curved in all directions, not only on one plane as in coniferous hosts (Wood 1982), possibly due to the lack of dense annual rings as found in conifers. Pupal and adult cradles (±SE) were 4.6 ±0.4 mm long, 2 mm wide, and 1 mm apart (n=25), staggered in an alternate pattern in one plane on both sides of a main gallery. The mean number of summed niches and cradles in five completely dissected galleries was 13.2 ± 5.5, a similar level of brood production as occurs in conifers (Liu and McLean 1993).

Our observations indicate that attack and brood production by *G. retusus* in red alder is consistent with descriptions of the beetles' biology in coniferous host species (Liu and McLean 1993). These results show conclusively that *G. retusus* in British Columbia can breed successfully in an angiosperm host.

ACKNOWLEDGEMENTS

This research was supported by the Natural Sciences and Engineering Research Council of Canada, Forest Renewal B.C., the Science Council of B.C. and 19 forest industry companies.

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When the manuscript is accepted for publication, the Editor will need one copy of the corrected draft and a 9 cm (3½") floppy disk containing the text and, if possible, digital figures in TIF, GIF, or JPG format. Files from the common word-processing programs or plain ASCII text are acceptable but Postscript© and Acrobat© formats are not; more information will be included with the returned manuscript.

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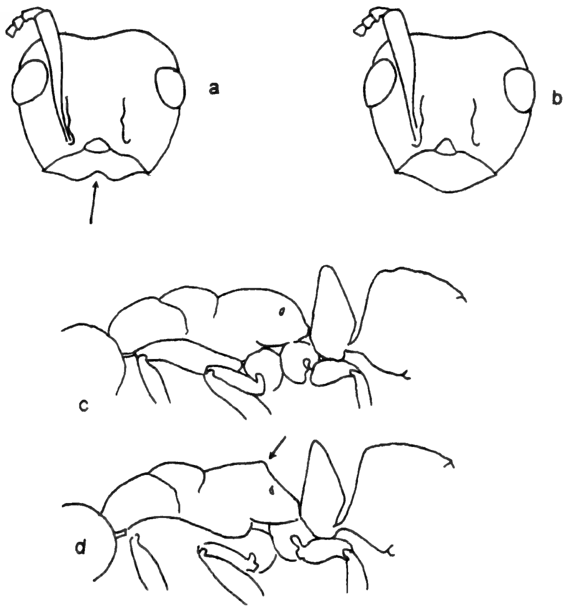

Figure 10. Features referred to in the Key to the Major Workers of the Species. a) Clypeus bearing a notch in the ventral border; b) clypeus without a ventral notch; c) profile of a rounded epinotum; d) profile of an angulate epinotum.

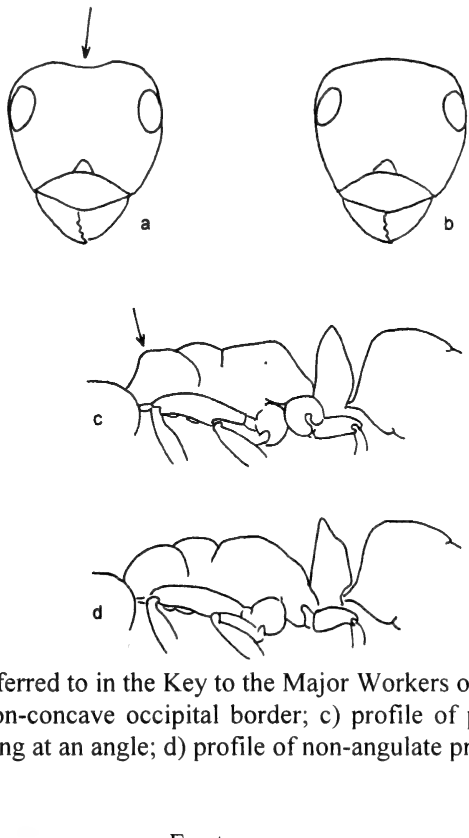

Figure 11. Features referred to in the Key to the Major Workers of the Species. a) Concave occipital border; b) non-concave occipital border; c) profile of pronotum with basal and declivitous faces meeting at an angle; d) profile of non-angulate pronotum.

Erratum

The Editor regrets that Figs. 10 and 11, pg. 55, Volume 96, December 1999 were inadvertently reversed and should have been printed as shown above.

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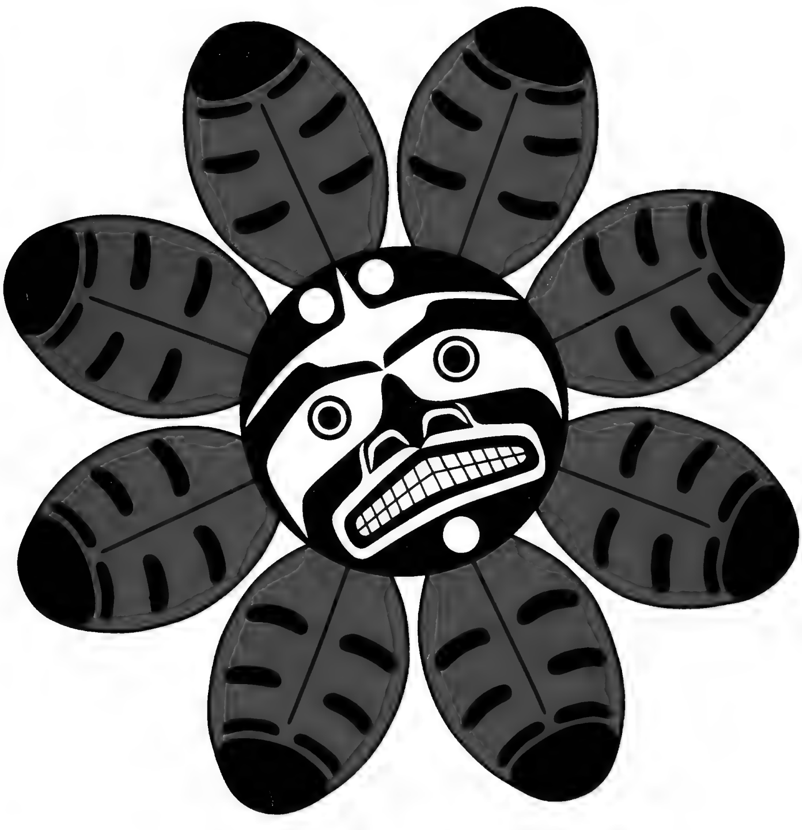

ESBC

Entomological Society
of British Columbia

COVER: 'Beetles' is the art of Richard Hunt, Victoria BC.
Richard kindly granted permission to use the design on the cover of Volume 98 of the Journal, marking the 100th anniversary of the Entomological Society of British Columbia. 'Beetles' was the emblem for the International Congress of Entomology, Vancouver, BC, Canada, 3-9 July 1988.

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Preface

The Entomological Society of British Columbia marks its 100^{th} anniversary in 2001. To commemorate the occasion, the Executive of the ESBC decided to publish 14 invited, six-page papers that sample the numerous entomological subjects that have been explored in the province of British Columbia during the last 50 years. The response to this idea has been overwhelming. In some cases the authors thought that it was important to review work during the last 100 years, and many authors extended the length of their articles in order to do the topic some justice. Given the finite resources of the ESBC, several topics have been partially covered. Other topics have not been specifically examined, for example, biological control and amateur entomology. However, the reader will catch a glimpse of the enormous breadth and depth of entomological studies that have been conducted in the Province. The scientific contribution of entomologists, on all scales from local to international, is clear. Deep thanks are due to the authors and reviewers for taking the time to contribute to this volume; to several authors who found additional funding to defray the publication costs of their papers; and to Richard Hunt for permission to use his art on the cover of this Volume.

David A. Raworth Editor

Journal of the Entomological Society of British Columbia

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SCIENTIFIC CONTRIBUTIONS – 2001

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The second 50 years of entomology in British Columbia – a brief perspective

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Fifty years ago the history of entomology in the Province was reviewed in seven articles dealing with different regions or subjects in our journal, then called the Proceedings (Vol. 48, 1952).

It was the heyday of chlorinated hydrocarbon pesticides and new government laboratories were being set up to study not only pest control with these new compounds but also biology, biological control and the identification of difficult groups of insects like root maggots and wireworms.

Entomological training in the Province was in the capable hands of Prof. G.J. Spencer of the University of British Columbia, the Society's President in 1951. Many of his students became well-known in their own right, such as D.A. Chant, K. Graham, J.D. Gregson, G.P. Holland, H.R. MacCarthy, and A.L. Turnbull. Between 1934 and 1937, Spencer was also in charge of summer operations at the Dominion Insect Unit in Kamloops following the untimely death of Eric Hearle, the Province's founding medical entomologist. Spencer was much more than just a capable academic. He retired in 1953 and the role of guiding entomologist at UBC was taken over in 1958 by Prof. G.G.E. Scudder for the remainder of the century. Other entomologists expanded the topics covered at that University when C.S. (Buzz) Holling was appointed to the new Institute of Animal Resource Ecology, set up to study the interactions between fisheries and forestry. Holling was its first full-time director and appointed another forest entomologist, W.G. Wellington to it in 1970. The latter took over as director from 1973 to 1979, retiring in 1986. J.H. Myers joined the institute in 1972. The Faculty of Forestry also employed entomologists including Spencer's former student, K. Graham, Professor from 1948-1977 and later, J.A. McLean from 1977 to the present. The Faculty of Agriculture, Plant Science also employed an entomologist, J. Sandess in the late 1960s, succeeded by B. Philogène, R.H. Elliott and in 1983 by the present incumbent, M.B. Isman.

R.A. Ring was hired to teach entomology for a year at UBC in 1964, and after a spell at the Biosystematics Research Institute, Ottawa, returned and was appointed by the University of Victoria in 1966, where he continues to teach.

There was a major influx of entomologists to the newly founded Simon Fraser University in 1967. J.H. Borden had been appointed a year earlier but was soon joined by B.P. Beirne and seven of his staff from the Federal Research Institute for Biological Control in Belleville ON. Beirne set up the Pestology Centre, which flourished (with a change of name to Centre for Pest Management) for about 30 years as an integral part of the Department of Biological Sciences. The Masters of Pest Management Degree

Programme started in 1973 and is still attracting students from all over the world. Over 250 MPM degrees have been awarded since its inception.

The Province's newest University of Northern BC in Prince George opened in September 1994 and one of the first faculty appointed was a former J.H. Borden student, the forest entomologist and inventor, B.S. Lindgren.

By 1951, the predominantly British Victorian naturalists, who had collected and listed the insects in many different groups during the first 50 years, were being replaced, as Marshall (1952) put it, by Canadian 'spray blokes'.

The Dominion Department of Agriculture was then well represented in the Province. The oldest laboratory was the original Experimental Farm Station set up in Agassiz in 1886 by T. Sharpe with the aim of serving the farming community and developing our embryonic agricultural industry. Many of the ornamental trees and shrubs he planted, after clearing the forest at the turn of the century, still stand impressively around the new research building that opened there in 2001. R. Glendenning was in charge of the entomology laboratory at Agassiz for 37 years until his retirement in 1953 and in 1956 a substation for soft fruit was set up in Abbotsford.

The Plant Protection Laboratory in Vancouver had also been running for many years. Vancouver was the site of a Stored Product Insect Laboratory and a Biological Control Investigations Laboratory with J.H. McLeod from the then Dominion Parasite Laboratory in Belleville in charge. Turnbull and Chant were both employed there after they graduated from UBC in the 1950s. A fourth laboratory, for Plant Pathology, was already on the UBC campus and a Dominion Field Crop Insect Laboratory was opened there in 1955.

The Dominion was represented in the Interior by Livestock Insect and Field Crop Insect Laboratories in Kamloops and a Fruit Insect Laboratory in Summerland. There was another Field Crop Insect Laboratory in Victoria. The Kamloops Research Station was directed by R.H. Handford from 1962 to 1970. He was the western expert on the biology and control of grasshoppers since the death of N. Criddle and had a wealth of experience in their management (Riegert 1980).

In 1960 a new Research Station was opened on the UBC campus. One of its main functions was to act as a National Plant Virus Research Laboratory, but the outlying Plant Pathology, Stored Product and Field Crop Insect Laboratories together with a substation in Chilliwack were brought together in a seven-man Entomology Section under H.R. MacCarthy. The station had modern rearing facilities, greenhouses, library and an administrative section. After some 30 years the Department of Agriculture closed the Vancouver Research Station in 1996 and the entomologists moved to Agassiz and Summerland.

Entomology in the Province was directed in 1951 from the Vernon courthouse by the Provincial Entomologist. C.L. Neilson, a talented field man and administrator, was in Vernon at that time and by 1955 had replaced E.R. Buckell's associate I.J. Ward as Provincial Entomologist after Ward's untimely death. Later the headquarters moved to, and remains in, Victoria.

J.C. Arrand was appointed Assistant Provincial Entomologist in 1957 and maintained entomological continuity in the Ministry, retiring as Director of the Crop Protection Branch in 1987. During his tenure, the Province was involved in research into alternatives to organochloride insecticides. Several crop pests had developed resistance to DDT by that time and secondary pests were emerging as the populations of beneficial insects were reduced by the 'pesticide treadmill'. Several mishaps in the 1960s persuaded the Social Credit government of the time to order the Department of Agriculture to draft regulations for the Pharmacy Act in 1965 and to establish a new Analytical Laboratory for pesticides. In 1963, the Provincial Entomology and Plant Pathology Branches and the Field Crops Branch moved to larger buildings in Cloverdale and there were similar but smaller laboratories in Kamloops, Sidney, Summerland and Victoria. In 1995 the Provincial Laboratories in Cloverdale were closed and most entomologists and their programs moved to modern facilities in the Abbotsford Regional Office.

Forest insect pests were managed by the Canada Department of Agriculture (Science Service) in 1951, and H.A. Richmond, who had carried out forest insect surveys on horseback for R. Hopping in Vernon in the 1920s, was in charge of the Victoria laboratory until 1955. In the interior, the laboratory in Vernon, headed by R. Hopping for two decades solved many of our urgent forest pest problems. D.A. Ross became its head in 1955, but moved to Victoria in 1970 when the Vernon laboratory closed. L.H. McMullen moved to Victoria from Vernon in 1955 and became head of entomological research there in 1965. Many other well known entomologists have worked in these laboratories and more details are given elsewhere in this Volume.

In the 50th ESBC Anniversary volume, Spencer (1952) summarised the 'status of our knowledge of the insects of British Columbia'. He pointed out that federal officers of the Division of Entomology sent their specimens to the Canadian National Collection in Ottawa and that complete lists of Provincial records would be almost impossible to obtain. Many of the specimens of the more colourful Lepidoptera, Hemiptera and Coleoptera were divided between the National and Provincial collections with most of Spencer's own collection at 'The University'. R. Hopping's "huge" beetle collection from Vernon was left to the California Academy of Science where H.B. Leech went, taking his own collection of water beetles with him. At the Provincial Museum in Victoria, G. Hardy, the Botanist/Entomologist, collected Lepidoptera and Coleoptera until his retirement in 1959 but then the collections were almost completely neglected until 1970 when a severe insect infestation was discovered. B. Ainscough volunteered to look after the collection until a full-time curatorial division was established. R.H. Carcasson took over as Senior Curator in 1973 and the collection continued to recover as he and later R.A. Cannings, were in charge of it. Two museum handbooks were published dealing with insects of the Province, 'The Dragonflies' (#35) by R.A. Cannings and K.M. Stuart (1977) and 'The Mosquitoes' (#41) By P. and E.M. Belton (1983).

Our Journal, apart from its name, has not changed greatly. The 50th ESBC Anniversary volume had 17 research papers (as well as the seven retrospectives) in 104 pages. It had 5 full-page advertisements and eight smaller ones, some of which were congratulations. It was typeset, printed on good quality paper, stitched in 'signatures' and 'perfect bound' in 'sugar-bag blue' card by Chapman and Warwick in Vancouver. The latest issue, Vol. 97, 2000, had 16 research papers in 105 pages. It was laser printed, not typeset, and then trimmed to size ('camera ready' apart from a few figures) by the Editor and printed on glossy coated paper using photo-offset by the Reprographics Unit at Simon Fraser University. It is also 'perfect bound' in blue, but is without advertising. Stages in this evolution included green and even a white, stapled cover. R.A. Ring, introduced computer printing in 1992, when the design and printing was done by the Graphics Group at the University of Victoria. The scientific quality and reputation of the Journal has remained one of the highest in Canada.

Our Society also continues to attract enthusiastic and dedicated entomologists (Riegert 1991) and a list of its presidents during the second half-century is appended. On June 14th 1951, 53 members were photographed at the 50th annual general meeting at UBC and a similar number attended our 100th in September 2001 at the Summerland Research Station (Figs. 1,2). A handful of the 1951 veterans maintain an interest in entomology but none attended the 100th meeting. The proportion of student members attending has increased greatly over the years, D.A. Chant and L.E. Wade may have been the only graduate students there in 1951 but today, with four Universities and many Regional Colleges, we

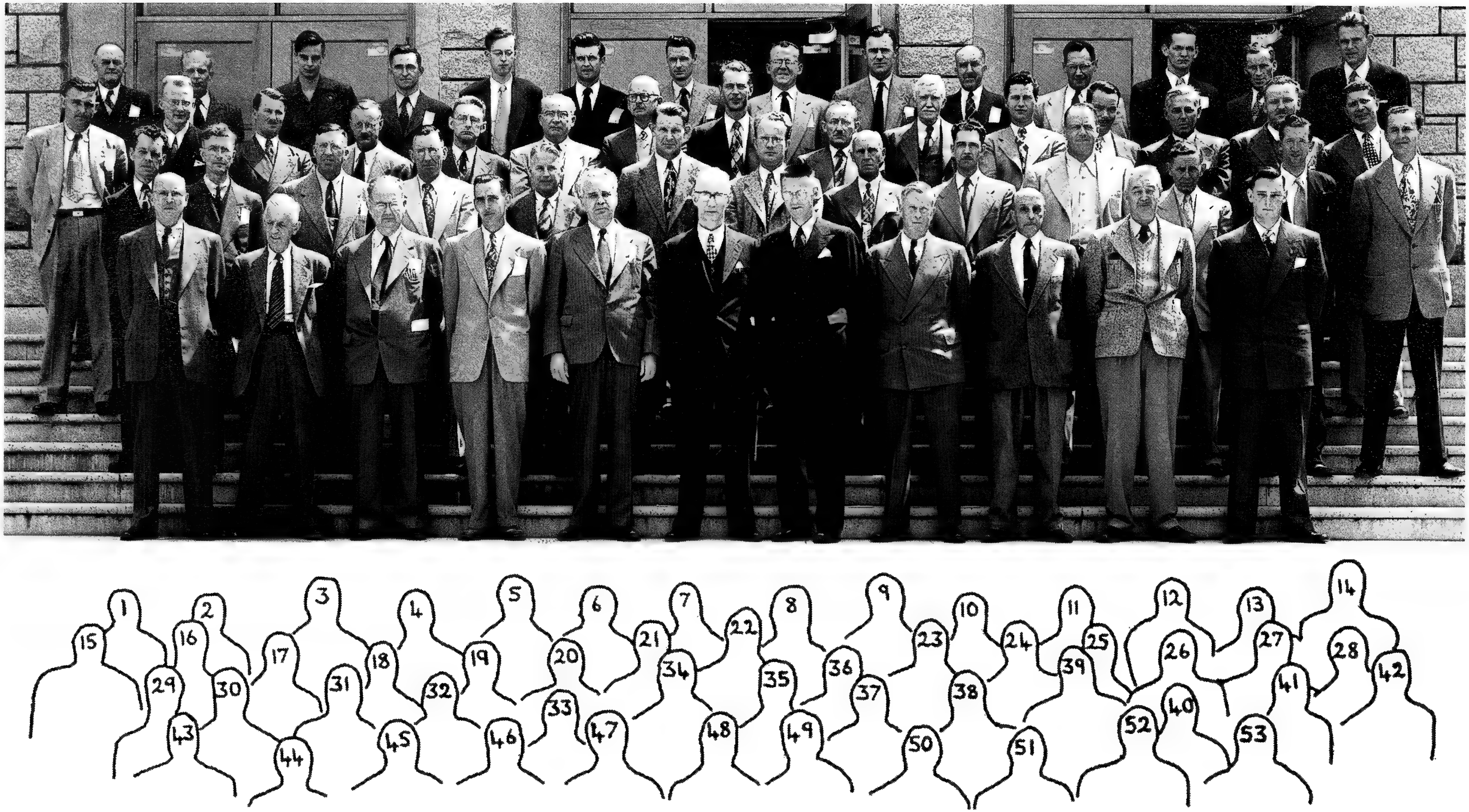

Figure 1. Group photograph of those at the 50th Annual General Meeting of the Entomological Society of British Columbia (taken 14 June 1951 at the University of British Columbia, Vancouver, BC): 1 J.R.J.L. Jones, 2 N.V. Tonks, 3 L.E. Wade, 4 C. Morgan, 5 A.R. Forbes, 6 A.T.S. Wilkinson, 7 A.D. Henderson, 8 P. Zuk, 9 G.E. White, 10 A.E. Barss, 11 J. Weintraub, 12 D.A. Chant, 13 G.B. Rich, 14 N.B. Wright, 15 W.H. Wilde, 16 R. Robertson, 17 G. Thompson, 18 H.R. MacCarthy, 19. W. Lazorko, 20 D.K. Campbell, 21 C.P. Clausen, 22 W. Waddell, 23 J.W. Eastham, 24 D.R. Finlayson, 25 K. Graham, 26 R.E. Fitzpatrick, 27 F.L. Billings, 28 J. Follwell, 29 H. Richmond, 30 L.C. Curtis, 31 K.M. King, 32 M.C. Lane, 33 W.G. Mathers, 34 H.G. Fulton, 35 C.L. Neilson, 36 J.H. Foster, 37 E.R. Buckell, 38 D. Arnott, 39 O. Hitchcock, 40 C.R. Cunningham, 41 R. Stace-Smith, 42 D.A. Ross, 43 G.J. Spencer, 44 E.P. Venables, 45 M.H. Hatch, 46 J.D. Gregson, 47 W.A. Ross, 48 H.F. Olds, 49 J. Marshall, 50 J.H. McLeod, 51 W. Downes, 52 R. Glendenning, 53 F.L. Banham.


Figure 2. Group photograph of those at the 100th Annual General Meeting of the Entomological Society of British Columbia (taken 27 September 2001 at the Pacific Agri-Food Research Centre, Summerland, BC): 1 R.G. Bennett, 2 A. Henderson, 3 N. Jeans-Williams, 4 N. DeLury, 5 L. Jensen, 6 T. Hueppelsheuser, 7 E. Desautels, 8 B. Roitberg, 9 E. Belton, 10 W. Strong, 11 K.M. Needham, 12 P. Jones, 13 G.G.E. Scudder, 14 P. Belton, 15 R.A. Cannings, 16 L. Overton, 17 A. Borkent, 18 S. VanLaerhoven, 19 J.A. Rumph, 20 J. Cossentine, 21 R.D. Kenner, 22 T. Shore, 23 I. Wilson, 24 H. Philip, 25 Y. Herbison, 26 T. Lowery, 27 D.A. Raworth, 28 C. Guppy, 29 A. Strope, 30 M.-Y. Choi, 31 M. Claudius, 32 H.M.A. Thistlewood, 33 S. Tjokrodiningrat, 34 M. Smirle, 35 J. Perry, 36 B. Riel, 37 N. Verpahlst, 38 L. Maclauchlan, 39 L. Harder, 40 K. Deglow

can expect them to make up almost half of those registering. The last issue of Boreus, the Society's newsletter, first issued in a formal binding by R.A. Cannings in April 1981 was mailed in June 2001 to 160 'more or less paid up' members according to our Secretary-Treasurer.

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APPENDIX

Presidents of the Entomological Society of British Columbia 1951 - 2001

YEAR	PRESIDENT	AFFILIATION
1951	G.J. Spencer	Zoology, University of British Columbia, Vancouver
1952	H. Olds	Agriculture Canada, Vancouver
1953	J. Marshall	Agriculture Canada, Summerland
1954	J.H. McLeod	Agriculture Canada, Vancouver
1955	M.H. Hatch	University of Washington, Seattle
1956	R.H. Handford	Agriculture Canada, Kamloops
1957	H. Andison	Agriculture Canada, Victoria
1958	M.D. Proverbs	Agriculture Canada, Summerland
1959	P. Zuk	Agriculture Canada, Vancouver
1960	D.A. Ross	Canada Dept. of Forestry, Forest Entomology Laboratory, Vernon
1961	H.R. MacCarthy	Agriculture Canada, Vancouver
1962	C.L. Neilson	BC Department of Agriculture, Victoria
1963	D.P. Pielou	Agriculture Canada, Summerland
1964	R.R. Lejeune	Canada Dept. of Forestry, Forest Biology Laboratory, Victoria
1965	M.G. Thompson	Canada Dept. of Forestry, Forest Biology Laboratory, Victoria
1966	J.C. Arrand	BC Department of Agriculture, Victoria
1967	G.G.E. Scudder	Zoology, University of British Columbia, Vancouver
1968	F.L. Banham	Agriculture Canada, Summerland
1969	H. Madsen	Agriculture Canada, Summerland
1970	W.T. Cram	Agriculture Canada, Vancouver
1971	D.G. Finlayson	Agriculture Canada, Vancouver
1972	R.A. Ring	Biology, University of Victoria, Victoria
1973	J. A. Chapman	Canada, Dept. Fisheries and Environment, Pacific Forestry Research Centre, Victoria
1974	R.D. McMullen	Agriculture Canada, Summerland
1975	T. Finlayson	Biology, Simon Fraser University, Burnaby

1976	J.R. Carrow	Canada, Department of Environment, Pacific Forestry Research Centre, Victoria
1977	H.S. Gerber	BC Ministry of Agriculture, Cloverdale
1978	A.L. Turnbull	Biology, Simon Fraser University, Burnaby
1979	P. Belton	Biology, Simon Fraser University, Burnaby
1980	R.H. Elliot	Plant Science, University of British Columbia, Vancouver
1981	A.R. Forbes	Agriculture Canada, Vancouver
1982	L. Safranyik	Canada, Department of Environment, Pacific Forestry Research Centre, Victoria
1983	J.A. McLean	Forestry, University of British Columbia, Vancouver
1984	R.A. Ring	Biology, University of Victoria, Victoria
1985	N.P. Angerilli	Agriculture Canada, Summerland
1986	R.A. Cannings	BC Provincial Museum, Victoria
1987	B.D. Roitberg	Biology, Simon Fraser University, Burnaby
1988	M.B. Isman	Plant Science, University of British Columbia, Vancouver
1989	C.S. Guppy	Royal BC Museum, Victoria
1990	D.A. Raworth	Agriculture Canada, Vancouver
1991	J.E. Cossentine	Agriculture Canada, Summerland
1992	R.S. Vernon	Agriculture Canada, Vancouver
1993	T.L. Shore	Forestry Canada, Pacific Forestry Centre, Victoria
1994	S.M. Fitzpatrick	Agriculture Canada, Vancouver
1995	L.A. Gilkeson	BC Ministry of Environment, Victoria
1996	G.S. Anderson	Biology, Simon Fraser University, Burnaby
1997	D.R. Gillespie	Agriculture and Agri-Food Canada, Agassiz
1998	B.S. Lindgren	Biology, University of Northern BC, Prince George
1999	M.B. Isman	Faculty of Agricultural Science, University of British Columbia, Vancouver
2000	N.N. Winchester	Biology, University of Victoria, Victoria
2001	R.A. Cannings	Royal BC Museum, Victoria

The G.J. Spencer Memorial Lecture Series at the University of British Columbia

A landmark in the past 35 years has been the G.J. Spencer Memorial Lecture series at the University of British Columbia. This series of lectures was to commemorate the achievements of G.J. Spencer, and ran from 1967 to 1999. The 33 lectures by eminent entomologists exposed faculty, students and guests to some of the major entomological research accomplishments in the world. The following gives a brief note on Spencer attached to the annual brochure circular each year, the list of lectures and their titles.

Prof. Emeritus George Johnston Spencer was born of missionary parents in Yercaud, South India, January 18, 1888 and died at his home in Vancouver, Canada, July 24, 1966. Prof. Spencer was renowned as a teacher. In 1924 Prof. Spencer was appointed Assistant Prof. at the University of British Columbia, and in 1945 Prof. at the same Institution. Retiring in 1953 he was elected Prof. Emeritus, Special Lecturer and Curator of the Entomological Museum.

In the early years of the University of British Columbia on its Point Grey campus, Prof. Spencer played a major role in establishing the Department of Zoology and his particular pride was the fine Entomological Museum that he established and which now bears his name. When he came to the University there were "less than a handful" of unlabelled specimens; when he left in 1966 the Museum contained over 300,000 specimens of perfectly mounted and labelled insects belonging to all orders. As a scientist he directed much of his energy to assembling a representative collection of the insect fauna of British Columbia. Prof. Spencer was a prodigious collector, even when ailing in the early months of 1966. His favourite study area was always the Dry Belt of British Columbia, an area that he insisted was "God's Own Country".

Year	Lecturer	Affiliation	Title
1967	Prof. Sir V.B. Wigglesworth	Cambridge University	Jan Swammerdam, preformation and insect growth.
1968	Prof. H.A. Schneiderman	Case Western Reserve University	Control systems in insect development.
1969	Prof. K.D. Roeder	Tufts University	Sonar and countersonar; the interaction of bats and moths.
1970	Prof. G. Hoyle	University of Oregon	Neural mechanisms underlying the behaviour of invertebrates.
1971	Prof. Th. Dobzhansky	Rockerfeller University	Genetics of behaviour in *Drosophila.*
1972	Prof. M. Locke	University of Western Ontario	Insect cells, and the study of basic problems in cell biology.
1973	Prof. L.P. Brower	Amherst College	Experimental proof of the palatability spectrum in natural populations of the monarch butterfly.
1974	Prof. V.G. Dethier	Princeton University	Hunger in the blowfly; a physiological analysis.
1975	Prof. D. Pimentel	Cornell University	The Economy of Insect Population.
1976	Prof. C.M. Williams	Harvard University	Hormones, Genes, and Metamorphosis.

1977	Prof. F.J. Ayala	University of California, Davis	The Genetics of Speciation: a Study with *Drosophila*.
1978	Prof. T.R.E. Southwood	Imperial College, University of London	Some Patterns of Nature.
1979	Prof. F. Engelmann	University of California, Los Angeles	Production of a yolky egg; aspects of hormonal control.
1980	Prof. E.B. Edney	University of British Columbia	Water balance in land Arthropods: some problems and solutions.
1981	Prof. P. Ehrlich	Stanford University	Population Biology of Checkered-Spot Butterflies: testing a theory in the field.
1982	Prof. E. Bursell	University of Bristol	The relationship of the tsetse fly and its host.
1983	Prof. G. Dover	Cambridge University	Molecular drive and the origin of insect species.
1984	Prof. K.G. Davey	York University	Sex among the arthropods.
1985	Prof. J.S. Edwards	University of Washington	Origin of flight in insects: an exercise in evolutionary neuroethology.
1986	Prof. C.S. Goodman	Stanford University	Embryonic development of the insect nervous system: the generation of neural specificity.
1987	Prof. H. Dingle	University of California, Davis	The genetic architecture of insect life histories.
1988	Prof. H.L. Carson	University of Hawaii	Newly-formed species: recognition and characteristics.
1989	Prof. R.G.H. Downer	University of Waterloo	Monoamines in insects.
1990	Prof. J.G. Hildebrand	University of Arizona	From semiochemical to behavior: Mechanisms underlying pheromonal communication in moths.
1991	Prof. J.H. Borden	Simon Fraser University	Semiochemicals: the essence of integrated management of the mountain pine beetle.
1992	Prof. G.M. Hewitt	University of East Anglia	Ice Ages, Species Substructure and the Significance of Hybrid Zones.
1993	Prof. G.R. Wyatt	Queen's University	The Juvenile Hormone of Insects: Elixir, Nemesis and Enigma.
1994	Prof. R.D. Alexander	University of Michigan	Species Problems in the Singing Insects.
1995	Prof. I.W.B. Thornton	La Trobe University	The recolonization of Krakatau.
1996	Prof. Jeremy N. McNeil	Laval University	Lepidopteran reproductive strategies and changing habitat quality.
1997	Dr. A.O. Nicholls	CSIRO, Australia	Conservation Evaluation, where to from here? An Australian Perspective.
1998	Prof. E. Bernays	University of Arizona	Why do insect herbivores specialize on plant hosts?
1999	Prof. G.G.E. Scudder	University of British Columbia	Insects in biodiversity conservation: some perspectives from the South Okanagan.

The H.R. MacCarthy Pest Management Lecture Series (Simon Fraser University and the University of British Columbia)

The purpose of the H.R. MacCarthy Pest Management Lecture is to present an annual lecture by a distinguished pest management scientist or practitioner. The venue of the lecture alternates between Simon Fraser University and the University of British Columbia. The lecture is managed by a committee consisting of representatives from Simon Fraser University (former Centre for Pest Management), the University of British Columbia (Faculty of Agricultural Sciences), Agriculture and Agri-Food Canada, the Professional Pest Management Association of British Columbia, and the Entomological Society of British Columbia. It is funded by revenues from the H.R. MacCarthy Endowment Fund. The following biographical note is part of the program for each year's lecture.

Dr. MacCarthy began his career in agricultural research in 1948 as a student assistant at the Field Crop Insect Laboratory at Kamloops. Mac grew up in England, was an agriculturist in Australia, a cattle rancher at Princeton, BC for 9 years, and spent nearly 6 years in war service with the Canadian Infantry Corps. After returning from war service in 1946, Mac attended the University of British Columbia, receiving his B.A. in Zoology in 1950. He went directly on to graduate study at the University of California at Berkeley and was awarded his Ph.D. in 1953.

He returned to Kamloops and worked there until 1955 when he was appointed Officer-in-Charge of the Field Crop Insect Laboratory on the campus of the University of British Columbia. He was named head of the Entomology Section of the Vancouver Research Station in 1959. Mac's research was largely on the transmission of potato leaf roll virus by aphids. Collaborative work by him and other scientists at the station has led to almost complete control of potato leaf roll virus in the province.

Mac has been an adjunct professor at Simon Fraser University's Centre for Pest Management since 1974. Immediately following his retirement from Agriculture Canada in 1976, he became a sessional lecturer at Simon Fraser University, and was acting director of the Centre for Pest Management for more than two years. He also held the title of Honorary Lecturer at the University of British Columbia for.almost two decades, and was editor of the *Journal of the Entomological Society of British Columbia* for over three decades. His specialty has always been to improve the English of thesis writers and others who need it – a category for which he has yet to identify an exception. Mac celebrated his 90th birthday on June 22, 2001.

Year	Lecturer	Affiliation	Title
1990	Prof. M. Kogan	University of Illinois	Implimentation of IPM programs – the impact of agroecological and socio-economic conditions
1991	Prof. R.N. Coulson	Texas A&M University	Intelligent geographic information systems and integrated pest management
1992	Dr. S. Finch	Horticulture Research International, Wellesbourne, U.K.	Integrated pest management in field vegetable crops – the challenge facing research scientists
1993	Prof. R.J. Prokopy	University of Massacheusetts	Integration of management practices for insect, weed and disease pests can be viewed as a stepwise process ultimately affected by socio-political concerns
1994	Prof. G. Norton	University of Queensland	Pragmatic economics for pest management

1995	Prof. W. Fry	Cornell University	Re-emergence of potato late blight, *Phytophthora infestans*: sex and the single fungus
1996	Prof. T.C. Baker	Iowa State University	Sex pheromones of moths: promise, premise and practice
1997	Prof. F. Gould	North Carolina State University	Evolutionary potential of crop pests: implications for integrated pest management
1998	Dr. P. Harris	Agriculture and Agri-food Canada, Lethbridge	The evolution of weed biocontrol in Canada
1999	Prof. J.T. Trumble	University of California, Riverside	Ethics, environment and economics in IPM: a case study in tomatoes
2000	Prof. J. Rosenheim	University of California, Davis	Predators that eat predators: implications for biological control theory
2001	Prof. S.B. Vinson	Texas A&M University	Is *Solenopsis invicta*, the imported fire ant, as invincible as its specific name implies?

Insect collections, surveys and conservation in British Columbia in the 20th century

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INTRODUCTION

In this brief summary of insect collections, surveys and conservation efforts in British Columbia during the 20th century, we emphasize the years since 1950, occasionally referring to activities in the first half of the century for historical perspective. Because of restricted space, our intent here is to stress accomplishments rather than the historical aspects of entomologists and their work.

Researchers and managers in many fields of biology have recognized that invaluable information on biological diversity is contained with specimens in natural history collections. Such collections are also crucial in education, essential references for identification of specimens, and critical for studies in environmental biology, ecology, evolution and other fields. Consequently, there is an effort in many parts of the world to emphasize the continued and future importance of collections and to make specimen-based information available on the Internet to researchers and others (Bisby 2000; Edwards *et al.* 2000). Collections of British Columbia insects are an important source of information relevant to a number of provincial initiatives in the assessment and conservation of our biodiversity. Miller (1985, 1993) and the Biological Survey of Canada (1991) emphasize the importance of biological collections in these and other roles. The Biological Survey of Canada (Terrestrial Arthropods) promotes, develops and coordinates national initiatives in systematic and faunistic entomology. It has published several briefs outlining guidelines for successful arthropod surveys (Biological Survey of Canada 1994, 1996).

Over the years, many biological surveys have been undertaken in the province. However, there has been little attempt to document those inventories that involve insects and ascertain where the results from these might be located. Indeed, it is often unclear if voucher or residue material from these studies are available for further study or verification of records. Furthermore, we must maintain provincial initiatives in collection growth at a time when funding is being curtailed. Ironically, with the decline of funding for taxonomic research, insects collected in association with various fish/forestry interaction programs may be our best, and perhaps only, source of new records of British

[1]Authors are in alphabetical order, not necessarily in order of the importance of their contribution.

Columbia insects in the future. All faunal surveys conducted in the province should be required to submit voucher specimens to a museum collection (Miller and Nagorsen 1992) before the project is considered complete. In this way, identifications can be confirmed and valuable records made part of the developing biodiversity database. Guidelines for the preparation and deposition of such collections are part of the provincial government's Resources Inventory Committee standards (Resources Inventory Committee 1999).

This paper summarizes the current situation with respect to collections of BC insects. It also outlines some of the major surveys that have been undertaken, and notes a few of the major results. The last section details some of the ongoing biodiversity conservation initiatives that need entomological input.

COLLECTIONS

Many collections around the world contain insects collected in BC, but only a few have large holdings of specimens from the province. Scudder (1996) gives a more comprehensive list of collections housing provincial material. In general, the larger collections containing BC specimens, both inside and outside the province, are dominated by Coleoptera and Lepidoptera material, although some other orders, such as Hemiptera and Odonata, are well represented in the province's collections. Of the larger orders, Diptera and Hymenoptera show the most serious gaps in taxonomic coverage, and the apterygote taxa are poorly covered.

Provincial collections contain limited type material, especially holotypes. Most type specimens of BC taxa are housed in larger collections, especially the Canadian National Collection of Insects, Arachnids and Nematodes in Ottawa.

COLLECTIONS IN BRITISH COLUMBIA

Royal British Columbia Museum (RBCM)

The Royal British Columbia Museum's entomology collections in Victoria began accumulating with the Provincial Museum's establishment in 1886. E.H. Blackmore, a well-known lepidopterist, volunteered as curator from 1913 to 1928. Through the first half of the 1900s, holdings grew through gifts of specimens and the energetic collecting of staff members E.M. Anderson (1903-1916) and G.A. Hardy (1924-1928/ 1941-1953). Although Hardy was primarily a botanist, his insect collections on southern Vancouver Island, especially of Lepidoptera and Coleoptera, formed the backbone of the collection. The collections were never fully organized and properly stored, however, and between Hardy's retirement in 1953 and the arrival of the collection's first full-time curator, R.H. Carcasson, a lepidopterist (1973-1978), they suffered considerable neglect and damage. Carcasson was assisted by B.D. Ainscough (1972-1983) and A. Mackie (1974-1975). R.A. Cannings, the present curator, succeeded Carcasson in 1980. C.S. Guppy (1987-1993) and D.C.A. Blades (1997-present) have served as collections managers.

The RBCM has approximately 250,000 specimens; about 55,000 of these are Lepidoptera, 60,000 Coleoptera and 35,000 Diptera. Cannings' specialty, the Odonata, number 35,000. Important collections included are those of A.W. Hanham (Lepidoptera and Coleoptera), G.O. Day (Lepidoptera), T.A. Molliet (Lepidoptera), G.A. Hardy (Geometridae, Noctuidae and Cerambycidae), G. Straley (Lepidoptera), F.C. Whitehouse (Odonata) (in part), J. Grant and R. Guppy. The RBCM has a small collection of fossil insects, mainly from the Eocene shales of the Interior.

Spencer Entomological Museum (SEM)

This teaching and research museum is located in the Department of Zoology at the University of British Columbia (UBC) in Vancouver. It was founded in 1953 on the retirement of G.J. Spencer, and is named after this outstanding teacher, prodigious collector and investigator of insect biology. Currently the museum contains 600,000 specimens (500,000 pinned, 75,000 alcohol preserved, 25,000 slide mounted) in 110 12-drawer metal cabinets.

As well as containing specimens from student collections, and voucher material associated with UBC student theses, the SEM houses some of the most important private collections made in the province over the years. These include the Buckell, Cannings (pre-1980) and Whitehouse (in part) collections of Odonata; the Buckell and Spencer collections of Orthopteroid insects; the Downes and Scudder collections of BC Hemiptera (the Alice McDouglass collection of aphids is on permanent loan to the CNC, see below); the Spencer collection of Phthiraptera and Siphonaptera slides; the Blackmore, Kimmich and Llewellyn Jones collections of Lepidoptera; the R. Guppy (in part) and Stace-Smith collections of Coleoptera (including many of the Hatch types described from the latter collection); and the Foxlee collection of Diptera and Hymenoptera. The museum also holds, on permanent loan, the small insect collection formerly maintained by the Vancouver City Museum.

G.G.E. Scudder has been the academic curator since 1965. Curators in the museum have included R.A. Cannings, S.G. Cannings, K.M. Stuart and J. van Reenen; K. Needham is the current curator. R. Kenner has been a volunteer since 1995. Because of budget retrenchments, the museum has been closed to the public since 1993.

Pacific Forestry Centre

The collection of the Canadian Forest Service, Pacific and Yukon Region, is housed at the Pacific Forestry Centre in Victoria. This collection was built mostly through the efforts of the Forest Insect and Disease Survey (FIDS) during the more than 50 years of its existence. Some of the specimens came from the federal laboratory in Vernon, which was amalgamated with the Victoria laboratory in 1969. Recently, the surveys of forest canopy biodiversity made by the University of Victoria have provided many new accessions. The Pacific Forestry Centre collection consists primarily of forest species. It is particularly well represented in Lepidoptera, bark and wood-boring Coleoptera, sawflies and hymenopteran parasitoids and predators of these groups. The collection holds approximately 100,000 specimens of 7,000 species.

D. Evans curated the collection from 1949 to 1985, assisted for much of this time by D. Ruppel. More recently, the collection has been maintained by B. Duncan, L. Humble and J. Seed. Entomologists associated with the Vernon collection before its assimilation included D. Ross and J. Grant.

British Columbia Department of Agriculture

The BC Department of Agriculture in Kelowna contains a small collection of insects relevant to agriculture in BC.

Agriculture and Agri-Food Canada

The AAFC centre at Agassiz also houses a small collection of insects relevant to BC agriculture. Some of these collections were formerly at AAFC stations in Vancouver and elsewhere in BC.

Other University Collections

Small insect collections are also contained in the Department of Biology at the University of Victoria, the Department of Biological Sciences at Simon Fraser University in Burnaby, and in the Department of Natural Resources at the University of Northern British Columbia in Prince George. These collections have specimens obtained during teaching assignments and voucher material associated with research theses in these universities.

Private Collections

Several people in the province maintain collections that contain important material for documenting insect distribution and biology in the province. The most striking of these are the large Lepidoptera collections of C. Guppy, N. Kondla, J. Shepard and J. Troubridge. These collections made important contributions to the data analyzed and mapped in the recently published 'Butterflies of British Columbia' (Guppy and Shepard 2001). The extent and significance of private collections in the province is unknown, and an initiative to document these resources would be useful.

COLLECTIONS OUTSIDE BRITISH COLUMBIA

Many other collections in Canada, the USA and elsewhere contain specimens of BC insects (Scudder 1996). Undoubtedly the most important is the Canadian National Collection of Insects, Arachnids and Nematodes at Agriculture and Agri-Food Canada in Ottawa. This contains not only the abundant material collected in BC by government scientists and technicians over the years, but it also houses the Ricker collection of Plecoptera and the Glendenning and McGillivray collection of aphids, and much of the Forbes and Chan collection of these insects.

BC specimens are also held by the Lyman Entomological Museum at Macdonald College of McGill University in Ste.-Anne-de-Bellevue, Québec, and in the Royal Ontario Museum in Toronto. The Hopping collection of BC Coleoptera and the H.B. Leech collection of water beetles are in the California Academy of Sciences in San Francisco, together with the large collection of beetles collected by D. Kavanaugh in the Queen Charlotte Islands and elsewhere in the province. The entomological collection at Oregon State University in Corvallis houses the Hatch collection of beetles, rich in BC specimens. The American Museum of Natural History in New York and the National Museum of Natural History in Washington, DC also contain much BC material. J. Bergdahl (Spokane, WA) has a large collection of ground beetles that includes much material from BC, especially the Kootenays, Vancouver Island and the Gulf Islands. L. Crabo (Bellingham, WA) owns a significant collection of noctuid moths from the province.

COLLECTION DATABASES

Rapid access to the information contained in collections has become a major concern and a large portion of the meagre resources available to collections has been directed to the production of electronic databases. Much of the collection in the RBCM is databased and some of the insect orders in the SEM have also been computerized. The major private butterfly collections were databased during the production of 'Butterflies of British Columbia' (Guppy and Shepard 2001).

SURVEYS

Over the years surveys and inventories have increased our understanding of BC insects and their distribution. The important and wide-reaching FIDS initiative has already been mentioned. Many of the private collections made in the past, and many of those being made today, were made by collectors interested in surveying the distribution of species in their favourite groups. Recently, entomologists and naturalists have joined in informal insect forays (Cannings 1996), usually to some unstudied area, in an attempt to further knowledge of insect status and distribution. However, in the last 40 years or so, several projects with a more or less formal survey component have been undertaken in the province. The distinction between surveys and general collecting is often not definite, and we have tried to include only the former. Most of these surveys are summarized below, emphasizing the publications produced. The surveys are arranged according to the general type of environment sampled (aquatic habitats, forests, grasslands, and so on).

In order that available resources are focused on important habitats and taxa, Scudder (1996) recommended priorities for terrestrial and freshwater invertebrate surveys. These included suggestions for surveys of Lepidoptera in the Nanaimo Lowlands and Okanagan Basin, invertebrates of coastal old-growth forests, and invertebrates in caves and springs.

AQUATIC SURVEYS

Lakes

Carl (1953), Clemens *et al.* (1938, 1939), Rawson (1934), Robertson (1954), and Withler (1956) surveyed insects and other benthic organism in a number of the larger lakes in the province. Saether (1970) studied the bottom fauna of lakes in the Okanagan Valley, paying special attention to the Chironomidae.

Scudder began surveys and detailed studies on saline lakes and other waterbodies, including peatlands, in the Cariboo, Chilcotin and Kamloops regions in 1959. These studies continued for 25 years. The physical and chemical limnology of most of the larger lakes were described by Topping and Scudder (1977), and many of the smaller ponds were characterized by Scudder (1988). Scudder (1969, 1988) listed some of the insects that showed a differential distribution in the lakes, and the community structure in the Coleoptera and Hemiptera was discussed by Lancaster and Scudder (1987). The distribution of Odonata in these same lakes was examined by Cannings *et al.* (1980) and Cannings and Cannings (1987), and the Chironomidae by Cannings and Scudder (1978).

Surveys have been an important stimulus to the development of entomological collections in British Columbia – Rob Cannings collecting chironomid larvae during a survey of saline lakes near Williams Lake, August 1970. Photo by Syd Cannings.

Some insects in meromictic lakes were listed by Northcote and Halsey (1969), and the benthic insect fauna of several lakes in the UBC Research Forest near Maple Ridge was reported in Hindar *et al.* (1988) and Rempel and Northcote (1989). Northcote *et al.* (1978), Northcote and Hall (1983), Hume and Northcote (1985), Chapman *et al.* (1985) and Walters *et al.* (1987) also gave records of the occurrence of *Chaoborus* species in some coastal and interior lakes.

Streams and Rivers

Collections of stream and river insects in BC have been made by fisheries inventory personnel of the now-titled provincial Ministry of Sustainable Resource Management, and members of the Federal Department of Fisheries and Oceans. Some of the streams studied, for which samples are available, are Loon Creek near Clinton, Centennial/ Slim/Rosanne creeks east of Prince George, Adam and Keogh rivers on northern Vancouver Island, Big Silver Creek on Harrison Lake, Mesilinka River on Williston Reservoir, Torpy and Upper Nechako rivers east and west of Prince George, respectively, and Takla Lake creeks north of Fort St. James (P. Slaney, *in litt.*)

Insects were also collected in two major fish/forestry interaction programs in coastal BC: the Carnation Creek Experimental Watershed Study on the west coast of Vancouver Island, which began in 1970 (Hartman and Scrivener 1990), and the Fish/Forestry Interaction Program (FFIP) in the Queen Charlotte Islands, initiated in 1981. Over 30 watersheds were studied in this program (Hogan *et al.* 1998). In addition, collections have been made during environmental surveys on contract to government or private industry. For instance, Perrin and Associates (Vancouver) worked for many years conducting invertebrate surveys in the Nechako River for Alcan. Unfortunately, most records for many of these studies exist only in government reports or in non-refereed documents that are difficult to locate. The species names mentioned in such “grey literature” may be unreliable, since voucher specimens are seldom deposited in provincial or university collections where they are easily accessible to taxonomic experts and where identifications can be confirmed.

Idyll (1943) studied portions of the Cowichan River and considered it a “Trichoptera” stream because of the density of these insects in the bottom fauna. Filmer (1964) surveyed the mayfly fauna in the Alouette River, and Wigle and Thommasen (1990) studied this order in the Bella Coola and Owikeno watersheds. Ricker surveyed many streams and rivers around Cultus Lake (see aquatic insects paper), and benthic insects in the lower Fraser Valley were listed by Northcote *et al.* (1976). S. Salter (pers. comm.) has followed Scudder’s (1996) suggestion that collections in springs should be a priority by undertaking a preliminary inventory of invertebrates in selected warm springs and associated streams in the province.

Reece and Richardson (2000) surveyed benthic macroinvertebrate assemblages of coastal streams in the UBC Research Forest near Maple Ridge, continental streams in the Merritt area, and large rivers, namely the Fraser River near Agassiz and the Thompson River near Spences Bridge. Compared to small streams, large rivers had low invertebrate abundance, species richness and diversity. Coastal streams were richer in species, but Interior ones contained more individual insects.

Odonata Surveys

Despite the extensive collecting of Buckell (1938) and Whitehouse (1941) and the collecting and small-scale inventories of the Cannings brothers (e.g., Cannings and Cannings 1987, 1997), formal, large-scale inventories of dragonflies really were not organized until the 1990s. From 1996 to 2001, dragonfly surveys planned by the BC Conservation Data Centre and the Royal BC Museum (partly funded by Forest Renewal

BC, Parks Canada, and the Habitat Conservation Trust Fund) were undertaken to build collections, to improve understanding of species status, distribution and habitat requirements, and to better characterize the conservation status of species previously considered rare. The surveys covered southern Vancouver Island and the lower Fraser Valley; the Okanagan Valley (Cannings *et al.* 1998); the Peace River-Fort Nelson lowlands; the Columbia-Kootenay region, including the mountain National Parks (Cannings *et al.* 1999); the Cariboo-Chilcotin and Prince George-Robson Valley regions; and the Mackenzie and Omineca-Fort St. James regions. These surveys, which will continue until the whole province is covered, have added greatly to our knowledge of the distribution and ecology of this presumably well-known group of insects.

Burns Bog and other peatlands

The future of Burns Bog, the huge raised peatland near the mouth of the Fraser River, became a controversial issue in the late 1990s. In 1999 a preliminary survey of the insects of the bog was undertaken as part of the Burns Bog Ecosystem Review, an assessment of the habitat's value as a potential protected area. The results (Kenner and Needham 1999) showed that some insects in the centre of the bog were obligate peatland inhabitants, liable to be negatively affected if large areas of the bog were not conserved. Others found in the surrounding forested habitats were more widely distributed species, including a high proportion of introduced ones.

Insect surveys in other peatlands have mainly been associated with the dragonfly projects mentioned above. Seven of the 23 dragonfly species of management concern in the province inhabit bogs and fens, and surveys have focused on these habitats in the regions under study (Cannings 1994, Cannings *et al.* 1999). Much of the collecting done in the Brooks Peninsula project occurred in coastal bogs (Cannings and Cannings 1997).

FOREST SURVEYS

The most significant, long-term survey of the forests of BC is the Forest Insect and Disease Survey of the Canadian Forest Service. In BC, the FIDS collected specimens and ecological data on forest insects from 1946 to 1995.

Aided by the impressive systematic monograph on the ground beetles of Canada and Alaska by Lindroth (1961-1969), workers have undertaken several studies on carabid diversity in various forested ecosystems in the province. The variability of this diversity with succession and various logging and silvicultural practices has been stressed, largely because much of the financing for these studies has come from Forest Renewal British Columbia, a fund established in the 1990s to sustain the forest industry. Craig (1995) investigated carabid community structure in a chronosequence in the dry east coast Vancouver Island subzone of the Coastal Western Hemlock Zone. The litter spiders from this same pitfall trap study were studied by Brumwell (1996). Peak diversity in these taxa occurred in regenerating (3-8 year old) forest (Brumwell *et al.* 1998). The BC Conservation Data Centre sponsored a survey by J. Bergdahl of the rare carabid beetles in old-growth forests on Vancouver Island; results are not yet fully compiled.

McDowell (1998) examined ground beetle diversity in the Engelmann Spruce-Subalpine Fir (ESSF) and Interior Cedar-Hemlock (ICH) zones near East Barriere Lake. The ESSF forest sites had more individuals, but fewer species, than the ICH sites. Logging had a positive impact on generic and species diversity, but a negative impact on total number of individuals. Carabids in the ESSF zone were also studied by both Lemieux (1998) and Lavallee (1999), who studied the response of the carabid community to prescribed logging practices, in the Copper River Valley near Smithers, and at Sicamous Creek, respectively. Both studies showed a peak diversity following regrowth after logging. The Sicamous Creek insect surveys, largely undertaken by D. Huggerd, were part of a larger, interdisciplinary investigation of the effects of logging on the subalpine ecosystem.

J. Jarrett (pers. comm.) investigated the much more diverse carabid community in the Interior Douglas-fir (IDF) zone at Opax Mountain, studying both the wet (IDFdk) and dryer (IDFxh) subzones. He has shown that there is much more diversity in the latter subzone, much of it shared with the adjacent grassland habitats. S. Carlson (pers. comm.) has documented the aerial dispersing Coleoptera fauna in the IDF zone at its northern limits near Fort St. James. In a comparison of the beetle fauna attracted to non-pheromone and Douglas-fir beetle pheromone baited traps, she found that a vast array of non-target beetles are attracted to the latter. In the course of this research, many species of Coleoptera new to BC were discovered.

Inventories of Collembola in forest soils have greatly increased our knowledge of the diversity and status of this important group. Vlug and Borden (1973) reported that the Collembola fauna was reduced by logging and slash burning near Maple Ridge. Marshall *et al.* (1990) surveyed springtails in forest nurseries and found 22 species, 10 of which were new to the province; observations on pest species were reported. Battigelli *et al.* (1994) examined the soil fauna in adjacent stands of old-growth Western Redcedar-Western Hemlock and Amabilis Fir-Western Hemlock forests on northern Vancouver Island and found the relative abundance of Collembola was equal in both types. In the Interior, Nadel (1999) studied the fauna of soils and litter in subalpine ecosystems as part of the interdisciplinary Sicamous Creek project.

Marshall (1993) compared the soil fauna of Coastal Douglas-fir, Interior Douglas-fir, Subalpine Fir-Engelmann Spruce and Coastal Western Hemlock forests and showed that the highest densities of Collembola occurred in hemlock forests. Addison *et al.* (1998) studied the diversity and abundance of microarthropods in successional Douglas-fir forests on Vancouver Island. The same species tended to occur in all seres studied; differences were mostly in relative and absolute abundance. Setälä and Marshall (1994), Setälä *et al.* (1995) and Marshall *et al.* (1998) studied the succession of springtails in tree stumps at the same study sites. Seventy-two species were identified; some of these were not found in the regeneration sere but most were either positively correlated with stand age or were ubiquitous. Berch *et al.* (2001) examined the diversity and abundance of springtails in the wettest subzone of the Coastal Western Hemlock Zone near Franklin River on Vancouver Island. In a comparison of habitats based on tree species, Sitka Spruce cover had the highest average number of species (21) and the highest densities (32,000/m^2).

On the Gulf Islands, Scudder surveyed insects in forested areas on the north end of Galiano Island; sweeping, beating, and window-intercept and pitfall traps were used.

As an adjunct to the ambitious survey of the insect fauna of the Yukon, mostly in the 1980s (Danks and Downes 1997), field parties on their way to the Yukon collected extensively in northern BC. Much of this collecting was in forested areas, but northern grassland and aquatic sites were also sampled.

In the 1990s, working in the canopies of Sitka Spruce forests in the Carmanah Valley on Vancouver Island, Winchester and his colleagues found more than 300 new arthropod species, many of which are restricted to habitats found only in these ancient forest treetops (Behan-Pelletier and Winchester 1998, S.A. Marshall and Winchester 1999, Winchester and Ring 1999). This work has been expanded to other biogeoclimatic zones such as the subalpine forests at Mount Cain on Vancouver Island (Winchester and Fagan 2000). Studies continue on species life cycles and factors that influence the distribution, abundance, organization and ecological importance of these aerial communities (Winchester and Ring 1999). This pioneering canopy and conservation work demonstrates that loss of unique canopy microhabitats may cause local species extinctions.

GRASSLAND AND SHRUB-STEPPE SURVEYS

Over the years, considerable collecting has been done in the interior grasslands by Buckell, the Cannings brothers, Guppy, Spencer and Scudder. Much of this work occurred in the Cariboo, Chilcotin, Kamloops, Merritt and Hat Creek regions, and results have been published in various faunistic (e.g. Scudder 1993) and systematic papers. More recently, there has been considerable insect sampling in the South Okanagan, much of this associated with the conservation of the potentially rare and endangered species and habitats there.

Cannings (1989) made a nine-year study of the robber flies of *Festuca* grasslands near Penticton. As part of the South Okanagan Conservation Areas Program, and sponsored by the Royal BC Museum, Blades and Maier (1996) published the results of a survey of grassland and montane arthropods around Mount Kobau carried out in the summer of 1991. A sampling transect from low to high elevation produced 1101 species; 12 of these were new to Canada, 12 were new to BC and two were undescribed. Subsequently, a collaborative study of the impact of livestock grazing on the Antelope-brush (*Purshia tridentata* (Pursh) DC) community was initiated; in 1994-95, Scudder studied the ground-dwelling arthropods at nine sites between Osoyoos and Vaseux Creek. The sites had different livestock grazing histories, and analyses to date show that some of the species at risk are affected by grazing, while others are not (Scudder 2000). Also, while Heteroptera diversity varies with grazing impact, ant (Heron 2001) and orthopteroid insect (S. Liu, pers. comm.) diversity does not.

In 1996, pitfall trap sampling of ground-dwelling arthropods was extended to the Chopaka and White Lake areas to examine diversity in habitats potentially suitable for the endangered Sage Thrasher. Insects were also surveyed in areas inhabited by Burrowing Owls, and their crop pellets were analyzed; they contained a high proportion of beetle remnants, especially parts of carabid, silphid and tenebrionid beetles.

In 1997-1998 pitfall trapping was continued in and around the South Okanagan to document the species of management concern that were actually confined to the South Okanagan Valley. Most were found not to occur outside the valley.

The shrub-steppe at the Desert Centre in Osoyoos has been sampled to determine changes in the ground-dwelling arthropod fauna associated with both the removal of livestock grazing and attempts at habitat restoration. Samples were taken during two years of grazing as well as after livestock were removed in 1998.

Following a number of years of pitfall trapping of arthropods associated with the Antelope-brush community on the Haynes Lease Ecological Reserve near Osoyoos, first by S.G. Cannings and then Scudder, Scudder has studied the recovery of the arthropod fauna in this community following its virtual destruction by fire on 9 July 1993. Scudder (2001) reported the fallout of airborne insects onto the reserve in the first three weeks after the fire; the highest rate was 1.768 billion/km^2/24 hrs, recorded on 22-23 July.

OTHER SURVEYS

Brooks Peninsula and other Coastal Surveys

Cannings and Cannings (1997) reported on the terrestrial arthropods collected during the RBCM's 1981 interdisciplinary expedition to study the presumed ice age refugium of the Brooks Peninsula, on the northwest coast of Vancouver Island. Over a two-week period in August, 420 species of insects in 15 orders and 139 families were collected. In addition, 34 species of spiders and 22 of oribatid mites were identified. The project found 31 species and 4 genera new to science.

The RBCM has organized other, smaller interdisciplinary surveys to the north coast. In 1950, G.C. Carl, then the Director of the Provincial Museum, along with G.A. Hardy and other colleagues visited the Scott Islands off northern Vancouver Island to study the biogeography of these remote sites (Carl *et al.* 1951). They collected a small number of insects and other terrestrial invertebrates. In 1987 the RBCM visited Zayas and Dundas islands near the Alaska border, and the Tatshenshini River drainage in 1992.

Since the 1980s, there has been some specialized collecting on the Queen Charlotte Islands by R.A. Cannings, G.G.E. Scudder and others. D.H. Kavanaugh (California Academy of Sciences), in particular, has studied the carabid beetle fauna of the islands, first visiting them, accompanied by D.H. Mann, in July 1981. In 1986 he joined Scudder and other biologists on a survey of the biota of mainland and island localities between Vancouver and Prince Rupert. This coastal expedition aimed to confirm that the species endemic to the Queen Charlotte Islands were actually confined to the islands; most were found to be so restricted. In a monograph on the ground beetles of the Queen Charlottes, Kavanaugh (1992) listed collection data and assessed the composition, affinities and origin of the fauna.

Lepidoptera Surveys

In 1995, the BC Conservation Data Centre organized butterfly surveys to document the status of these insects in two conservation hot spots -- southeastern Vancouver Island (Shepard 1995) and the Okanagan-Similkameen valleys (S.G. Cannings, pers. comm.). Subsequently, Shepard studied the butterflies of the Peace River Lowlands (Shepard 2000) and Kondla (1999) surveyed the butterflies of south-facing slopes along the Pend d'Oreille River.

Fischer *et al.* (2000) conducted a major survey of the macrolepidoptera of the Cariboo-Chilcotin grasslands and grassland-forest interface, and reported an impressive 538 species. This is 96 per cent of the estimated total number of species in the study area. A voucher collection of over 2500 specimens was deposited at the RBCM.

These surveys contributed to the data analyzed in the 'Butterflies of British Columbia' (Guppy and Shepard 2001), the definitive work on the butterflies of the province.

Cave Surveys

Caves often contain little-known, rare and endemic species and are often threatened by groundwater changes and other disturbances. A 1995 survey initiated by the BC Conservation Data Centre examined caves on Vancouver Island (S.G. Cannings, pers. comm.). Results are not fully compiled. The first females of *Parasimulium melanderi* Stone were discovered; these rare simuliids throw light on the origins of the black fly family (Borkent and Currie 2001).

CONSERVATION

The history of insect conservation in BC is short. The first published reference to endangered insects in the province may be Scudder's (1980) symposium presentation on the Osoyoos Arid Biotic Area, in which he listed some representative invertebrates along with vertebrates and plants confined to this endangered ecosystem and emphasizes the need for conservation of all of these populations. Later, he prepared a preliminary list of the arthropod species that might be at risk in the South Okanagan (Scudder 1992). Cannings (1990) discussed the diversity of insects on a provincial scale, outlined the problems in determining conservation risk for them, and presented a short sample list of potentially endangered or threatened species. Later, Guppy *et al.* (1994) and Guppy and Shepard (2001) listed species of butterflies and skippers of conservation concern in the province.

A major problem in developing defensible lists of invertebrates of conservation concern is the lack of comprehensive inventories. Even in supposedly well-known groups such as butterflies or dragonflies, species known from only one or two localities may be subsequently discovered to be widespread, or at least much more common than the previous collection records had indicated. But with very limited resources, the common question is, where should we start?

To help address this question, Scudder was contracted by the provincial government to develop a list of inventory priorities, and out of this work two publications emerged. One (Scudder 1994) was an annotated list of 818 terrestrial and freshwater invertebrates that, on the basis of limited known occurrence or restriction to obviously endangered habitats or ecosystems, were potentially rare and/or endangered. This list included 168 species endemic to the province (based on collection information at that time) and an additional 203 species restricted to BC in Canada. The other publication (Scudder 1996) gave a list and discussion of inventory priorities, a discussion of sampling methods and resources needed, a list of taxonomic experts, and a series of annotated lists that divided the species noted in Scudder (1994) by ecoprovince.

THE RED AND BLUE LISTS

The Red and Blue lists of species of conservation concern were originally developed for vertebrates by the Wildlife Branch in the provincial Ministry of Environment, Lands and Parks. The British Columbia Conservation Data Centre (CDC) began in 1991 as a cooperative venture of the BC Ministry of Environment, Lands and Parks, The Nature Conservancy (US), and the Nature Trust of British Columbia; it is now a section within the provincial Ministry of Sustainable Resource Management. The CDC assumed the role of assigning provincial status ranks to not only vertebrates, but to plants, plant communities, and invertebrates as well. The CDC assigns status ranks using a methodology that was created originally by The Nature Conservancy (US) and is now used by conservation data centres and natural heritage programs throughout North America and much of Latin America. The provincial Red (endangered or threatened) and Blue (vulnerable) lists of species and ecosystems are now translated directly from the CDC's ranks; up-to-date lists can be viewed or downloaded at the CDC's website (http://srmwww.gov.bc.ca/cdc/trackinglists/red_blue.htm).

All species of dragonflies, butterflies, and tiger beetles have been assigned ranks, and Scudder's (1994) list has been used to rank a number of other species where the status can be confidently assigned. Currently, 69 species of insects are on the Red List and 74 are on the Blue List. However, the problem of lack of inventories is so acute in most groups that the majority of uncommonly collected species cannot be assigned useful ranks.

The Red and Blue lists offer no direct legal protection to any species; they simply provide an account of the conservation status of species of concern within the province. Insects and other invertebrates are not considered 'wildlife' under the provincial *Wildlife Act*, so cannot be officially designated as Endangered or Threatened under that Act. However, under two more recent pieces of legislation, the *Forest Practices Code Act* and the *Fisheries Protection Act*, there is the provision for possible protection of the habitat of certain endangered insects. Under the Forest Practices Code, listed invertebrates that are deemed to be affected by forest or range practices may be designated as "Identified Wildlife" and have management practices for them specified for certain areas. A number of insects have been proposed for this designation, and have had preliminary management accounts written for them (K. Paige, pers. comm.).

NATIONAL DESIGNATIONS

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is a national body made up of representatives of federal government agencies and all provincial and territorial governments. COSEWIC has recently expanded its mandate to include Lepidoptera, the first insect order that it has considered. Status reports have been accepted and designations made for six BC species: *Euchloe ausonides* (Lucas) *insulanus* Guppy and Shepard (Extirpated), *Plebejus saepiolus* Boisduval *insulanus* Blackmore (Endangered), *Euphydryas editha* (Boisduval) *taylori* (W.H. Edwards) (Endangered), *Satyrium behrii* (W.H. Edwards) *columbia* (McDunnough) (Threatened), *Euphyes vestris* (Boisduval) (western population, Threatened), and *Danaus plexippus* (Linnaeus) (Special Concern). These designations come with no legal protection but, under the proposed federal *Species at Risk Act*, insect species designated by COSEWIC as threatened or endangered would be recommended to the federal cabinet for official designation under that Act. National designations are detailed at the COSEWIC website at http://www.cosewic.gc.ca/cosewic/default.cfm.

RECOVERY PLANS

Once a species is designated provincially or nationally, the next stage in its conservation is the development of a recovery strategy. To date, no recovery plans have been written for specific insect species. However, recovery plans for endangered or threatened insects from the south Okanagan-Similkameen and southeastern Vancouver Island-Gulf Islands areas are now being included in the work of two ecosystem recovery teams: the South Okanagan Ecosystem Recovery Team (now part of the South Okanagan-Similkameen Conservation Program) and the Garry Oak Ecosystem Recovery Team.

BIODIVERSITY MAPPING

One way to select areas for protection is to focus efforts on sites with concentrations of species diversity and rare species. Scudder, in his research on these hotspots of richness and rarity in the province, has assembled georeferenced databases for the known, specialist-determined specimens of Odonata, Plecoptera, Hemiptera (Prosorrhyncha = Heteroptera), Lepidoptera (butterflies), Megaloptera, Raphidioptera, and Neuroptera. Databases on other groups such as carabid beetles, water beetles and aphids are being prepared. Results obtained by mapping these data with WORLDMAP software show that the provincial insect richness and rarity hotspots are in the South Okanagan and southeastern Vancouver Island-Gulf Island areas. Concentrations of rare species and total species numbers seem to coincide, and they also match similar concentrations mapped for vascular plants and small mammals.

PROTECTED AREAS

Because there is little, if any, specific protection for insects and their habitats, the general conservation of habitat in parks and other areas plays a crucial role in insect conservation. Since 1991, the area of BC protected in 'protected areas' (that is, national or provincial parks, ecological reserves, and other protected areas that fall under the *Environment and Land Use Act*) increased from 5.74 million hectares to over 11 million hectares—over 12 per cent of the province's area (BC Ministry of Sustainable Resource Management 2001). However, the ecological representation of these protected areas remains less than ideal. Even though there was some initial effort to target ecological areas that had been poorly represented in the past, 68 per cent of ecosections still have less than 12 per cent of their area protected (BC State of Environment Reporting 2000). Furthermore, a number of ecosections where endangered species are concentrated, such as the Lower Mainland and southeastern Vancouver Island, still have less than 2 per cent of their area protected.

Data on rare insect species have contributed to the success of some conservation efforts. Most of the grassland inventories noted in the present paper were undertaken in conjunction with conservation planning and strategies for protecting threatened habitats in the Okanagan Valley. Several of these important grassland areas (e.g., Chopaka, Mt. Kobau, White Lake and Kilpoola Lake) have been preserved, either as parkland through provincial government processes, or by the Nature Trust and other conservation organizations. The results of the interdisciplinary Brooks Peninsula project were instrumental in the decision to create a provincial park there, as were the findings of the canopy studies in the Carmanah Valley. Scudder's inventories on Bodega Ridge on Galiano Island helped preserve that site, as did his aquatic surveys at Westwick and Rock lakes, now ecological reserves in the Cariboo-Chilcotin. Inventories in Burns Bog were designed to gather data for conservation purposes and, if present negotiations go well, this critical peatland may be protected in the future.

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An overview of systematics studies concerning the insect fauna of British Columbia

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INTRODUCTION

This summary of insect systematics pertaining to British Columbia is not intended as an historical account of entomologists and their work, but rather is an overview of the more important studies and publications dealing with the taxonomy, identification, distribution and faunistics of BC species. Some statistics on the known size of various taxa are also given.

Many of the systematic references to the province's insects cannot be presented in such a short summary as this and, as a result, the treatment is highly selective. It deals largely with publications appearing after 1950. We examine mainly terrestrial groups. Although

Geoff Scudder, Professor of Zoology at the University of British Columbia, at Westwick Lake in the Cariboo, May 1970. Scudder is a driving force in many facets of insect systematics in British Columbia and Canada. He is a world authority on the Hemiptera.
Photo: Rob Cannings.

we mention the aquatic orders (those in which the larvae live in water but the adults are aerial), they are more fully treated in the companion paper on aquatic insects in this issue (Needham *et al.*) as are the major aquatic families of otherwise terrestrial orders (e.g. the Dytiscidae in Coleoptera, Corixidae in Hemiptera, Culicidae in Diptera, and so on). However, when numbers of species are reported below for various orders or families, aquatic species are included. The classification used here follows Kristensen (1991) except that the so-called entognathous hexapods (e.g., Collembola) are treated as classes. A great benefit of this scheme is that it is based on a cladogram and is supported by phylogenetic discussion.

Danks (1979) summarized the insect fauna of Canada and indicated that there are about 54,000 insect species in the country, with almost half of these undescribed or unrecorded. Cannings and Cannings (1996) estimated that there are about 35,000 species in BC, over 60 per cent of the Canadian fauna.

Spencer (1952) briefly reviewed the status of knowledge of the insect orders in the province up to 1951. Since this, major advances have occurred in many, but not all, groups. The systematic overview of many groups in the Yukon (Danks and Downes 1997) is a useful basis for the study of the insect fauna of northern BC, even though collections from the region may be scattered or lacking. In an annotated list of the potentially rare and endangered species in BC, Scudder (1994) gave references to the available checklists, major monographs and keys useful for the identification of our insect fauna. Nadel (1996), Scudder (1996) and Biological Survey of Canada (1996) listed some systematic specialists able to identify BC material.

SYSTEMATIC SURVEY

Class Protura

Based on regional distributions elsewhere, Marshall (1993) estimated that 25 species of proturans should live in BC. However, only three species in two families have been reported: *Nipponentomon bifidum* Rusek, *N. kevani* Rusek and *Vesiculentomon marshalli* Rusek – all described from Douglas-fir forest near Shawnigan Lake (Rusek 1974). The North American genera were keyed by Copeland and Imadaté (1990); the world fauna was treated by Tuxen (1964).

Class Collembola

Spencer (1948a) published a preliminary list of the springtails known in BC. This was augmented by Skidmore (1995) who, in a recent checklist of the Collembola of Canada and Alaska, listed 145 species and 14 families from the province. This list, however, represented species from only a small number of localities and habitats, and omitted some recorded ones; for example, about 19 taxa listed by Battigelli and Marshall (1993) were not included. In addition, one more family and at least 25 other species, as well as several undescribed species, have since been collected in BC by J. Addison, H. Nadel and B. Baumbrough (J.A. Addison, *in litt.*; G. Marshall, *in litt.*). Marshall (1993) estimated 200 species occur in the province and noted that there is a desperate need for basic taxonomic and ecological studies in BC's soil fauna. A detailed and annotated checklist of the Collembola for the entire province is sorely needed; a good basis for such a work is the treatment of the North American fauna by Christiansen and Bellinger (1998).

Class Diplura

Three species of Diplura in two families are recorded in BC (Spencer 1952; Marshall 1993), but more are likely to occur (V.G. Marshall, *in litt.*). As well as the widely distributed *Campodea* and the japygid, *Evalljapyx sonoranus* Silvestri, recorded from Victoria, another japygid from the Gulf Islands and the Queen Charlotte Islands is apparently undescribed (M.A. Muegge, *in litt.*). Ferguson (1990a) provided a key to the families of Diplura and genera of Campodeinae in the United States.

Class Insecta

Order Archeognatha

The two families of jumping bristletails, the Machilidae and Meinertellidae, both occur in the province, but there is no current checklist. *Mesomachilis canadensis* Sturm (Machilidae) and *Nearctolinus auriantiacus* (Schoett) (Meinertellidae) are rarely collected species of grassland and dry forest communities in the Interior (Scudder 1994). A species of *Pedetontus* is common above high tide on rocky seashores on the south coast. New records and new species from BC have been published by Sturm (1991) and Sturm and Bach de Roca (1992) but these were not included in the available key to the genera of the contiguous United States (Ferguson 1990b).

Order Thysanura

Two alien species of bristletails, *Lepisma saccharina* Linnaeus (silverfish) and *Thermobia domestica* (Packard) (firebrat) commonly occur indoors in BC (Scudder 1994). Both are household pests. Ferguson (1990b) published a key for the identification of these and other species.

Order Ephemeroptera

Ten families and 92 species of mayflies are recorded in BC. Needham *et al.*, in a companion paper to this one, discuss systematic and ecological studies on the aquatic insects of the province.

Order Odonata

There are 87 species of dragonflies and damselflies known in the province. These are contained in ten families. Needham *et al.*, in a companion paper to this one, discuss systematic and ecological studies on the aquatic insects of the province.

Order Blattodea

Vickery and Scudder (1987) recorded 14 species of cockroaches in three families in BC, but probably fewer than five of these are established. *Blattella germanica* (Linnaeus) is the most common and has been reported throughout the southern part of the province (Vickery and Kevan 1985). All our species have been introduced from elsewhere through commerce (e.g. Belton *et al.* 1986) or from laboratory cultures; none live freely outside buildings except, perhaps, *B. germanica*, which is known to survive in refuse heaps. Vickery and Kevan (1985) provided keys for their identification.

Order Mantodea

There are only two species of mantids in the province, both in the family Mantidae -- the rare, native *Litaneutria minor* (Scudder) and the alien, introduced *Mantis religiosa* Linnaeus (R.A. Cannings 1987; Vickery and Scudder 1987). Both species are restricted to the Okanagan Valley, although recent specimens of *Mantis* from southern Vancouver Island suggest a population may be established there. Vickery and Kevan (1985) gave keys for identification and R.A. Cannings (1987) documented the occurrence and ecology of *Litaneutria.*

Order Isoptera

Three native and one introduced termite species live in BC. They are *Reticulotermes hesperus* Banks (Rhinotermitidae), *Zootermopsis angusticollis* (Hagen) and *Z. nevadensis*

(Hagen) (Termopsidae) and the alien *Cryptotermes brevis* (Walker) (Kalotermitidae) (Vickery and Scudder 1987). *Cryptotermes* occurs only in indoor colonies here. Beall (1931) and Spencer (1937a) wrote about the provincial species, but the most comprehensive early work was never published – J.K. Jacob's Masters thesis (Jacob 1938). Vickery and Kevan (1985) provided identification keys.

Order Grylloblattodea

Buckell (1925) first collected *Grylloblatta campodeiformis* Walker in 1925 under logs at 2286 metres elevation in the Selkirk Mountains near Invermere. The species was captured a second time in BC beneath rocks on a talus slope on Mt. St. Pauls (Mt. Paul) near Kamloops (Gregson 1938). This collection at only 427 metres elevation in dry forest on 14 November 1936 surprised entomologists, because earlier reports associated this unusual insect with high altitude habitats. Campbell (1949) detailed the circumstances of its occurrence at Kamloops and in this paper Spencer speculated that the *Grylloblatta* at Kamloops might be a separate race from the Rocky Mountain one.

Kamp (1973) made extensive collections of *Grylloblatta* throughout BC and the western United States; he considered the Kamloops populations to be the nominate subspecies, *G. c. campodeiformis*; this is also the opinion of V.R. Vickery (*in litt.*). Kamp (1973) also extensively studied the habits, habitats, temperature preferences, and comparative lipid composition of *Grylloblatta* and later described new species and subspecies from BC, namely *G. c. athapaska* Kamp from Stone Mountain, *G. c. nahanni* Kamp from the Cassiar Mountains and *G. scudderi* Kamp from Whistler Mountain in Garibaldi Provincial Park (Kamp 1979). All of these are potentially rare in BC (Scudder 1994). *Grylloblatta c. campodeiformis* is widely distributed and recently was collected commonly in both logged and unlogged terrain at high elevation forests in the Interior (D. Huggard, *in litt.*). Gregson (1996) gave a popular summary of *Grylloblatta* in the province. The species and subspecies were keyed by Vickery and Kevan (1985).

Order Dermaptera

Four alien species of earwigs in three families are reported from BC (Vickery and Scudder 1987); they were keyed by Vickery and Kevan (1985). The species are: *Anisolabis maritima* (Bonelli) and *Euborellia annulipes* (Lucas) (Anisolabididae), *Labia minor* (Linnaeus) (Spongiphoridae) and *Forficula auricularia* Linnaeus (Forficulidae). *Anisolabis* frequents ocean beaches on the southwest coast; *Forficula* is the common earwig, an irritant to many gardeners.

Order Orthoptera

Early studies on the ecology and systematics of the Orthoptera in the province were published by Buckell (1921, 1922, 1924, 1925), Handford (1961), and Treherne and Buckell (1924a, 1924b). Spencer (1958a) outlined the natural control complex affecting grasshoppers in Southern Interior grasslands. He also described the habits, larval stages and economic importance of two nemestrinid flies that parasitize the grasshoppers in this region (Spencer 1958b). More recently, Vickery and Nagy (1973) documented additional ecological information on local species and Scudder and Kevan (1984) published an updated list.

In the most recent annotated checklist of the Orthoptera in Canada, Vickery and Scudder (1987) listed 117 species in 12 families from the province. Of the 40 species of Ensifera (katydids, crickets) listed, 5 are adventitive (recorded but not established) and one is an alien introduced species. Among the 77 Caelifera (grasshoppers), 2 are adventitive. Eleven Orthoptera species in BC are possibly rare (Scudder 1994).

Vickery and Kevan (1985) published a monograph on the fauna, and Otte (1981, 1984) provided invaluable additional information. Although the species are relatively well studied, the identity of some is still in doubt. For example, the Jerusalem Cricket recorded in BC as *Stenopelmatus fuscus* Haldeman is actually an undescribed species and the identities of *Gryllus* species need clarification (D. Wiesmann, pers. comm.). In fact, the correct identity of all material in collections in BC needs verification.

Order Plecoptera

Nine families of stoneflies containing 132 species are recorded in BC. Needham *et al.*, in a companion paper to this one, discuss systematic and ecological studies on the aquatic insects of the province.

Order Psocoptera

Although the bark lice have not been well studied in BC, 22 species in 13 families have been recorded (Mockford 1993). This work supplies identification keys, but determinations are difficult.

Order Phthiraptera

The bird lice (Amblycera) and mammal lice (Anoplura) were favourite groups of G.J. Spencer, who published the original lists of our fauna. The Amblycera were examined by Spencer (1928, 1948b, 1957) and Ballard and Ring (1979). The most modern treatment of bird lice in Canada (Wheeler and Threlfall 1989) listed four families, 168 species and subspecies and their known hosts in BC. Emerson (1972) is also a useful reference for bird lice.

Spencer (1966) published an annotated list of the Anoplura of BC, and some of the entries were corrected by Kim *et al.* (1986), who also provided identification keys. Twenty-six species in 8 families are known from the province. Both Spencer (1966) and Kim *et al.* (1986) listed the known hosts.

Order Thysanoptera

Chiasson (1986) recorded 44 species of thrips in 3 families in BC. The fauna has not been well studied.

Order Hemiptera

Following the many early records of Hemiptera from BC published before 1920 in the 'Annual Report of the Entomological Society of Ontario', Parshley (1919, 1921), Stoner (1920, 1925), Downes (1924), and Torre-Bueno (1925) reported other species from the province.

Downes (1927), the first true hemipterist to intensively survey the provincial bug fauna, produced a complete checklist. Subsequently, many additions have been published, including those by Downes (1935, 1957), Scudder (1960, 1961a, 1961b, 1985, 1986, 2000) and Schwartz and Scudder (1998, 2000). Waddell (1952) made a list of the Hemiptera from the Kootenay Valley, but this lacked precise locality records.

Published papers on the scale insects in the province include Venables (1939) and Kozar *et al.* (1989), while Kitching (1971) listed and keyed the Psyllidae. Gillespie (1985) published a paper on whiteflies. Following a series of 19 papers on aphids by A.R. Forbes and C.K. Chan (with various co-workers) that appeared from 1973 to 1989, Forbes and Chan (1989) published a list of aphids and host plants known from BC. Two more papers (Forbes and Chan 1991; Chan and Frazer 1993) followed. The recent checklist of Canadian and Alaskan species of Hemiptera (Maw *et al.* 2000) listed 580 species of Sternorrhyncha (aphids, psyllids, whiteflies and scales), 534 Clypeorrhyncha (cicadas, leafhoppers, froghoppers and treehoppers), 79 Archaeorrhyncha (planthoppers) and 815 Prosorrhyncha (true bugs), for a total of 2008 species in 72 families. Additional species new to BC have been added since, and several new species are being described.

The Heteroptera (Prosorrhyncha) of the Montane Cordillera Ecozone were listed by Scudder (1998), and the Clypeorrhyncha and Archaeorrhyncha by Hamilton (1998). Several monographs on the Canadian fauna are available to aid the determination of BC species. These include treatments of the minute pirate bugs (Anthocoridae) (Kelton 1978), the flatbugs (Aradidae) (Matsuda 1977), the spittlebugs (Cercopidae, Clastopteridae) (Hamilton 1982), the prairie plant bugs (Miridae) (Kelton 1980), stink bugs (Pentatomidae) (McPherson 1982), and genera of aphids (Aphidoidea) (Foottit and Richards 1993). References to other literature are given by Maw *et al.* (2000).

Order Neuroptera

Seven of the eight families of Neuroptera reported from BC are terrestrial – the Berothidae, Chrysopidae, Coniopterygidae, Hemerobiidae, Mantispidae, Myrmeleontidae and Polystoechotidae. The Sisyridae, whose larvae feed on sponges, are aquatic. Spencer (1942) gave preliminary lists of all families and most have been investigated in detail since then, resulting in a list of at least 66 terrestrial species.

Lomamyia occidentalis (Banks) is the only species of Berothidae known in the province, recorded from Lytton by Spencer (1942). The green lacewings (Chrysopidae) have been investigated in detail by Garland (1982, 1984, 1985, 2000, 2001); 18 species in 7 genera are now reported, some of which may be considered rare (Scudder 1994). The brown lacewings (Hemerobiidae), studied by Klimaszewski and Kevan (1985, 1987, 1988, 1992), are represented by 33 species in 5 genera; some of these may be at risk (Scudder 1994). In his monographs on the Coniopterygidae, Meinander (1972, 1974) listed only four species from the province, but the family has been little studied here.

Two species of Mantispidae occur, *Climaciella brunnea* (Say) and *Mantispa pulchella* (Banks), the former from Vancouver Island to the Rockies, the latter only in the Okanagan Valley. *Mantispa pulchella*, at least, may be at risk in the province because of its rarity and limited distribution. In BC there are five species of antlions in three genera, but only four species have been named with certainty; works useful in the identification of Myrmeliontidae include Banks (1927) and Stange (1970). The family Polystoechotidae is represented by a single rare species, *Polystoechotes punctatus* (Fabricius).

Order Raphidioptera

Spencer (1942) listed two species of snakeflies, but the recent world revision of the Raphidioptera by Aspöck *et al.* (1991) indicates that eight species in two families occur in the province. Of these, *Agulla adnixa* (Hagen) is the most common and widespread. *Agulla bicolor* (Albarda), known only from the Osoyoos area, and *A. crotchi* Banks, collected only from Summerland in BC, may be at risk.

Order Megaloptera

The Megaloptera is a small order in BC; this aquatic group includes the dobsonflies (Corydalidae) and the alderflies (Sialidae). The former family contains three species, the latter has five recorded in the province. Needham *et al.*, in a companion paper to this one, discuss systematic and ecological studies on the aquatic insects of the province.

Order Coleoptera

The most recent checklist of the beetles of Canada and Alaska (Bousquet 1991) listed 3626 species in BC, which is about half the total number in Canada. One-hundred families are represented; the ten most speciose are the Staphylinidae (581), Carabidae including the tiger beetles (483), Curculionidae (261), Elateridae (194), Chrysomelidae (181), Dytiscidae (167), Cerambycidae (145) and Scolytidae (134), Coccinellidae (94) and Scarabaeidae (88). There are probably another 1200 or more species still unrecorded in the province.

This list, of course, rests on many earlier works in the province. Spencer (1952) noted a few of them, and Hatch (1952) added detail. Mentioned are the studies of Keen (1895) in the Queen Charlottes, the long list by Auden (1925) from Midday Valley near Merritt, the collections of Clark (1948, 1949) around Terrace and those of Hardy, especially in the Cerambycidae and Buprestidae, on Vancouver Island (1942, 1944, 1950) and elsewhere (1948). The large collections and studies of Stace-Smith (1929, 1930), R. Hopping (1922) and G. Hopping (1932, 1937) were also critical. The most significant publication on the province's beetles remains Hatch's monumental five-part treatise (Hatch 1953, 1957, 1962, 1965, 1971) keying and describing all the species in the Pacific Northwest (including southern BC) known at that time. Arnett (1983) compiled North American species, and most genera can be identified using Arnett (1968); Bousquet (1991) highlighted generic revisions and good sources for species keys. Scudder (1994) listed 114 rare beetle species and subspecies in the province. Campbell (1979) summarized the Canadian fauna. Anderson (1997) compiled the fauna of the Yukon; the biogeography of many BC species, especially northern ones, is clarified by this work.

The Carabidae has been a favourite family of study in the province, and much of the systematic and ecological work on the ground beetles has depended on the identification power of the keys and descriptions in Lindroth (1961-1969). Wallis (1961) wrote a monograph on the tiger beetles (Cicindelidae) of Canada and Freitag (1999) provided an up-to-date taxonomy of the group, which is placed by many in the Carabidae (see Bousquet 1991). A sampling of significant papers revising ground beetle groups that deal with BC species include Ball (1966) (*Pterostichus* subgenus *Cryobius*), Bousquet (1988) (*Dyschirius*), Erwin (1970) (*Brachinus*), Goulet (1983) (*Elaphrus*) and Maddison (1993) (*Bembidion* subgenus *Bracteon*).

Kavanaugh examined the biogeography of the Carabidae, especially of the Queen Charlotte Islands (1992) and, in the genus *Nebria*, throughout northwestern North America (Kavanaugh 1980, 1988). Spence and Spence (1988) studied the introduced ground beetles of western Canada and the influence humans have had on their distribution. Some of the surveys of carabids in the province are noted in the companion paper on collections, surveys and conservation (Cannings *et al.*) in this issue.

Anderson and Peck (1985) treated the Silphidae and Agyrtidae of Canada and Campbell (1968) revised the Micropeplidae. The extensive provincial diversity of the Leiodidae (small scavenger beetles) is not well known, but some genera have been revised, for example, *Anisotoma* (Wheeler 1979). Modern revisions of many genera of the huge family Staphylinidae occurring in BC are available, for example, *Bledius* (Herman 1986), *Quedius* (Smetana 1971) and *Tachinus* (Campbell 1973, 1988), although large gaps remain. The largest Canadian subfamily, the Aleocharinae, is especially poorly known, although some genera have been studied, such as *Aleochara* (Klimaszewski 1984). Scudder (1994) listed several rare species; *Pseudohaida rothi* Hatch (Omaliinae) was found for the first time in Canada during the canopy studies in the Carmanah Valley (Campbell and Winchester 1993).

J. Cooper is currently revising the Scarabaeidae of Canada and Alaska (Bousquet 1991). The dung beetles of the Aphodiinae are common in the province; Gordon and Cartwright (1988) reviewed the tribe Aegialiini. The Buprestidae of Canada and Alaska was revised by Bright (1987); this work includes keys to, and descriptions of, all the 88 known species in the province. Everson (1978) recorded 23 species from southern Vancouver Island. The Ptilodactylidae, with only three species in Canada, is represented in

BC only by *Ptilodactyla serricollis* (Say); Cannings and Fisher (1987) recorded the species for the first time in the province. The Elateridae are speciose in BC, but there is no overall treatment. However, Lane (1952) summarized earlier work and produced a preliminary list of 150 species. Becker (1956, 1979) treated several large genera, including *Agriotes* and *Athous*. The introduction of two European species of *Agriotes* was reported by Vernon and Päts (1997). The most common BC lampyrids, those in the genus *Ellychnia,* do not produce light as adults, and few people have ever reported fireflies in the province. However, there are two light-producing species recorded in the literature, *Pyropyga nigricans* (Say) and *Photuris pennsylvanica* (DeGeer) (Bousquet 1991) and a study by R.A. Cannings and B. McVickar has turned up one or two more.

BC has at least 94 species of Coccinellidae, more than any other Canadian province. Some of these have been introduced for biological control, and the interaction of native and alien species is of interest. The taxonomy of BC (and nearctic) species is rather well known, owing to the monograph of Gordon (1985). Belicek (1976) examined the western species and analysed the biogeographic relationships between those in Alberta and BC.

The pioneering work of Hardy in the study of BC's Cerambycidae was mentioned earlier. The family in the province is large; the 145 species represent 40 per cent of the Canadian fauna. Linsley (1962a, 1962b, 1963, 1964) and Linsley and Chemsak (1972, 1976, 1985) treated the North American fauna. With 181 species in the province, the Chrysomelidae is even larger. The Chrysomelinae were reviewed by Wilcox (1972). Numerous genera common in BC have been revised, for example *Chrysomela* (Brown 1956), *Cryptocephalus* (White 1968) and *Plateumaris* (Askevold 1991).

Bright (1992) revised the Canadian curculionoid families, except Curculionidae and Scolytidae. Anderson (1988a) documented the weevils of the Queen Charlotte Islands and the Montane Cordillera Ecozone in the southern Interior (Anderson 1998). Some revisions that include significant provincial taxa deal with the Rhynchaeninae (Anderson 1989), the Cleonini (Anderson 1988b), and genera such as *Dorytomus* (O'Brien 1970) and *Tychius* (Clark 1971). The Scolytidae have a high profile in BC forestry and are well known taxonomically; Bright (1976) revised the Canadian species. Duncan (1987) provided an identification guide to *Dendroctonus* in the province.

Order Strepsiptera

The Strepsiptera are endoparasites of Hemiptera and solitary *Andrena* bees, often classified with the Coleoptera. Although there are a number of unpublished observations in the province, only two species in the Stylopidae, *Stylops advarians* Pierce, and *S. leechi* Bohart, are recorded by Bousquet (1991). Kenner (*in litt.*) collected *Stylops shannoni* (Pierce) parasitizing *Andrena hippotes* Robertson in a Richmond garden.

Order Hymenoptera

The excellent treatment of the Hymenoptera families edited by Goulet and Huber (1993) keyed all the BC families of this huge order and gave many references to systematic studies. Krombein *et al.* (1979) is the latest catalogue of the North American fauna; it included taxonomic details and brief summaries of distribution and biology of the species. Masner (1979) summarized the Canadian fauna. Nevertheless, no complete checklist of species has ever been produced. The number of species, even described ones, in the province has not been calculated, but our estimate of recorded and unrecorded species is about 10,000 in around 70 families. The Hymenoptera is probably the largest order in BC, and contains the largest number of unrecorded and undescribed species. The diverse parasitic forms are especially inadequately known. Scudder (1994) listed 79 rare species that may be of management concern.

Spencer (1952) gave the most important early compilations of provincial species: the lists of ants (Buckell 1927, 1932), bees (Buckell 1949, 1950, 1951), vespid wasps (Buckell and Spencer 1950), sphecid wasps (Spencer and Wellington 1948) and ichneumonid wasps (Guppy 1948).

The fauna of Symphyta (sawflies and relatives) in the Montane Cordillera Ecozone (the southern half of the BC Interior) was nicely summarized by Goulet (1998). The 254 species recorded represent 69 of the 119 Canadian genera. Most of the species (95 per cent) are native and about 17 per cent occur nowhere else in Canada. The alien fauna arrived mainly through Pacific coastal ports and via the nursery trade. Sawfly systematics is generally up-to-date for most BC genera. Goulet (1992) covered all the fauna at the generic level and many other groups have recently been treated. Goulet (1986) studied the Dolerini (Tenthredinidae) and Middlekauf (1984) examined the Orussidae. Smith published monographs on several subfamilies of the Tenthredinidae, including the Allantinae (Smith 1979) and revised genera such as *Nematinus* (Smith 1986) and *Arge* (Smith 1989). Examples of other genera treated are *Deda* (Gibson 1980a), *Fallocampa* (Wong 1977), *Macrophya* (Gibson 1980b) and *Tenthredo* (*arcuata* group) (Goulet 1996).

Basic taxonomic studies of the vast superfamilies Ichneumonoidea, Proctotrupoidea, Chalicidoidea, Cynipoidea and others that relate to species in Canada and BC are meagre. Examples of classificatory studies in the Parasitica include works on the Braconidae by Marsh (1965), Mason (1978, 1981) and Quicke and Sharkey (1989) and on the Ichneumonidae by Barron (1976) and Townes (1969-1971). Finlayson (1990) and Gillespie and Finlayson (1983) studied the larvae of the Aphidiidae and Ichneumonidae, respectively, and made significant contributions to the systematics of these groups. Mackauer (1968), Mackauer and Campbell (1972) and Smith *et al.* (1999) also examined various aspects of the systematics of the Aphidiidae, important parasitoids of aphids, in BC. Masner (1979) noted that the Proctotrupoidea in North America is, perhaps, the least known of the superfamilies of parasitic Hymenoptera – about 90 per cent of the species are undescribed or unstudied; he (Masner 1976) revised part of the Diapriidae in North America. In the Platygastroidea, Masner (1980) keyed the genera of the Scelionidae of the Holarctic. Yoshimoto (1984) outlined the classification and identification of the Canadian families and subfamilies of chalcidoid wasps. Darling (1983) revised the nearctic species of *Euperilampus* (Perilampidae) and keyed the New World genera of Chrysolampinae (Pteromalidae) (Darling 1986). Heraty (1985) keyed the genera and revised the species of Eucharitinae (Eucharitidae) in North America and Huber (1988) examined *Gonatocerus* in the Mymaridae.

The hymenopterous parasitoids of various forest pests have been documented in BC: for example, 13 species attacked the black-headed budworm on Vancouver Island (Gray and Shepherd 1993) and 9 parasitized, or were hyperparasites in, the larch casebearer (Andrews and Geistlinger 1969).

The aculeate Hymneoptera are diverse in the province. Omitting the bees, Finnamore (1998) tallied 408 species in BC, about 45 per cent of the known Canadian fauna. He calculated that although 243 species are recorded from the Montane Cordillera Ecozone in BC (this includes all of the southern Interior), this is about 70 per cent of the true total. About two-thirds of aculeate wasps found in the Montane Cordillera Ecozone prefer grasslands or the dry, warm habitats found on lower south-facing slopes; 69 species (25 per cent) are restricted to the Okanagan Valley (Finnamore 1998). The superfamily Chrysidoidea is represented in BC by four families; relevant systematic works include Bohart and Kimsey (1982) (Chrysididae), Evans (1978) (Bethylidae), Olmi (1984) (Dryinidae) and Olmi (1995) (Embolemidae).

The five BC families of the Vespoidea are striking and mostly familiar insects. The Tiphiidae were treated by Allen (1965, 1968, 1971). There are few relevant works for the

Mutillidae; only Finnamore (1998) and the early paper by Mickel (1928) dealt with the BC species. Although there were a few preliminary lists of Formicidae from the province (e.g., Buckell 1932, Blacker 1992), the descriptions, keys, and distributional information provided by Naumann *et al.* (1999) are the most detailed data available on the ants in BC. The spider wasps of the family Pompilidae were, in part, dealt with by Townes (1957) and the vespid wasps by Akre *et al.* (1980), Miller (1961), Carpenter and Cumming (1985), Cumming (1989) and others. Gerber (1990) documented the spread into BC, in the 1980s, of the introduced yellowjacket wasp, *Paravespula germanica* (Fabricius) and Cannings (1989a) recorded an Asian hornet, *Vespa simillima xanthoptera* Cameron, on Vancouver Island.

The Apoidea of BC can be split into two general groups, the sphecid wasps and their relatives, the bees. The Sphecidae are diverse, often spectacular and especially abundant in the dry Interior; 174 of the 189 species recorded in BC are found in the Montane Cordillera Ecozone (Finnamore 1998). Revisions relevant to BC species include those of the tribes Sceliphronini and Sphecini (Bohart and Menke 1963) and the genera *Crabro* (Bohart 1976), *Cerceris* (Ferguson 1984), *Mimesa* (Finnamore 1983) and *Tachysphex* (Pulawski 1988). The genera of bees in North America were detailed and keyed by Michener *et al.* (1993). Some useful bee studies include those of the huge genus *Andrena* (Andrenidae) by LaBerge (1986-1989), the Anthophorini (Brooks 1988), the genera of New World Megachilini (Mitchell 1980) and *Bombus* (Milliron 1971). Although much bee research is done in BC at M. Winston's laboratory at Simon Fraser University, it is mostly in fields other than systematics. The diversity of native bee species pollinating berry crops in the Fraser Valley was examined; 13 species were recorded, most of them bumblebees (Winston and Graf 1982).

Order Mecoptera

The genus *Boreus* in the Boreidae is the only known taxon of Mecoptera in BC. These snow scorpionflies are small flightless insects that most commonly are found hopping on the snow in winter. Penny (1977) published a monograph on the family; the five named species in BC were included in the descriptions and identification keys. D. Blades (pers. comm.), now studying the genus in the province, believes that there is at least one undescribed species from the south coast. *Boreus elegans* was chosen as the emblem of the Entomological Society of BC and the Society's newsletter is named for the genus (Cannings 1981).

Order Siphonaptera

Spencer (1936, 1937b) and Wagner (1936) published the main early papers on the fleas in BC. Holland (1985), in his superb work on the group in Canada, Alaska and Greenland, listed 6 families, 98 species and 6 additional subspecies in the province. There apparently is some endemism; for example, *Megarthroglossus sicamus* Jordan and Rothschild is restricted to Bushy-tailed Woodrats (*Neotoma cinerea* (Ord)) in the Dry Interior. Fleas transmit bubonic plague to mammals in the Interior. The bacterium was recorded in Yellow-bellied Marmots (*Marmota flaviventris* (Audubon and Bachman)) in 1950 (Holland 1985) and in woodrats and some carnivores in 1988 (D. Nagorsen, pers. comm.)

Order Diptera

The Manual of Nearctic Diptera (McAlpine *et al.* 1981, 1987, McAlpine and Wood 1989) is the major single resource for information on systematics and biology of North American (and BC) Diptera. Illustrated keys identify adult (and often immature) specimens to family and genus, citations for generic revisions are given and phylogenetic hypotheses for higher categories are outlined. Subsequently, significant advances in higher classification directly relevant to BC studies were published by dipterists at the Canadian National Collection of Insects, Arachnids and Nematodes in Ottawa (Wood 1991, Sinclair *et al.* 1994, Cumming *et al.* 1995). The taxonomic and distributional status, to the early 1960s, of many BC species was outlined by Stone *et al.* (1965). Stone (1980) also summarized the history of North American dipterology, and included many major publications and biographies of workers important in naming the province's fly species. The work of McAlpine (1979), who summarized the Canadian fauna, and Cole (1969) has relevance to most fly families in BC, but no complete checklist of species has ever been developed and it is unclear how many species are known for the province. Our estimate of recorded and unrecorded species is about 8500 in almost 100 families. Scudder (1994) listed 76 species that are possibly rare and threatened.

Spencer (1952) mentioned the pioneering work of Osburn (1908), Sherman (1920), Garrett (1925) and Spencer (1943, 1948c). Spencer (1948c) listed the Tipulidae known at that time. A most interesting genus in this huge family is *Chionea*, wingless crane flies that walk about on the snow. These are common in the province and have been monographed by Byers (1983); S.G. Cannings (1987) added *C. macnabeana* Alexander to the Canadian list. *Cramptonomyia spenceri* Alexander, named after the famous University of BC professor who discovered it, is the sole member of the Pachyneuridae in Canada; the larvae live in dead red alder (*Alnus rubra* Bong.) logs. Its biology and distribution were recorded by Vockeroth (1974) and Cannings and Cannings (1979).

The Bibionidae are by far the most common Diptera fossils in the abundant Eocene shales of the province. Rice (1959) gave an overview of many of the species; 20 of 22 are in the genus *Plecia*, which today is largely a tropical taxon. Cecidomyiidae and Mycetophilidae are huge families in the forests of BC but remain largely unknown despite their importance in plant and soil health. A little work has been done, however. For example, in the Cecidomyiidae, Tonks (1974) found a species of *Oligotrophus* new to Canada on junipers on Vancouver Island; Coher (2000) made some changes to the taxonomy of the mycetophilids based on collections from Winchester's surveys of forest insects in the Carmanah Valley.

Curran (1927) and McFadden (1972) listed a number of the Stratiomyidae in the province. Although many of its species develop in wetlands, we have not included the Tabanidae in the aquatic insect chapter, but deal with the family here. The deer and horse flies are of great importance because the females suck mammalian blood. Both Teskey (1990) and Turner (1985) are useful for identifying BC species. Teskey (1985) also dealt with some of the immature stages. Irwin and Lyneborg (1980) described and keyed the nearctic genera of the Therevidae. The single member of the Apioceridae in Canada, *Apiocera barri* Cazier, one of the rarest of the province's flies from the sandy shrub-steppes of the South Okanagan, was included in a revision of the genus by Cazier (1982). The same locations support another rare fly, *Nemomydas pantherinus* (Gerstäcker), the sole species of the Mydidae in BC and one of only two in Canada. In the Asilidae, revisions of large genera such as *Cyrtopogon* (Wilcox and Martin 1936), *Efferia* (Wilcox 1966), *Lasiopogon* (Cole and Wilcox 1938) and *Dioctria* and related genera (Adisoemarto and Wood 1975) included references to species in BC. The various taxonomic works of Curran, for example, the designation and summary of the genus *Eucyrtopogon* (Curran 1923) also are relevant. Foxlee's (1942) intensive collecting around Robson in the Columbia Valley of the West Kootenay region resulted in specimens that are still the main source of our knowledge for that region. Adisoemarto (1967), in his overview of the Asilidae of Alberta, included records from the province. Cannings (1994) updated the species list for the region and published an account of the species found in a grassland typical of mesic sites at low elevations in the southern Okanagan Valley (Cannings 1989b). He has studied the taxonomy and biogeography of *Rhadiurgus* (Cannings 1993) and the large genus *Lasiopogon* (Cannings 2002). Cannings' (1997) work on the fauna of the Yukon gave a picture of the probable robber fly fauna of BC's northern regions. Cannings (1998) outlined the fauna of the Montane Cordillera Ecozone, covering much of the Interior. There remains much work to be done on the provincial fauna of the two very diverse families of the Empidoidea. Spencer (1943) made an early list of the Dolichopodidae, and Pollet and Cumming (1998) revised *Achalcus.* Sinclair studied the higher classification of the Empididae and reviewed *Trichoclinocera* (Sinclair 1994).

There is much more known about the large family Syrphidae in the province. Osburn (1908) made an early list, added to by Allan (1969) and Morgan and Arrand (1971). Vockeroth revised a number of genera including *Paragus* (1986) and *Platycheirus* (1990) and published a monograph of the large subfamily Syrphinae (1992) – all vital for an understanding of the province's flower flies. Also in the Achiza, other genera have received relevant and useful revisions by students elsewhere; examples include *Gymnophora* (Phoridae) (Brown 1987) and *Pipunculus* (Pipunculidae) (Skevington and Marshall 1998).

Few acalyptrate families have been treated from a provincial perspective, let alone a Canadian one. Smith (1959) produced a preliminary list of the Conopidae of the province. In the Sphaeroceridae, Marshall and others have revised a number of genera, for example, *Spelobius* (Marshall 1985). The Canadian fauna of a handful of families has been analysed, including the Agromyzidae (Spencer 1969), the Micropezidae (Merritt and Peterson 1976) and the Piophilidae (McAlpine 1977). Likewise, in the calyptrate Cyclorrhapha, reference to the BC fauna is found in a number of works such as Hall (1948) for the Calliphoridae and Wood (1985) for the blondeliinine tachinids.

Order Trichoptera

There are 279 species of caddisflies in 15 families recorded in BC. Needham *et al.*, in a companion paper to this one, discuss systematic and ecological studies on the aquatic insects of the province.

Order Lepidoptera

The authoritative list of the Lepidoptera of North America that has been the basis of systematic study in BC for almost 20 years is Hodges *et al.* (1983). Munroe (1979) summarized the Canadian fauna. The recently published 'Butterflies of British Columbia' (Guppy and Shepard 2001) is the major single resource on the butterflies of the province. It thoroughly covers the description, distribution, taxonomy and status of the 187 species recorded in BC and provides an exhaustive bibliography of publications dealing with the systematics and biology of the fauna. The authors described eleven new subspecies and estimated that nine more peripheral species will be added to the provincial list. There are several older publications dealing with the butterflies on a broader geographical scale; the most useful is the recent 'The Butterflies of Canada' (Layberry *et al.* 1998). There is no modern treatment of the moths of the region, although the ongoing and detailed 'Moths of North America north of Mexico' (selected monographs are cited below under specific families) covers some important groups. Studies on the moth families of the province at the species level are sorely needed. Approximately 4000 species of Lepidoptera in about 60 families occur in BC. Scudder (1994) listed 61 species that are possibly rare and threatened. Guppy *et al.* (1994) and Guppy and Shepard (2001) gave details of the butterflies and skippers that are of conservation concern.

In Guppy and Shepard (2001), Shepard wrote an excellent account of the early history of Lepidoptera collections and systematics in BC, a history that goes back to 1850. The discussion focuses on butterflies and skippers, but it is a good source of historical papers on all BC Lepidoptera. The monumental three volume work by Edwards (1868-72, 1874-

84, 1887-97) was the earliest North American butterfly work that included some of the BC fauna; it is still of great taxonomic significance. Anderson (1904) published the first synthesis of BC material, followed by several provincial and regional lists culminating in Blackmore (1927). This was followed 24 years later by Llewellyn Jones' (1951) 'Annotated Check List of the Macrolepidoptera of British Columbia', which not only summarized the known distribution of each species, but included flight periods and larval food plants.

G.A. Hardy documented the Lepidoptera fauna of southern Vancouver Island in the 1950s and 1960s, and published a number of studies of the larval stages and life histories of both butterflies and moths in the 'Proceedings of the Entomological Society of British Columbia' (e.g., Hardy 1957, 1963). Also in the 'Proceedings' and the 'Journal' that succeeded it, a long series of annotated lists documented the forest insects of the province, and Lepidoptera played a large role (Ross and Evans 1957; Sugden 1968). Guppy (1956) studied the macrolepidoptera of Vancouver Island. Underhill surveyed the fauna of Manning Provincial Park (Harcombe and Underhill 1970) and Threatful (1989) studied the butterflies of Mount Revelstoke and Glacier National Parks. Kondla *et al.* (1994) documented the butterflies of the Peace River district and Kondla (1999) reported on the species he collected in the Pend d'Oreille Valley. Fischer *et al.* (2000) recorded the macrolepidoptera of the Chilcotin. Significant range extensions, including additions of butterfly and moth species to the province's fauna, have been recorded in the annual 'Field Season Summary' of the Lepidopterists' Society for over 50 years. Other recent inventory efforts are discussed in the paper by Cannings *et al.* on insect collections and surveys in this issue. The affinities of Yukon Lepidoptera were examined by Lafontaine and Wood (1997), throwing light on the biogeography of many BC forms. The introduction of alien Lepidoptera is documented in publications such as Gillespie and Gillespie (1982), which recorded 48 plant feeding species and their history in the province.

Numerous taxonomic and biogeographic studies have been published by BC butterfly specialists. Shepard published on the taxonomy of *Boloria* (Shepard 1975), *Parnassius* (Shepard and Manley 1998) and other taxa. Guppy (1986) studied geographic variation in the wing melanism of the butterfly *Parnassius phoebus* (Fabricius) and Troubridge and Parshall (1988) reviewed the *Oeneis polixenes* (Fabricius) complex. All this butterfly work is encapsulated in Guppy and Shepard (2001).

The moths of BC need much work, but many treatments of taxa of various sizes are scattered through the literature; those listed here are only a small sample. In the huge Gelechioidea, with many BC species, Landry (1991) has studied the North American Scythrididae and Hodges (1974) the Oecophoridae. The typical leafrollers of the Tortricoidea are represented in the province by the large, economically important Tortricidae; much of the work of interest deals with the population dynamics of spruce budworm taxa and the fight against codling moth, best discussed in other papers in this volume. The Pyraloidea is dominated by the family Pyralidae; much of the North American fauna was revised by Munroe (1972-1976). The coneworms of the genus *Dioryctria*, important in BC forests, were reviewed by Mutuura *et al.* (1969), Mutuura and Munroe (1972-1973) and Sopow *et al.* (1996).

In BC the Geometridae makes up most of the superfamily Geometroidea, and the family is abundant in provincial collections. Many taxa were reviewed by McGuffin (e.g., McGuffin 1988) and he also made important contributions to the description of larvae (e.g. McGuffin 1958). Bolte (1990) revised the genus *Eupethecia*. In the Bombycoidea, the tent caterpillars of the Lasiocampidae have received much attention, and were studied by Franclemont (1973). The Saturniidae includes some of our largest insects, the giant silkmoths, which are noticed by everyone who comes across them. The BC species were included in the revision by Ferguson (1971-1972) and in Tuskes *et al.* (1996). Cannings and Guppy (1989) recorded *Hyalophora gloveri* Strecker for the first time in BC and Morewood (2000) studied the colour pattern dimorphism in the more common *H. euryalis* (Boisduval). The hawkmoths of the Sphingidae in the superfamily Sphingoidea also attract the attention of the general public. The BC fauna is small (16 species) but spectacular. They are described and illustrated in Borkent and Greenway (1997). The nearctic species are treated by Hodges (1971).

The superfamily Noctuoidea is probably the largest in the order; its largest family, the Noctuidae, alone has about 2000 species in Canada (Munroe 1979). Hardwick (1970) studied the genera of the nearctic Heliothidinae and Lafontaine (e.g., 1987, 1998) revised parts of the family. He also discussed in detail the biogeographic history of *Euxoa* in western North America (Lafontaine 1982). The northern and Asian affinities of Beringian noctuids were examined by Lafontaine and Wood (1988); this puts the distributions of many BC species into perspective. Troubridge and co-workers have recently described a number of noctuid species from BC, including several *Oncocnemis* (Troubridge and Crabo 1998).

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Aquatic insects in British Columbia: 100 years of study

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INTRODUCTION

Aquatic habitats in British Columbia are diverse and numerous. BC is home to large rivers, small ponds, and lakes which vary tremendously in size, depth, and chemical composition (Northcote and Larkin 1963), as well as a variety of fens, marshes, and bogs (Rosenberg and Danks 1987). Not surprisingly, studies in aquatic insects have a long history in our Province. The status of entomological knowledge from 1901 to 1951 in BC was summarized by Spencer (1952), including short paragraphs on each of the aquatic orders. The history of many of the entomologists involved and their collections are highlighted in Hatch's (1949) charming summary of a century of entomology (1835-1948) in the Pacific Northwest.

In the past, provincial studies have emphasized the importance of freshwater fisheries, and these have been accompanied by benthic invertebrate surveys. In recent years, forestry-fisheries interactions have come to the fore. The role of insects in this interaction is creating a new interest in aquatic entomology. The current concerns over water quality and groundwater pollution will undoubtedly involve more study of aquatic insects as environmental indicators.

EPHEMEROPTERA

Since the outstanding and prolific work of J. McDunnough in the 1920s and 1930s on the mayflies of Canada, the only BC-wide survey of Ephemeroptera was conducted by Filmer (1964). Most records since then have been obtained incidentally during other faunal studies. A checklist of BC species was produced by Scudder (1976). McCafferty and Randolph (1998) published a Canadian mayfly compendium that added seven new species to Scudder's 1976 list, as well as containing two species that Scudder (1976) omitted as probable erroneous records, for a total of 92 species in BC. Since this new list was compiled without examining specimens from the Royal British Columbia Museum, the Spencer Entomological Museum, or the Fisheries Branch of the Ministry of Water, Land and Air Protection, these collections may contain more new records for the Province.

Locally, Wigle and Thommasen (1990) collected and recorded ecological notes on 26 species of mayflies in the Bella Coola and Owikeno Lake watersheds of mid-coastal BC.

One of these, *Epeorus nitidus* Eaton, was a new record for the Province. Another new record for BC, *Acentrella turbida* (McDunnough), was found there later (McCafferty *et al.* 1994). Zloty (1996) and Zloty and Pritchard (1997) collected at various southwestern BC locales in search of *Ameletus* species, and to date have found one, *Ameletus pritchardi* Zloty, new to the Province and to science. S. Salter (pers. comm.) recently collected a new mayfly species for the Province, *Caenis youngi* Roemhild, during some invertebrate surveys at Liard Hot Springs in northern BC. In their comparison of the macroinvertebrate assemblages of coastal and continental streams and large rivers in southwestern British Columbia, Reece and Richardson (2000) found that *Paraleptophlebia temporalis* McDunnough predominated in coastal streams.

Heise (no date) in a study of the effect of logging on the fauna of streams in the Penticton Creek and Sicamous Creek watersheds found that mayflies were very sensitive to logging. Richardson and Kiffney (2000) studied the response to metal pollutants of macroinvertebrate fauna in experimental streams off Mayfly Creek in the UBC Research Forest near Maple Ridge, and found that *Ameletus*, *Baetis,* and *Paraleptophlebia* (mainly *P. temporalis*) were very sensitive to Cu, Zn, Mn, and Pb, typical components of urban runoff. Rempel *et al.* (2000) in a study of the macroinvertebrates along gradients of hydraulic and sedimentary conditions in a 10-km reach of the Fraser River near Agassiz, found that the distribution of several genera of mayflies was correlated with hydraulic conditions. Rempel *et al.* (1999) also showed that the densities of *Baetis* and *Rhithrogena* were highest at a depth of 1.5 m before flooding, but shifted to depths of 0.2-0.5 m at peak flow.

Keys to genera of BC mayflies can be found in Edmunds *et al.* (1976), Merritt and Cummins (1996), and Needham (1996). Keys to species have only been completed for a few genera (e.g. *Ameletus*, Zloty (1996), Zloty and Pritchard (1997); *Caenis*, Provonsha (1990); *Tricorythodes*, Alba-Tercedor and Flannagan (1995)).

ODONATA

Spencer (1952) in his brief summary of the status of the knowledge of Odonata in British Columbia did not cite what is perhaps the most significant work of the period, Whitehouse's (1941) delightful and detailed treatment of the provincial fauna. He also neglected Walker's important monographs on two of our most speciose genera, *Aeshna* (Walker 1912) and *Somatochlora* (Walker 1925); although these dealt with the entire North American fauna of these genera, they included much information on the species in British Columbia.

Walker's major opus on the Odonata of Canada and Alaska (Walker 1953, 1958) led off the second half of the century and was completed by the international Odonata expert P. Corbet (Walker and Corbet 1975). It listed many of the locality records known to this time and summarized ecological information.

Since the mid 1970s the study of the Odonata in BC has been continuous. It has been helped by work in adjacent areas, particularly the Biological Survey of Canada's Yukon insect project (S.G. Cannings and R.A. Cannings 1997; S.G. Cannings *et al.* 1991) and the extensive studies of Paulson (e.g. 1997, 1999) to the south in Washington State. This followed the annotated checklist produced by Scudder *et al.* (1976) and the book written by R.A. Cannings and Stuart (1977). The latter published the first distribution maps for the species of the Province.

Robert and Sydney Cannings, periodically helped by their brother Richard, have been the driving force in odonatology in the Province during the past 25 years. They organized numerous dragonfly inventories across the Province, from the Brooks Peninsula on the outer coast of Vancouver Island (R.A. Cannings and S.G. Cannings 1983), to the grasslands of the Chilcotin (R.A. Cannings and S.G. Cannings 1987), to the Rocky

F.C. Whitehouse, a pioneering odonatologist, collecting specimens from his caravan at Harrison and Cultus Lakes in the summer of 1936.

Mountains (R.A. Cannings *et al.* 2000) and the North (R.A. Cannings *et al.* 2001). Others who have made significant contributions to these collections and inventories include G. Hutchings, L. Ramsay, C. Guppy, R. Kenner, D. Blades, and H. Nadel. In addition, the Cannings, along with their colleagues, have documented new species to the Province (R.A. Cannings 1988, 1997; Kenner 2000a) and published much faunistic (R.A. Cannings 1978, 1996; R.A. Cannings *et al.* 1980; S.G. Cannings 1980; S.G. Cannings and R.A. Cannings 1994) and ecological work (R.A. Cannings 1980, 1982a; R.A. Cannings *et al.* 1980; Paulson and R.A. Cannings 1980). Significant in the taxonomic work done on the Odonata in British Columbia and Yukon over the past 25 years is the description of four previously unknown larvae (R.A. Cannings 1981; S.G. Cannings and R.A. Cannings 1980; R.A. Cannings and Doerksen 1979; Kenner *et al.* 2000) and the redescription of several others, along with improved keys to this important life stage (R.A. Cannings 1982b; Kenner 2001).

G.P. Doerksen had begun to examine local dragonflies intensively (Doerksen 1980) when he was killed by a Grizzly Bear while on a research trip to Liard River Hot Springs in 1981. His wonderful dragonfly photographs, willed to the Royal BC Museum, are a valuable research and interpretative resource. Peters (1998), while on a visit from Germany, published a useful study on variability in *Aeshna*. R. Kenner (Kenner 1996, 2000b, 2000c; Kenner and Lane 1997; Kenner and R.A. Cannings 2001) and I. Lane (Lane 2000) have improved our knowledge of the fauna of the Lower Mainland, including the documentation of the first Canadian breeding site of *Tanypteryx hageni* Selys.

Few experimental studies on the Odonata have been undertaken in the Province. G. Pritchard, University of Calgary, has studied the ecology and development of Odonata, especially *Argia vivida* Hagen, of warm springs in British Columbia and adjacent regions (Pritchard 1989, 1991). At the University of BC, P. Pearlstone (1973) examined the food of larval *Enallagma boreale* Selys and R. Baker (1983) studied the larval competition and feeding behaviour of *Ischnura cervula* Selys.

An important recent development has been the listing of species of management concern by the BC Conservation Data Centre (Ramsay and S.G. Cannings 2000; R.A. Cannings 2001). At the end of the 2001 field season, 23 species were listed. This highlighting of rare species spurred research into their status and habitats, and stimulated regional inventories.

Odonata are now the best known aquatics insects in the Province. Of course, there is still much to learn, especially regarding the ecology of the fauna and the distribution of northern species. Spencer noted 78 species in 1952, but the most accurate published record up to that time was from Whitehouse (1941), who recognized 74 species in 23 genera. By 1977, R.A. Cannings and Stuart could report 80 species and 23 genera. In 2001, 87 species in 27 genera are known from the Province (there are 201 recorded in Canada). Perhaps the most striking addition to the provincial list in the past 50 years was the discovery of *Calopteryx aequabilis* Say at Christina Creek in 1998 (R.A. Cannings *et al.* 2000). This added a new family to British Columbia, the Calopterygidae, making a total of 10.

All available records for the Odonata in BC are databased, georeferenced, and mapped, ready to serve as baseline data for the faunal changes of the new millennium. Useful works for identification, in addition to Walker (1953, 1958), Walker and Corbet (1975), and R.A. Cannings and Stuart (1977) are Westfall and May (1996), Needham *et al.* (2000), and Dunkle (2000).

PLECOPTERA

Ricker (e.g. 1943, 1954) conducted early systematic and distributional studies on stoneflies. An annotated checklist of the Plecoptera of BC was published by Ricker and Scudder (1976). S.G. Cannings (1989) also provided a number of new records, especially for capniids. An up-to-date checklist can be extracted from the North American stonefly list provided on the internet by Stark (2001). Currently, 132 species are known from the Province. More detailed systematic studies that are relevant include Nelson and Baumann's (1989) work on *Capnia*, Stanger and Baumann's (1993) work on *Taenionema*, and Stark and Nelson's (1994) work on *Yoraperla*. Kenneth Stewart (University of North Texas) and Mark Oswood are actively writing "Stoneflies of Alaska and Northwestern Canada," which will include history, keys, illustrations, new locality records, maps, species accounts, and biological notes on the species documented for Alaska, British Columbia, Yukon, and Northwest Territories; publication is anticipated in 2003.

D.B. Donald and R.S. Anderson of the Canadian Wildlife Service (Edmonton) surveyed the stoneflies of the Rocky Mountain National Parks. The lentic stoneflies of these collections were summarized in Donald and Anderson (1980). Donald and Patriquin (1983) related the wing length of Rocky Mountain lentic capniids to their inferred postglacial recolonization history.

A number of studies investigating stonefly population dynamics, foraging ecology, species interactions, and life history in coastal streams have been undertaken by J. Richardson and his colleagues at UBC (Reece and Richardson 2000; Rempel *et al.* 2000; Richardson 2002; Soluk and Richardson 1997). Muchow and Richardson (2000) reported the occurrence of Plecoptera in small headwater streams in the UBC Research Forest near Maple Ridge. They found the fauna differed in intermittent and continuous flow streams. While *Paraleuctra vershina* Gautin and Ricker and *Visoka cataractae* (Neave) occurred only in continuous flow streams, *Alloperla pilosa* Needham and Claassen, *Despaxia augusta* (Banks), *Moselia infuscata* (Claassen), *Ostracerca foesteri* (Ricker), *Pteronarcys californica* Newport, *Soyedina producta* (Claassen), *Zapada cinctipes* (Banks), and *Z. oregonensis* (Claassen) occurred in both. Even in small streams (less than half a metre wide) with intermittent flow, the univoltine *Moselia infuscata*, *Soyedina producta*, and

Zapada cinctipes were found to emerge in periods when no flow was perceptible. *Despaxia augusta*, with a 2-year life cycle, was also able to complete its development in the periodically 'dry' channels and reached its highest densities in intermittent streams. The authors suggest that suitable refugia exist for this species and others in the wet sediments of these habitats despite the periodic disappearance of detectable surface flows.

All available, reliably identified records are now databased, georeferenced, and mapped. References useful for identification include Baumann *et al.* (1977), Harper and Stewart (1984), Jewett (1959), Ricker (1943), Stark *et al.* (1986), and Stewart and Stark (1988).

HEMIPTERA

In addition to records in the early literature of Hemiptera in British Columbia, Scudder (1977) published an annotated checklist of the aquatic and semi-aquatic bugs in the Province. In the recent checklist for Canada (Maw *et al.* 2000), a total of 46 species of aquatics (Infraorder Nepomorpha: Families Belostomatidae, Nepidae, Gelastocoridae, Corixidae, Notonectidae) and 14 species of semi-aquatics (Infraorder Gerromorpha: Families Mesoveliidae, Hebridae, Hydrometridae, Gerridae, Veliidae) are recorded.

Over the past 40 years, detailed studies of the biology of both Corixidae and Gerridae have been undertaken, much of this associated with a study of the saline lakes of the British Columbia interior. Scudder (1965a, 1969a, 1969b) investigated the distribution of two closely related species of *Cenocorixa* in these lakes, and found that while *C. bifida* (Hung.) was evidently a freshwater species, *C. expleta* (Uhler) was more saline tolerant.

Extensive study of the osmotic and ionic balance in these two corixid species (Scudder 1971a; Scudder *et al.* 1972; Szibbo and Scudder 1979; Needham 1990) and an investigation of their cuticular permeability (Oloffs and Scudder 1966; S.G. Cannings 1981; S.G. Cannings *et al.* 1988) was accompanied by detailed histological and ultrastructural studies of their excretory organs (Jarial and Scudder 1970) and other organs that were evidently involved in osmotic and ionic regulation (Jarial *et al.* 1969; Lo and Acton 1969; Jarial and Scudder 1971). Although the two species differed in their osmotic and ionic regulatory abilities at high salinities, both were able to regulate equally well in low salinity waters. Indeed, the more saline tolerant *C. expleta*, which in the field does not live in freshwater lakes, was successfully reared in freshwater (S.G. Cannings 1978). These studies subsequently led to much more detailed research on the coastal *C. blaisdelli* (Hung.) (Cooper *et al.* 1987, 1988, 1989) and other corixid species (Scudder 1987).

Both of the interior species of *Cenocorixa*, and other Corixidae, were found to be predaceous (Jansson and Scudder 1972; Reynolds 1975), which permitted laboratory rearing and led to other studies. Once species had been reared and the immature stages of both *C. bifida* and *C. expleta* described (Scudder 1966a), studies were carried out on their life cycle (Jansson and Scudder 1974), flight muscle development (Scudder 1971b), and flight muscle polymorphism (Scudder 1964; Acton and Scudder 1969; Scudder and Meredith 1972; Scudder 1975).

Jansson (1972, 1973, 1974a, 1974b), in his extensive study of stridulation in these *Cenocorixa* species, found species-specific mating signals and hence an effective pre-mating isolating mechanism. Further, in an intensive study of their feeding biology, using serological and other techniques, Reynolds and Scudder (1987a, 1987b) studied both the fundamental and realized feeding niches of *C. bifida* and *C. expleta*.

In a review of the factors governing the distribution of *C. bifida* and *C. expleta*, Scudder (1983), following studies on mite parasitism of these species (Smith 1977), suggested that *C. expleta* was excluded from freshwater lakes by mite parasitism. This suggestion has been substantiated by more research (Bennett and Scudder 1998), which showed that for

C. expleta saline lakes are enemy-free space. This research has been cited as an example of a parasite-structured animal community (Minchella and Scott 1991).

In the Gerridae, several species were found to coexist in BC lakes (Maynard 1969; Scudder 1971c). Following the rearing and description of the immature stages of these (Scudder and Jamieson 1972; Spence and Scudder 1978), detailed studies were undertaken of their food consumption and predatory behaviour (Jamieson and Scudder 1977, 1979), growth patterns (Spence *et al.* 1980a), life cycles (Spence and Scudder 1980; Rowe and Scudder 1990), mating and other behaviours (Spence *et al.* 1980b; Rowe 1992, 1994). Spence (1981, 1983, 1989) was then able to undertake a detailed analysis of habitat selection, life cycle strategy, species-packing, and coexistence in these pond skaters. Subsequently, Spence (1990) discovered introgressive hybridization in two species of *Limnoporus* within British Columbia and Alberta, and has gone on to look at the mating system of these (Spence and Wilcox 1986; Wilcox and Spence 1986), and some of the genetic factors accompanying this hybridization between non-sister species (Spence and Maddison 1986; Sperling and Spence 1990, 1991; Sperling *et al.* 1997).

Seven species of Notonectidae occur in BC (Scudder 1965b, 1977). *Notonecta borealis* Hussey was discovered to be primarily a flightless species (Scudder 1966b). Ellis and Borden (1969) have investigated the effect of temperature and other environmental factors on *N. undulata* Say.

MEGALOPTERA

Spencer (1942) treated the Megaloptera, which includes the dobsonflies and the alderflies, within his listing of the Neuroptera, and recorded 4 species from British Columbia. A systematic review of the Sialidae by Ross (1937) gives a key to the species of *Sialis*; 5 species are now know to occur in the Province. Munroe (1951, 1953) sorted out the identity of material from British Columbia that Spencer (1942) reported as *Neohermes disjunctus*, and now 3 species of Corydalidae are known from BC.

While *Dysmicohermes disjunctus* (Walker) is widely distributed, both *Chauliodes pecticornis* L. and *Protochauliodes spenceri* Munroe may be at risk, as they have a restricted distribution in areas of the Province subject to heavy human impact. *Chauliodes pecticornis* is known from Cloverdale and Cowichan, while *Protochauliodes spenceri* is restricted to south-east Vancouver Island in Canada. All known records of Megaloptera in the Province are databased, georeferenced, and mapped.

NEUROPTERA

Of the 8 families of Neuroptera reported from British Columbia, only the family Sisyridae has aquatic larvae. In the Sisyridae, although Spencer (1942) recorded only *Sisyra vicaria* (Walker) from BC, based upon a specimen from Agassiz determined by F.M. Carpenter, it is now known that another species of spongilla fly, *Sisyra fuscata* (Fab.), also occurs in the Province. While *S. vicaria* is widely distributed, *S. fuscata* is only known from Kaslo and Seton Lake. A key to the species of Sisyridae is given in Parfin and Gurney (1956). All known records of aquatic Neuroptera in BC are now databased, georeferenced, and mapped.

TRICHOPTERA

Some of the earliest records of Trichoptera from British Columbia come from N. Banks, who worked on the group from the early 1900s to the early 1940s. H.H. Ross also contributed significantly to these early records, collecting in the 1930s, 1940s, and 1950s throughout North America. The first attempt to pull all of these scattered records together into one publication was made by Ross and Spencer (1952), who created a preliminary list of the Trichoptera of BC. This list was added to significantly by Nimmo and Scudder (1978) when they published their annotated checklist containing 248 species, 43 of which were new records for BC. At this time, they stated that "there has been no concerted Trichoptera collecting in British Columbia as a whole, so the fauna must still be regarded as incompletely known."

To partially rectify this, A. Nimmo spent the spring, mid-summer, and fall of 1979 exploring much of the Province in search of caddisflies (Nimmo and Scudder 1983). He added many range extensions to known species, and also recorded 36 new species for BC (Nimmo and Scudder 1983), thus bringing the provincial total to 279 species (they removed 5 species from the 1978 list). However, Nimmo admitted that the northern half of the Province, the Queen Charlotte Islands, and many alpine areas still remain uncollected (Nimmo and Scudder 1983).

Also in the 1970s, G. Wiggins published his invaluable and beautifully illustrated identification guide to the larval caddisflies of North America (Wiggins 1977). A second edition in 1996 recognized some 1400 species of Trichoptera in North America by the end of 1993 (Wiggins 1996). More specific to our region are the keys provided by Schmid (1980) to the genera of Trichoptera in Canada and adjacent States. An English version of this Insects and Arachnids of Canada (Part 7) publication has also been recently made available (Schmid 1998). Unfortunately, keys to caddisflies of BC at the species level are still lacking.

Collections of caddisflies from specific areas of our Province can be found in Clemens *et al.* (1939) for Okanagan Lake, Hardy (1955) for the Forbidden Plateau area of Vancouver Island, Nimmo (1971, 1974, 1977) for eastern BC, Rawson (1934) for the Kamloops region, Schmid and Guppy (1952) for southern Vancouver Island, Scudder (1969b) for the Fraser Plateau, and Winterbourn (1971a,b) for Marion Lake, BC.

On the biology of caddisflies, Richardson (1991) found *Lepidostoma roafi* (Milne) to be univoltine. In a study contrasting the fauna of coastal and continental streams and large rivers in southwestern BC, Reece and Richardson (2000) found that *Onocosmoecus unicolor* (Banks) was unique to coastal streams, while *Brachycentrus occidentalis* Banks was unique to larger rivers. *B. americanus* (Banks) was unique to continental streams in the Merritt area. In Marion Lake, Trichoptera larvae, in particular *Banksiola crotchi* Banks, were the most important food item of rainbow trout (Efford and Tsumura 1973). The effects of the mosquito larvicide *Bacillus thuringiensis* on caddisflies was reported by Duckitt (1986).

Rempel *et al.* (1999), in an investigation of the effect of flooding on benthic invertebrates in the Fraser River near Agassiz, noted that *Hydropsyche* was most abundant at 1.5 m in all months of the years, but the location shifted laterally over a distance of 30 m through the flood cycle. They evidently migrated to the shore zone with the rise in water level, so maintaining a suitable hydraulic microhabitat. Heise (no date), in a study of the effect of logging on the fauna of streams in Penticton Creek and Sicamous Creek watersheds, found that while some caddisfly larvae showed a constant pattern of distribution in response to logging, *Psychoglypha*, a shredder, declined after logging and *Ecclisocosmoecus*, an algal feeder, increased after logging.

Caira and Scudder (1985) reported parasitism of *Psychoglypha alascensis* Banks (Trichoptera: Limnephilidae) by *Pseudoallocreadium alloneotenicum* (Wootton) (Digenea: Allocreadiidae). Caira (1981) investigated parasitism of Trichoptera by *Bunodera mediovitellata* Zimbaluk & Roytman (Digenea: Allocreadiidae) and the encapsulation response. This hemocyte encapsulation response in *P. alascensis* was studied later using Epon implants (Caira and Scudder 1987).

COLEOPTERA

British Columbia has a very rich aquatic beetle fauna. For example, BC has more species of Dytiscidae, Amphizoidae, Haliplidae, and Hydraenidae than any other Province (Larson *et al.* 2000; Bousquet 1991). Yet, beetles appear to be one of the more neglected groups of aquatic insects in BC. Early lists of Coleoptera from various parts of the Province (e.g. Keen 1895, 1905; Stace-Smith 1929, 1930) do contain some aquatic species, but there has been no published provincial checklist, although a preliminary list was developed by Scudder (unpublished). Most of the works dealing with aquatic beetles in BC have been as parts of studies of particular taxa over larger geographical areas. References to keys for aquatic beetles are in Bousquet (1991) and Arnett and Thomas (2001). Species lists for BC are in Bousquet (1991) and Larson *et al.* (2000).

The most important person to study aquatic beetles in BC was H.B. Leech. Leech was born in Kamloops, received much of his early education in Vernon, and graduated from UBC in 1933. From 1930-1947, he worked at the Forest Entomology Laboratory in Vernon where he collaborated with R. Hopping. In 1947, he joined the California Academy of Sciences. He described his first new species in 1937, *Agabus vancouverensis* Leech (Leech 1937), and subsequently described over 50 beetle taxa (Kavanaugh and Arnaud 1981). His collection of over 30,000 specimens of aquatic beetles, many from BC, was donated to the California Academy of Sciences in 1947. Several species of aquatic beetles found in BC are named after Leech: *Haliplus leechi* Wallis, *Helophorus leechi* McCorkle, and *Cymbiodyta leechi* Miller, which is known from Washington and probably occurs in BC (Smetana 1988).

Several other people are associated with aquatic beetles in BC mostly as collectors; for example, G.J. Spencer, R. Hopping, and G. Stace-Smith. M.H. Hatch described several species of aquatic beetles found in BC and is best known for his "Beetles of the Pacific Northwest" (Hatch 1953-1971). Each of them has at least one aquatic beetle from BC named in his honor.

In more recent times, Scudder (1969b) reported some species from interior saline lakes, and he, his students, and associates have collected aquatic beetles as part of more general surveys and added to our knowledge of the distribution of various species, especially in the Gulf Islands and in the northern part of the Province. In addition, J. Lancaster has conducted an ecological study of aquatic beetles in a comparison of the community structure in a series of saline lakes on the Chilcotin Plateau (Lancaster and Scudder 1987). Kenner (2000d) described the distribution of two species of gyrinids in BC, the Yukon, and Alaska.

DIPTERA

The Manual of Nearctic Diptera (McAlpine 1981, 1987) is a wonderful resource for information on systematics and biology of North American Diptera. Illustrated keys identify immature and adult specimens to family and genus. The taxonomic and distributional status, to the early 1960s, of many British Columbia species is outlined in Stone *et al.* (1965).

The Mountain Midges (Deuterophlebiidae) are peculiar, little-known flies found in streams in the western mountains. Courtney (1990) documented the systematics of the Nearctic species, including those known from BC.

In the Chaoboridae, Northcote (1964) and Teraguchi and Northcote (1966) studied the vertical distribution and vertical migration of *Chaoborus* larvae in BC lakes. Taxonomic works on the Phantom Midges that relate to the provincial fauna include Saether (1970) and Borkent (1979, 1993).

Early work on the Culicidae in BC includes that of Hearle (1926, 1927) and Curtis (1967). Belton (1978) studied the mosquitoes of Burnaby Lake, and more recently produced a monograph on the 46 species known in BC (Belton 1983). This work, together with Wood *et al.* (1979), can be used to identify these species.

In his study of the fauna of saline lakes on the Fraser Plateau, Scudder (1969b) found that *Aedes campestris* Dyas and Knab occurred in the most saline of them. The osmotic and ionic regulation in the larvae of this mosquito is therefore of interest; it has been studied by Phillips and Meredith (1969a). They also investigated the active transport of sodium and chloride by the anal papillae of the larvae (Phillips and Meredith 1969b) and the electron microscopic structure of these organs (Meredith and Phillips 1973a, 1973b). Regulation and active transport of magnesium by the Malphighian tubules of these larvae was described by Kiceniuk and Phillips (1974) and Phillips and Maddrell (1974). They also discovered that these tubules could actively transport sulphate ions (Maddrell and Phillips 1975). This work led to comparative studies on other saline-water mosquito larvae including *Aedes dorsalis* (Meigen) and *A. togoi* (Theobald) (Meredith and Phillips 1973c; Strange *et al.* 1982, 1984; Strange and Phillips 1984), both of which occur in the Province. Important reviews resulted from this research (Bradley and Phillips 1977; Phillips *et al.* 1978; Phillips and Bradley 1978; Strange and Phillips 1985; Ng and Phillips 1985).

Gammarid predation on *Aedes togoi* at Horseshoe Bay was reported by Hossack and Costello (1979). Oviposition of *Culex pipiens* L. in water at different temperatures was described by Gillespie and Belton (1980). Ishii and Belton (1984) provided evidence for autogenous egg development in this species and Belton (1982) described the cuticular vestiture of *Aedes communes* (DeGeer) and *A. nevadensis* Chapman and Burr.

The comprehensive treatment of the Black Flies (Simuliidae) of North America by P. Adler, D. Currie, and D.M. Wood is nearing completion; when published, this work will deal with all aspects of the systematics of BC species. Early studies by Curtis (1954) and Shewell (1957, 1959) were followed by research by Peterson (1970), Mahrt (1982), Currie and Adler (1986), and Corkum and Currie (1987). Currie's work in Alberta (1986) and the Yukon (1997) has direct application to the BC fauna. Studies on *Parasimulium* (Borkent 1992; Borkent and Currie 2001) have led to a better understanding of the phylogenetic origins of the Simuliidae. Currie and Walker (1992) documented the use of fossil black fly larvae in paleoecological studies. Cytological research into the giant chromosomes of simuliids has been undertaken in the genus *Prosimulium* (Basrur 1962), in *Stegopterna* (Madahar 1969), in the *Simulium (Eusimulium) vernum* group (Hunter and Connolly 1986), and in the *S. (E.) aureum* group (Leonhardt 1985).

McMullen (1978) surveyed Ceratopogonidae in the Okanagan area of BC. Light trap catches of *Culicoides* in the Fraser Valley were described by Costello (1982). Anderson and Belton (1993) examined populations of *Culicoides obsoletus* Meigen in the lower mainland of BC and hypersensitivity of horses to *Culicoides* bites was reported (Anderson *et al.* 1988, 1991, 1993, 1996). A. Borkent of Enderby is a world authority on Ceratopogonidae and some of his systematic studies directly relate to BC (Borkent and Grogan 1995; Borkent 1998).

Both freshwater and saline-tolerant species of the Chironomidae inhabit saline lakes in the BC interior (Scudder 1969b). At the University of Victoria, Morley and Ring (1972a, 1972b) studied the life histories, ecology, and identification of the intertidal chironomids *Paraclunio alaskensis* Coquillett, *Saunderia clavicornis* (Saunders), *S. marinus* (Saunders), and *S. pacificus* (Saunders). The detailed study of the occurrence of midges in the littoral zone (R.A. Cannings and Scudder 1978) resulted in the discovery of a new species of *Chironomus* (R.A. Cannings 1975a) and many species new to BC and Canada (R.A Cannings 1975b). Subsequently, the physiology of this and other *Chironomus* species was investigated (Sargent 1978) and the phenology compared (R.A. Cannings and Scudder

1979). The ecology of one of these, *C. tentans* Fab., which has distinct chromosomal races in the Province (Acton and Scudder 1971), was researched by Topping (1971, 1972) and, experimentally, Topping (1969) and Topping and Acton (1976) examined the influence of environmental factors on the frequency of certain chromosomal inversions. Eastern Brook Trout were used as predators in this research. The chironomids of Marion Lake in the Fraser Valley were studied by Hamilton (1965); Schultze and Northcote (1972) documented chironomids as fish food in another coastal lake. Mundie (1971) studied their diel drift in Robertson Creek, an artificial spawning channel and secondary outflow of Great Central Lake on Vancouver Island, and found that larval drift rates increased almost two-fold in darkness.

Brillia retifinis Saether is a multivoltine species, able to track shifts in resource abundance in its habitat by virtue of its short generation time (Richardson 1991). The influence of *Brillia* on the decomposition of conifer leaves in a coastal stream was reported by Summerbell and R.A. Cannings (1981). Richardson and Kiffney (2000), in their study of the response of aquatic insects to metal pollutants, found that chironomids (mainly *B. retifinis*) showed no significant decrease in densities with increasing doses of copper, zinc, and manganese, typical urban pollutants. Parkinson and Ring (1983) examined more physiological adaptations of *P. alaskensis* to the marine environment. As part of a provincial government attempt to control the introduced aquatic weed, *Myriophyllum spicatum* L., in warm lakes and waterways, potential biological control agents were screened. The chironomids found in this study were documented by Kangasniemi and Oliver (1983). One of them, an unnamed, native species that feeds on the plant's apical buds, was subsequently described as *Cricotopus myriophylli* by Oliver (1984). Borkent's (1984) systematic work on the *Stenochironomus* complex relates to the BC fauna. Ian Walker and his students and colleagues (Walker *et al.* 1991, 1993; Heinrichs *et al.* 1999; Rück *et al.* 1998; Palmer 1998) have used chironomid fossils in lake sediments to reconstruct paleoenvironments in British Columbia. The larvae of Canadian chironomids can be identified to genus using Oliver and Roussel (1983).

CONCLUSION

The above clearly documents that there has been a dramatic increase in our knowledge of the aquatic insects in British Columbia over the past century. However, much remains to be done, with the Ephemeroptera in particular needing more attention. Additionally, many areas of the province remain to be surveyed, such as the far North and the numerous islands off the west coast. Many more interesting discoveries can be expected during the next 100 years.

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Spiders (Araneae) and araneology in British Columbia

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" . . . spiders are ruthless storm troops in the matriarchal anarchy that is the arthropod world: theirs is the most diverse, female-dominated, entirely predatory order on the face of the earth. As such, spiders are key components of all ecosystems in which they live."

Bennett 1999

THE SPIDERS . . .

In large part because of its cool temperate climate and the significant amount of Pleistocene time much of it spent under a series of transcontinental ice cubes, Canada is sadly lacking in arachnid diversity. Although six of the dozen or so orders of extant arachnids are represented in the national fauna, only two (Acari, mites and ticks; and Araneae, spiders) are significantly diverse in Canada and these contain only a small proportion of the world acarine and spider species.

Canada contains 1,400-1,500 members of the world's described fauna of nearly 40,000 spider species (Bennett 1999). With its tremendous range of biogeographical diversity, British Columbia (BC) provides habitat for nearly half of these – over 650 spider species are known to occur here (Table 1) and many are found nowhere else in Canada.

Canada has representatives of both mygalomorph (tarantulas and their kin) and araneomorph ("true") spiders. Mygalomorphs are most diverse in the subtropics and tropics; few are found in northern hemisphere cool temperate climates and always as northern populations of species more widespread to the south. Three of the four mygalomorph families occurring in Canada are restricted to BC. A tiny funnel-web weaving diplurid is known from a single locality near Creston. One small sheet-web weaving mecicobothriid occurs in disjunct populations in remnant old Vancouver Island wet forests. Two large antrodiaetid trapdoor spiders occur in BC: one is common in a wide range of coastal habitats from old, wet forest to dry Garry oak meadows and suburban lawns and gardens; the other is uncommonly encountered in the dry southern interior valleys.

Similarly, haplogyne ("primitive") araneomorphs are much more diverse and common south of Canada. Of five families with Canadian species, two (telemids and segestriids) and most of a third (pholcids) are found only in BC. The other Canadian haplogynes are cosmopolitan synanthropes. A single, tiny telemid is rarely encountered but likely locally abundant in deep litter in old forests. Extreme south-western BC is home to Canada's single tube-web weaving segestriid. Two swift, small and cryptic pholcids are uncommonly encountered on the undersurface of rocks and other objects (often in apparent association with *Latrodectus* widow spiders) in the hottest, driest parts of southern BC. A third pholcid, the common and familiar "daddy-long-legs" cellar spider is found in older homes throughout much of Canada. One feisty synanthropic dysderid makes meals of isopods in yards and basements across southern Canada.

The world araneofauna (especially in the Holarctic) is dominated by entelegyne ("higher") araneomorphs. Among BC's 643 known entelegynes, the crab-like philodromids and thomisids, orb-web weaving araneids, cob-web weaving theridiids, and active and highly visually orienting salticid jumping spiders and lycosid wolf spiders are familiar to most people with basic knowledge of natural history.

Table 1
Classification of spider families with Canadian and British Columbia representatives (modified from Bennett 1999).

	Approx. no. of species in Canada	No. of known species in BC
ORDER ARANEAE		
Suborder Opisthothelae		
Infraorder Mygalomorphae		
Fornicephalae		
Atypidae	1	0
Antrodiaetidae	2	2
Tuberculotae		
Mecicobothriidae	1	1
Dipluridae	1	1
Infraorder Araneomorphae		
Neocribellatae		
Araneoclada		
Haplogynae		
"Scytodoidea"		
Scytodidae	1	0
Telemidae	1	1
Pholcidae	3	3
Dysderoidea		
Segestriidae	1	1
Dysderidae	1	1
Entelegynae		
Palpimanoidea		
Mimetidae	6	2
Eresoidea		
Oecobiidae	1	0
"RTA Clade"		
Lycosoidea		
Lycosidae	110	47
Pisauridae	7	1
Oxyopidae	2	1
Dictynoidea		
Dictynidae	75-80	29
Cybaeidae	12	11
Hahniidae	16	15
Dionycha		
Anyphaenidae	7	2
Liocranidae	18	5

Clubionidae	35	15
Corinnidae	11	5
Gnaphosidae	100	49
Zoridae	1	1
Philodromidae	47	33
Thomisidae	68	32
Salticidae	110	43
Amaurobioidea		
Amaurobiidae	30	10
Titanoecidae	4	2
Agelenidae	11	9
Orbiculariae		
Deinopoidea		
Uloboridae	3	1
Araneoidea		
Nesticidae	2	1
Theridiidae	100	51
Theridiosomatidae	1	0
Mysmenidae	1	1
Pimoidae	2	2
Linyphiidae	>500	230
Tetragnathidae	23	12
Araneidae	74	33
TOTAL	~ 1,400	653

Uncommon in Canada, palpimanoids are represented in BC by two species of araneophagic mimetids found in the south. All other BC entelegynes are either orbicularians (orb-weavers and their kin) or members of the "RTA clade" (spiders with a distinctive process on the male pedipalpal tibia).

RTA clade diversity in Canada is dominated by dionychan (two-tarsal-clawed spiders) and lycosoid (true wolf spiders and their relatives) hunters. The other RTA groups (dictynoids and amaurobioids) are reasonably diverse web weavers but tend to be overlooked because members are mostly cryptic, litter inhabitants and many are tiny (except for a small number of amaurobiids and some synanthropic, introduced agelenids).

Lycosid wolf spiders often are the most abundant (but not necessarily most diverse) ground dwelling predators in any open habitat from forest openings and coastal shorelines to bogs and alpine meadows. Pitfall traps may be inundated, often by a single species. A good sign of spring is the first appearance of myriad small, dark *Pardosa* spiders in meadows as soon as the snow disappears. Nearly half of Canada's lycosid species have been found in BC. Of Canada's seven known pisaurids (nursery-web or fishing spiders), only one is found west of the Rockies. This is BC's loss – two eastern pisaurids are Canada's largest spiders and contribute greatly to the excitement of shoreline life east of the Rockies. One of Canada's two oxyopid lynx spiders is common in some agroecosystems and similar open habitat in southern BC.

Nearly half of Canada's approximately 400 species of dionychans occur in BC. Gnaphosid ground spiders, philodromid and thomisid crab spiders, and salticid jumping spiders predominate with a combined total of well over 150 species in the province. Gnaphosids are common ground dwelling hunters. Generally nocturnal and cryptic, gnaphosids are infrequently encountered by general collectors but may be as abundant as lycosids in many habitats. A few are well-known synanthropes. In contrast, salticids are often conspicuously coloured and diurnal. Although difficult and confusing taxonomically, they are well known by the general public and regularly serve as photogenic subjects of natural history essays. Thomisid and philodromid crab spiders are sit-and-wait, generally cryptic, diurnal hunters. Thomisids are rather bristly, slow moving, ground dwelling and very crab-like; philodromids are faster, hairier, less crab-like and mostly encountered above the ground layer.

The remaining dionychans form a diverse assemblage of primarily nocturnal hunters occupying a variety of habitats. Clubionids and anyphaenids are active on foliage while corinnids and liocranids are ground dwellers. Some corinnids and liocranids are ant mimics. Restricted to BC in Canada, Zoridae is a recent addition to our fauna. One species of these relatively small, ground dwelling, lycosid-like spiders has expanded its range northward into southern Vancouver Island and the south Okanagan Valley.

Most of Canada's dictynoids (dictynids, cybaeids, and hahniids) and amaurobioids (amaurobiids, titanoecids, and agelenids) weave more or less reduced sheet webs. Nearly all cybaeids are restricted to BC in Canada. All cybaeids are forest floor litter inhabitants and some are dominant but infrequently collected species where they occur. (It is interesting to note that few cybaeids are found in eastern Nearctic forests. Coelotine amaurobiids dominate cybaeid-type habitats there but are absent from western Nearctic forests.) Half of Canada's hahniids are restricted to BC. Like cybaeids, hahniids are generally small, cryptic litter inhabitants and often abundant but infrequently collected. Dictynidae is a large group of small to tiny, often exceedingly difficult to identify spiders. Many are arboreal and produce distinctive cribellate silk; their small, "hackled" webs may be abundant among conifer branch tips. Ecribellate dictynids are primarily litter inhabitants and, not surprisingly, often abundant but overlooked.

Canada is home to a range of cribellate and ecribellate amaurobiids; a third of these (all cribellate) occur in BC. Four are found nowhere else in Canada. Most amaurobiids are forest floor spiders. A couple of beefy *Callobius* species are common under bark or in bark crevices of coastal BC conifers; the exceedingly small and rare members of the genus *Zanomys* may be ground dwelling rodent associates. Agelenids construct large, distinctive, sheet-like funnel webs in a variety of habitats. In Canada, most species are widespread and often abundant. Three closely related introduced agelenids are well known BC synanthropes: one (*Tegenaria domestica*) is cosmopolitan, another (*T. duellica*) rivals the eastern pisaurids as Canada's largest spider and is very abundant around buildings, disturbed areas, and beaches in south western BC; the third (*T. agrestis*, the undeservedly infamous "hobo spider") is rare but locally abundant at various sites in southern BC. Canadian titanoecids are a small group of wide ranging, nondescript, small forest floor species. Half occur in BC.

The remaining BC spiders (fully half the known fauna) are orbicularians. Uloborids spin cribellate, radial sector webs and are uncommon in southern Canada. One species has been found in BC. Nesticids are cryptic, rare, often troglobitic "comb-footed" cobweb weavers. One of Canada's two species is restricted to southern Vancouver Island, the other is a European introduction in eastern provinces. Mysmenids are minute, rarely encountered deep litter inhabitants and troglobites. Canada's single mysmenid appears restricted to southern Vancouver Island. In Canada, the long spiny-legged pimoids also are restricted to BC. Two species hang underneath tangled sheet webs in relatively dark, humid places in southern BC: one is common on the south coast, the other is rare in the southern interior. The remaining orbicularians are widespread and much more diverse.

About half of Canada's nearly 100 species of orb-web weaving araneids (garden spiders) and tetragnathids (long-jawed orb weavers) are found in BC. Spinners of the radially symmetrical sticky webs familiar to most people around the world, individuals of certain species may be very abundant in fields or around homes. Theridiids are the quintessential cobweb-weavers. Over half of Canada's 100 theridiid species are found in BC in a wide variety of habitats. Black widow (*Latrodectus* sp.), false black widow (*Steatoda* spp.), and brown house (*Achaearanea* spp.) spiders are familiar to most British Columbians. Individuals of the latter two genera are common in and on homes throughout the province. Black widows are locally abundant in some areas of southern BC. The most interesting theridiids often are small, inconspicuous soil and deep litter inhabitants. Linyphiid species and individuals dominate the northern hemisphere, especially the Holarctic region. Over a third of Canada's araneofauna are linyphiids. At least 230 species are known to occur in BC. Linyphiids may be exceedingly abundant in certain habitats, especially meadows and old fields. Most are tiny to minute and famously difficult to identify.

For more detailed information on Canadian and Nearctic spiders, see Roth (1993) and Bennett (1999) and references therein.

. . . AND THE STUDY OF THEM . . .

Given that nearly half the total number of spider species known to occur in Canada are found in (and often only in) British Columbia (Table 1) and the obvious importance of spiders to all terrestrial and many aquatic ecosystems, one wonders why such fascinating creatures have received little scientific attention in the province. No professional arachnologist is employed anywhere in Canada currently and, in BC, few researchers have ever seriously considered spiders or other arachnids. In BC, araneology has largely been the realm of a few dedicated amateur natural historians.

A notable exception to this is A.L. Turnbull (Fig. 1). A pioneer of ecology in Canada, Turnbull's scientific career spanned most of the latter half of the 20th Century. His professional interest in spiders was sparked by mid-century encounters with "vast numbers of spiders" during spruce budworm (*Choristoneura* sp., Tortricidae) work in the vicinity of Lillooet, BC. He subsequently studied spider ecology as an Oxford graduate student and learned the arcane art of spider taxonomy at the American Museum of Natural History under Willis Gertsch, one of the granddaddies of modern arachnology. Turnbull's interests in spider ecology and taxonomy were honed during a stint at the federal lab in Belleville, Ontario. There C.D. Dondale, who went on to become Canada's premier professional arachnologist, eventually joined him. Turnbull returned to BC in the late 1960s to join the faculty of the nascent Simon Fraser University. During his tenure there he published his landmark summary review of spider ecology (Turnbull 1973). Following his retirement in 1982, failing eyesight has kept him from contributing further to araneology.

The difficulties and drawbacks of spider ecological studies noted by Turnbull (1973) are still relevant today: ecologists necessarily are reliant upon sound taxonomy; the work of taxonomists and systematists is often excellent but much taxonomy is deplorably produced and presented (where are the taxonomy police when we need them?); taxonomic studies should be undertaken at inclusive supraspecific levels; assessing species distributions is relatively simple but quantifying populations and communities and drawing meaningful ecological conclusions are exceedingly difficult to do well; spider ecology papers often are of questionable merit and; authors tend (understandably) to overlook relevant papers not published in their native language. Ecologists and taxonomists will do well to keep Turnbull's observations in mind.

Figure 1. Bert Turnbull, a pioneer of spider ecology in Canada, was a long-time faculty member of Simon Fraser University and is now in retirement in the Vancouver area.

In recent years at least one student at each of the Universities of Victoria, British Columbia, and Northern British Columbia and Simon Fraser University have worked on some aspect of local spider diversity or the ecology of single species. However, most of this work is unpublished and all the students have gone on to other things.

Most published knowledge on BC spiders, other than species descriptions, is in the form of faunal lists (Thorn 1967; West *et al.* 1984, 1988; Blades and Maier 1996). Much of the raw data for these came from the undirected efforts of a small number of amateur collectors working in only a few areas of BC. Thus, the spider fauna of large areas of BC remains unknown.

Two early spider collectors in BC were English expatriates Reverend John H. Keen and Marianne Hippesley-Clark. Better known as beetle collectors, both made important spider collections. Around the end of the 19th Century, as an Anglican missionary Keen collected in the vicinity of Massett and Metlakatla on the north coast of BC. His spiders apparently went to Nathan Banks. Subsequently, J.H. Emerton described several new species from these specimens including at least one, *Diplostyla keeni*, named in Keen's honour. Hippesley spent much of her life near Terrace. A challenge for spider collectors is to come up with new specimens of some of the tiny linyphiids unseen since collected by her.

George and Elizabeth Peckham collected BC jumping spiders late in the 19th Century. Emerton made at least one foray into the colonial wilds of BC, apparently making it as far west as the Yoho area. The famous duo of Ralph Chamberlin and Wilton Ivie collected in various areas of BC in the 1930s and described a number of new species from BC material. In later years, other well known arachnologists such as Takasuma Kurata, Boris Malkin and, most recently, C.D. Dondale made important collections of BC spiders.

A relatively small, good collection of about 4,400 vials of identified BC spiders is maintained at the Royal BC Museum. A large proportion of these specimens were amassed by S.L. Neave from the Kyuquot region of Vancouver Island and donated to the Museum in the late 1950s. The Museum collection has been considerably augmented by specimens collected from various BC localities by Rick West (primarily in the 1980s) or during studies conducted or directed by Dave Blades or Neville Winchester (1990s). The Universities of Victoria and British Columbia possess smaller collections. Geoff Scudder and some of his students have collected substantial numbers of spiders from the south Okanagan and south coastal BC. Robb Bennett, Don Buckle, Walter Charles, Robert Holmberg, Lee Humble, Douglas Knight, Robin Leech, Jeff Lemieux, Malcolm Martin, and others also have produced significant collections of BC spiders.

These collection efforts resulted in the publication of a series of BC provincial spider checklists. Thorn (1967) compiled the first comprehensive list of 212 species from Royal BC Museum holdings. These represented a relatively small number of collection localities, dominated by Kyuquot (Neave) and Masset/Metlakatla (Keen) records. Subsequently, efforts led by Rick West boosted the number of known BC spiders to 433 (West *et al.* 1984) and then 570 (West *et al.* 1988). Recent large collections by Winchester and others increased the list to 653 (Bennett *et al.* unpublished data) by the time of this writing. Apparently only one BC regional list has been produced: Blades and Maier (1996) listed spiders and other arachnids collected in their general survey of south Okanagan arthropods.

Large areas and many specific habitats of BC remain uncollected and no doubt many list additions are still to come, especially from northern areas and the deep south of BC. No effort has been made to produce a comprehensive, habitat-specific spider inventory for any area in BC. That new records can be made with relative ease is suggested by the following examples: hundreds of specimens of a gnaphosid previously only known from a couple of Washington specimens turned up in a simple pitfall study in Burnaby (see cover of Journal of the Entomological Society of BC, Vol. 96, 1999), the first specimen of a new family record for Canada came from the carpet of a provincial government office (Bennett and Brumwell 1996), and a new species record for BC came from the bathtub of an Osoyoos motel (Bennett unpublished data) in 2001.

Araneology in Canada at the start of the 21st Century is in a dismal state. Advancement of our knowledge of spiders depends upon the uncoordinated work of amateurs and occasional students provincially and, since the retirement of C.D. Dondale, nationally. Ecologists seeking expert identification of their data points depend upon the volunteer services of a small number of qualified amateurs – the majority of people with arachnid expertise in North America receive little or no payment for application of their knowledge (Coddington *et al.* 1990). This may change with growing interest in biodiversity, non-vertebrate endangered species, and habitat protection and restoration in Canada. But I'm not holding my breath.

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Arthropod introductions into British Columbia – the past 50 years

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Introduced arthropods have affected, and continue to affect many different aspects of life in BC. Social concerns arise from public reactions to both epidemics of introduced pests, and to government actions against these pests. Economic losses to both individuals and the provincial economy occur as a result of these introduced species. Finally, ecological impacts of potentially far-reaching nature inevitably occur as a result of these new additions. The extent of the impacts of these introductions spans forestry, agriculture, urban landscapes, and human health, and is too great to allow detailed treatment in these few pages. The effects of introduced species tend to develop over years, if not decades. Some species that were introduced over 100 years ago are still with us. Some of these have undergone important range extensions. Changes in agriculture or forest practices, and shifts in quarantine policies have made these species more or less important. Some species, i.e. natural enemies, have been deliberately introduced for biological control of pests. Changing perceptions of the importance of the impacts of these introduced natural enemies on native plants and arthropod communities has altered the way in which we view and value these introductions.

My objectives in writing this were not to provide an exhaustive account of alien insects in the province. Rather, I hope to touch on some of the significant events surrounding introductions of insects over the past 50 years.

ALIEN SPECIES IN BIODIVERSITY

An important question one might ask is to what extent has the fauna of the province been modified by the presence of introduced species? In their checklist of the Hemiptera of Canada, Maw *et al.* (2000) identify the introduced species of each genus, by province. In the Cicadellidae, 42, or about 9%, of the 485 species present in BC are introduced. The family Miridae has been particularly well studied in BC by Geoff Scudder and colleagues. Among the subfamilies of the Miridae, 2 of 16 Bryocorinae, 0 of 28 Deraocorinae, 10 of 142 Mirinae, 7 of 67 Orthotylinae, and 12 of 79 Phylinae are introduced. Within the Miridae as a whole, 9% are introduced. Among the Aphididae, 19 of 41 *Aphis*, 5 of 8 *Acrythosiphum*, and 8 of 10 *Myzus* are introduced, but only 2 of 31 *Macrosiphum* are of exotic origin. Among the aquatic families, none of the Gerridae, Corixidae, or Notonectidae are introduced.

Scudder and Kevan (1984) provided a checklist of the Orthopteroid insects of British Columbia. Ten of the 130 species listed are identified as alien to the province. These include cockroaches, such as *Blatta orientalis* L. and *Periplaneta* spp., and the praying mantid *Mantis religiosa religiosa* L. Interestingly, all four of the species in Dermaptera are alien, but none of the 74 species in the Order Orthoptera are introduced. To this list can be added the Surinam cockroach, *Pycnocelis surinamensis* L. (Belton *et al.* 1986).

An estimate that from 8 to 10% of the insect species of BC are be alien might be relatively accurate. The pest and beneficial species accidentally or deliberately introduced into the province certainly have economic impacts. However, not all alien species are pests. Since these aliens now form a substantial part of the provincial fauna, they are almost certainly having impacts in a wide variety of habitats in the province. These impacts will have long-term environmental consequences and implications for conservation.

ALIEN SPECIES AS PESTS

In a report on the status of economic entomology in British Columbia, R.C. Treherne (1914), remarked that few of the pests troubling other agricultural areas of North America occurred in British Columbia. He attributed this to the application of quarantine to restrict the importation of these pests. Glendenning (1952), in a review of fifty years of entomology in the Fraser Valley, noted that the pest complex had changed dramatically following Treherne's time, and that British Columbia agriculture was then plagued by many insect pests. Most of these had been introduced into British Columbia since Treherne's (1914) report. The fifty years following Glendenning's remarks have also seen a dramatic change in the insect pest fauna in the province. The pages of the Journal of the Entomological Society of British Columbia, and its antecedent, the Proceedings, are liberally sprinkled with reports of new pest insects, and with comments on management of recently introduced species. These pests range from species that have had dramatic impacts on the face of agriculture and forestry in the province, to those whose presence is scarcely of significance except to those directly affected. Some of the more noteworthy, interesting, or just plain curious examples are treated in the following paragraphs.

The oriental fruit moth, *Grapholita molesta* (Bsk) (Lepidoptera: Tortricidae) was introduced into the Okanagan valley in 1956. This serious pest of peaches was rapidly quarantined and eradicated within 2 years (Touzeau and Neilson 1957, 1958). The oriental fruit moth continues to be a pest in Washington and Oregon, to the south, but ongoing quarantine measures have apparently prevented its re-invasion. It could be argued that this was the single most significant introduction into the province in the past 50 years, since it demonstrated the opportunities for quarantine and eradication provided by the geographic isolation of the province. Eradication of the grape phylloxera, *Phylloxera vitifoliae* Fitch (Hemiptera: Phylloxeridae), first detected in 1961 in the Okanagan, was attempted then abandoned (Morgan *et al.* 1973). The application of sterile insect release methods against the codling moth, *Cydia pomonella* (L.) and its eradication in the Similkameen Valley (Proverbs and Newton 1975; Proverbs *et al.* 1976) also took advantage of the geographic isolation of the fruit-growing regions of the province. In the current iteration of sterile insect release techniques to control codling moth in the Okanagan Valley, re-introduction from outside of the treated regions, and thus quarantine, remains one of the most serious problems for the program. The apple maggot, *Rhagoletis pomonella* (Walsh) (Diptera: Rhagoletidae), continues to be conspicuous in its absence from the province despite its presence in Washington State. Whether this is because of sound quarantine or good fortune cannot be determined.

The most controversial attempt at control by eradication in this province is certainly that against the gypsy moth, *Lymantria dispar* (L.) (Lepidoptera; Lymatriidae). The first of the recent introductions into the province occurred in 1978, and proposals to eradicate it by widespread application of pesticides to an urban area were met with considerable resistance. Since then, a program of detection of new infestations by pheromone trapping and eradication by application of Btk has been followed. The value of this program is controversial, since some introductions appear to have become extinct without treatment, and the potential for gypsy moth to cause economic impact through defoliation continues to be disputed (Myers *et al.* 1998). A study of the potential range of gypsy moth in the province (Hunter and Lindgren 1995) suggested that this pest would be restricted to the southwest through a combination of climate effects and host availability, and that the garry oak, *Quercus garryana* Douglas (Fugaceae) zone would be the most affected. The most important impacts of the introductions of gypsy moth into BC have been the generation of a vocal opposition to all eradication attempts, and a general erosion of the public perception of both entomologists and biological control in the province.

The winter moth, *Operophtera brumata* L. was first found in British Columbia in 1977 in Victoria, BC, but had apparently been introduced some years earlier (Gillespie *et al.* 1978). Two exotic parasitoids, *Cyzenis albicans* (Fall.) (Diptera: Tachinidae) and *Agrypon flaveolatum* (Gravely) (Hymenoptera: Ichneumonidae) were introduced (Embree and Otvos 1984). This pest was brought under control by the action of endemic generalist predators, but is regulated under non-outbreak conditions by the exotic parasitoids (Roland 1994; Roland and Embree 1995). The winter moth has since spread to the lower mainland, where it is a pest of highbush blueberry crops (Fitzpatrick *et al.* 1991; Sheppard *et al.* 1990).

Severe defoliation of willows (shown here) and many other wild and domesticated trees and shrubs was caused by winter moth, *Operophtera brumata* in the Victoria, British Columbia area in the 1970s. Invasive pests such as this have long-term economic and environmental consequences. Photo by N.V. Tonks (deceased)

One of the significant legacies of the introductions of the gypsy moth and winter moth was the creation of the BC Plant Protection Advisory Council (BCPPAC). This inter-agency group, comprising representatives from provincial and federal departments, industry and universities, has facilitated communication and joint action on pests and pest threats, and also provides a forum for review of proposals for introductions of biological controls of weeds.

The European crane fly, *Tipula paludosa* Mg. (Diptera: Tipulidae) was first observed as a serious pest problem in BC in 1964, and was probably introduced some years earlier (Wilkinson and MacCarthy 1967). These authors noted heavy infestations causing extensive damage to pasture and horticulture crops, and consequent extensive use of organo-chlorine insecticides. Although releases of the parasitoid *Siphona geniculata* De Geer (Diptera: Tachinidae) established successfully, there is no evidence that the decline in *T. paludosa* numbers was due to the parasitoid (Wilkinson 1984). In all probability, the decline was due to the combined action of several diseases (Wilkinson 1984). Recently, a second exotic cranefly species, *T. oleraceae* L. has been found in the Fraser Valley (Costello 1998) which may add to injury to horticultural and pasture crops in the area.

The European pine shoot moth, *Rhyacionia buoliana* (Schiff.) (Lepidoptera: Tortricidae) and the balsam wooly adelgid, *Adelges piceae* (Ratzeburg) (Hemiptera: Adelgidae) were both first reported in the 1960s and were considered serious threats to forestry in the province (Harris and Wood 1967, Wood, 1968). Although *A. piceae* has restricted the replant of *Abies* spp. (McMullen and Skovsgaard 1972; Carrow 1973), no direct losses seem to have occurred. Similarly, *R. buoliana* does not appear to attack *Pinus contorta*, the major economic pine species in the province. The oak-ribbed casebearer, *Buccalatrix ainsliella* Murtf. (Lepidoptera: Lyoneliidae) has established on red oak, *Quercus rubra* L. (Gelok *et al.* 1998) planted as roadside trees in Vancouver. Larvae pupate on almost any surface available, regardless of make or model, causing some consternation in upscale neighborhoods. Although this species does not constitute an economic threat, it and other invasive oak herbivores pose a problem for conservation of garry oak meadows. Of the current threats to BC forests from introduced pests, the importation of wood-boring beetles in dunnage and crating seems to be the most dire (e.g. Humphreys and Allen 1999; Wulf 1999). Based on literature searches, no introductions appear to have established in BC forests.

Other pest introductions of note include the lettuce aphid, *Nasonovia ribisnigri* (Mosley) (Homoptera: Aphididae) (Forbes and MacKenzie 1982), an asparagus aphid *Brachycolus asparagi* Mordivillo (Homoptera: Aphididae) (Forbes 1981), the strawberry tortrix, *Acleris comariana* (Zeller) (Lepidoptera: Tortricidae) (Cram 1973), and the German yellowjacket wasp, *Paravespula germanica* (F.) (Hymenoptera: Vespidae) (Gerber 1990). Recently, the viburnum leaf beetle, *Pyrrhalta viburni* (Paykull) (Coleoptera: Chrysomelidae) and a hemerocallis gall midge, *Contarinia quinquenota* (Diptera: Cecidomyiidae) were reported for the first time in BC (Anon 2001).

Accidental introduction of exotic species is not the only way in which introduced species arrive. Deliberate introductions of biological control agents have also added to the fauna. Biocontrol introductions in Canada, including those made into BC, have been reviewed (Kelleher and Hulme 1984, Mason and Huber, in press). However, these works do not necessarily account for the accidentally introductions and range extensions of putatively beneficial species. *Harmonia axyridis* Pallas and *Coccinella septempunctatum* L. (Coleoptera: Coccinellidae) come to mind as dramatic examples in the latter category, but others have occurred recently, for example aphid parasitoids (Mackauer and Campbell 1972) and a staphylinid beetle (Puthz 1972). Range extensions have also resulted in invasions of new pests, for example the western grape leafhopper, *Erythroneura elegentula* Osborne (Hemiptera: Cicadellidae), (Philip 1998), and a tentiform leafminer, *Phyllonorycter mespilella* (Hübner) (Lepidoptera: Gracillariidae) (Cossentine and Jensen 1992).

The past 50 years of introductions should not be discussed in isolation from the entire complex of alien species in the province. In fact, many of the most serious of our agricultural pests arrived very early in the previous century, and continue as pests to this day. Because of their long residence in the fauna of the province, it might even be argued that these species are now endemic. Redistribution and range extensions of pests such as European wireworms, *Agriotes lineatus* L. and *A. obscurus* L., (Coleoptera: Elateridae) introduced at the turn of the previous century (Wilkinson *et al.* 1976; Vernon and Päts 1997), underscore the long-term costs of management of introduced pests.

Impacts of beneficial species introduced either deliberately or accidentally, on native fauna are becoming a serious issue in pest management and conservation, yet there is no comprehensive inventory of these species in our province, let alone the resources to consider such important questions as current geographic and host range. With trends to globalization of world trade in the last two decades of the 20th century, I expected to see an explosion of reports of new pest species and exotic introductions in the scientific literature of the past two decades. The reverse seems to be true – there appears to be a noticeable decline in reporting of new pests in scientific journals in the 1990s. Four of the species noted in the past 5 years have been reported in trade magazines and in-house publications, not in mainstream scientific literature. I can imagine many reasons for these trends. Is society becoming so "globalized" that there is no alarm over the appearance of new pests, which are simply viewed in the context of pest management, not from the perspective of potential disruption of native ecosystems? Have resources available to entomologists in this province become so restricted that free publication in trade and in-house magazines is the only option available? Have taxonomic and systematics resources declined to the point that it is impossible for economic entomologists to obtain authoritative consultations and identification on species of concern? Has the size of the entomological community in the province finally declined to a point where we are no longer able to recognize and address new threats to our health and food, fibre and forest production? In view of the continuing loss of entomology professionals in the province, the loss of resources for public-good research, and the emphasis on results-driven research for clients, I fear that all of the above have some vestige of truth. Given the continued threats that further introductions of alien species pose to the economic and social well-being of the province, it is essential that professional and amateur entomologists continue to place these issues in front of the public and argue for the much needed resources.

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Research in adaptations of arthropods in British Columbia

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One of the major problems in reviewing this topic is defining the term adaptation. Unfortunately, biologists have often used the word adaptation to mean various, quite different things. However, for the purpose of this paper I will use the definition accepted by the majority of modern ecologists i.e. an adaptation is any morphological, physiological, sensory, developmental or behavioural character that enhances survival and reproduction success of an organism (Lincoln *et al.* 1998). This subject matter was not covered in any of the review papers of Volume 48 of the Journal in 1951 (50 years of entomology in BC), so I will take it upon myself to cover the last 100 years of research on arthropod adaptations in BC – not that there is much to report from before the 1960s! Since many aspects of adaptation research are likely to be covered in the other invited contributions to this issue, for example in forest entomology, insect population ecology, behavioural and chemical ecology, etc. I will concentrate my efforts in the field of eco-physiology which is, after all, the closest to my primary area of research. The paper will include not only work **done by** BC entomologists but also work **done on** BC insects by BC and other entomologists, and it will be written in chronological order, as far as is possible.

The earliest contribution that I can find that pertains to eco-physiological adaptations in insects of BC is the brief communication from Cockle (1917), where he explains some of the behavioural adaptations of "snow fleas" (Mecoptera; *Boreus californicus*) and five species of spiders to alpine conditions in the Kaslo area. In particular, he observed active feeding behaviour at temperatures down to between -2^0 and -3^0 C. From there we jump 22 years to Gregson (1939) who, in another brief paper, describes some of the adaptive features of that most Canadian of all insects, *Grylloblatta campodeiformis*. In the Kamploops area, these grylloblattids appear on the surface of rocky ground at relatively low altitudes (430-820 m) after the first frosts in November. They are active all winter, feeding on hibernating moths, ladybugs, wasps, bugs and spiders and even on active thysanurans and collembollans (in captivity they can be fed cockroaches!). They only appear on the surface at or around 0^0C. Above and below this temperature they seek shelter in rock crevices, as they do also during summer and other warmer months of the year. Their optimal foraging temperature is, in fact, 3.7^0C with cold prostration setting in at -6.2^0C and heat prostration at 27.8^0C. They die very soon at room temperatures around 22^0C. Gregson thus demonstrated that these rock crawlers are adapted to a very narrow temperature range for their feeding and other activities.

In 1944, R.W. Salt, working out of the Dominion Entomological Laboratory (now Agriculture Canada) in Lethbridge, Alberta, studied the behavioural adaptations and tolerance to cold in the larvae and pupae of the warble fly, *Hypoderma lineatus*, a serious pest of cattle in BC and Alberta. Most of the experimental insects came from Kamloops, BC. He found that both larvae and pupae were what we now call "freezing intolerant" i.e. they avoid freezing by supercooling to low temperatures, in this case to between -20^0 and -24^0C, indicating that early–dropped warble grubs would be frozen and killed. However, his behavioural studies showed that early-dropped grubs were immature forms and incapable of reaching full maturity. Fully mature grubs were never observed to drop before the danger of cold weather was past. These findings had important implications for stockmen regarding whether or not to use early chemical sprays to control warble fly populations. R.W. Salt went on to become one of the "founding fathers" in the discipline of insect cryobiology, and, in 1961, published his paper on the "Principles of insect cold-hardiness" which remains the foundation in this field of study to the present day. Then follows a paper by Morgan (1952), published in the same volume as the 50th anniversary volume of the Proceedings of the Entomological Society of BC (Vol. 48). He describes the effects of low winter temperatures on four species of orchard mites in the Okanagan and Kootenay valleys after the coldest winter on record in this region of Western Canada (-28^0 to –36^{0}C). His experimental protocol involved collecting winter eggs from the field and incubating them at temperatures above 0^{0}C. His results showed that mortality increased from 40% at -27^{0}C to 100% at -40^{0}C. A few years later, Downes (1956) investigated the effects of the longest period of drought in southern BC – a continuous period of 95 days in summer with not more than a trace of water – on the insects of southern Vancouver Island and the adjacent mainland, particularly on some Hemiptera and Lepidoptera. Most populations of insects declined, although aphids increased their activities on Garry oak – probably due to the decline in populations of hemerobiids, chrysopids, coccinellids and syrphids. The main problem, however, was the associated decline in insect food plant production. The paper goes on to explain the harmful effects of the combination of heat and desiccation stress, but populations of these insects recovered, more or less, within 3 years.

The late 1960s was a relatively active period, particularly in studies of adaptations in forest insect pests. These studies, like most of the others described in the paper, were aimed at elucidating the "inherent" adaptations of each species, that is the built–in ability of the insect to adapt to its environment over time – including responses to changes in the environment within its own life cycle. Ross (1966) examined the ability of the introduced European pine shoot moth (*Rhyacionia buoliana*) to survive low winter temperatures in the Vernon area, and demonstrated that overwintering larvae can survive -4^0 F (-20^{0}C) which would be sufficient to allow this exotic pest to survive winters in most parts of the Okanagan Valley. In the meantime, Nijholt (1967, 1969) was studying the depletion of fat deposits during the long 7-month hibernation period of adult beetles of *Trypodendron lineatum*, an ambrosia beetle. Although his studies of fats were quantitative rather than qualitative, he did provide insights into how fat reserves affect the vigour of populations of these beetles during hibernation and the subsequent flight period and brood establishment. At the same time, Dyer (1969, 1970) and Gray and Dyer (1972) were elucidating the adaptive processes involved in diapause, cold tolerance, flight muscle degeneration and behaviour in the overwintering survival of bark beetles, *Dendroctonus* spp. There was not much further activity in this area of research during the remainder of the 1970s, although VanderSar (1977) wrote a very brief account demonstrating the ability of spruce beetle larvae (*Pissodes strobi*) to overwinter successfully in Sitka spruce leaders in coastal BC (Port Renfrew, Vancouver Island). Across most of its range, *Pissodes strobi* normally overwinters in the duff at the base of host trees and is thus protected from low winter temperatures by an insulating blanket of snow. Later, Safranyik and Linton (1991, 1998) studied the adaptations to low overwintering temperatures of the mountain pine beetle, *Dendroctonus ponderosae*, and the pine engraver beetle, *Ips pini*, under both field (1991) and experimental conditions (1998). Mortality to winter cold is one of the main factors determining the distribution and abundance of mountain pine beetle in BC, and it has been shown that overwintering larvae can withstand short exposures to –38°C. However, during autumn and spring, larvae are very susceptible to extreme cold, so unseasonably low temperatures (lower than –26^{0}C) at these times of year can cause widespread mortality. Under these conditions, mountain pine beetle larvae as well as the pine engraver beetle can only survive extreme low winter temperatures at the base of trees or among the duff where they are protected by a blanket of snow. In 1998, Li and Otvos, in attempting to provide a plentiful laboratory supply of western spruce budworm pupae (*Choristoneura occidentalis*) for research, reported their findings on adaptations to cold. Normally, western spruce budworm overwinters in obligatory diapause in the second larval instar in the field. However, a non-diapausing colony of this species can be induced in the laboratory and reared on an artificial diet. This has certain advantages for mass-rearing of a species for research purposes, and perhaps, for cold storage of beneficial biocontrol agents. Their results indicated that western spruce budworm pupae could be stored at low temperatures (2^0C) for up to 1 week without deterioration in subsequent adult quality.

Similar motives were involved in the work of Gillespie and Ramey (1988) and Morewood (1992a). Based on Morgan's (1952) work, these authors studied the cold hardiness and the cold storage potential of predatory mites (*Amblyseius cucumeris* and *Phytoseiulus persimilis*) as biocontrol agents that could be used as the controls for phytophagous mites and the western flower thrips, *Frankliniella occidentalis*. Gillespie and Ramey (1988) were able to show that *A. cucumeris* could survive at 9^0C for 10 weeks (63% survival) whereas only 1.2% survived 10 weeks at 2^0C. Similarly, Morewood's (1992b) techniques showed that although both species could survive short periods (e.g. 30 min) at -12.5^0C, all individuals died within 75 min of exposure to that temperature. He also calculated that under cold storage conditions, *A. cucumeris* could survive 2-3 weeks at 7.5^0C (the optimal temperature) whereas *P. persimilis* could survive 4-6 weeks under the same conditions. Gilkeson (1990) also worked on the problem of cold storage with the predatory midge, *Aphidoletes aphidimyza*, an important insect predator of aphids in greenhouses. The main aim of her cold storage program was to facilitate the balance between supply and demand in the biocontrol agent market.

The contributions from my laboratory at the University of Victoria have made many important advances in the field of insect cold-hardiness and eco-physiology (environmental physiology) in the last 20 years or so. With my graduate students and co-workers, we have attracted two international symposia on insect cold tolerance to the University of Victoria (in 1985 and 2000), the annual meeting of the Society for Cryobiology (1980) (where there was a special section on this topic), and a session at the International Congress of Entomology in Vancouver (1988). Most of this work is in the area of adaptations to low temperatures and desiccation resistance. Although many of these studies were conducted in the Canadian Arctic, some include insects from BC, such as the thimbleberry gall wasp (*Diastrophus kincaidi*) (Ring 1981), a willow leaf-gall sawfly (*Pontania* sp.) (Ring 1981), the cabbage-root maggot (*Delia radicum*) (Turnock *et al.* 1998), a pythid xylophagous beetle from high altitudes (*Pytho deplanatus*) (Ring 1981), the introduced European winter moth (*Operophtera brumata*), (Hale 1989; Ring and Danks 1994, 1998), the aphid, *Myzus persicae* (O'Doherty and Ring 1987) and several indigenous species of intertidal insects (Morley and Ring 1972; Parkinson and Ring 1983; Topp and Ring 1988a and 1988b; Ring 1989). During this time, I was also a collaborator in a comparative study carried out on the sub-antarctic island of South Georgia with the British Antarctic Survey, studying the adaptations of two endemic perimylopid beetles (*Perimylops antarcticus* and *Hydromedion sparsutum*) to low winter temperatures and relatively short summer growing seasons (Block *et al.* 1988; Ring *et al.* 1990).

Some of the major contributions from my laboratory have been: (1) identification of a multi-component cryoprotective system in the successful overwintering of insects, including a combination of glycerol, trehalose and sorbital (Ring 1977; Ring and Tesar 1980, 1981); (2) the discovery of the lowest supercooling point ever recorded for an insect, *Pytho americanus*, in the Western Canadian Arctic (Inuvik) at -61°C; and (3) identification of the various anomalies that exist in northern insects, such as not only being freezing tolerant but also having a very low supercooling point (Ring 1982a). There are several other anomalies awaiting elucidation, such as the winter survival in the arctic of coccinellid beetles, which, apparently, lack any known cryoprotectant molecules (Ring 1982b). Humble (1987) made an important attempt to tease apart the co-evolutionary problems of cold versus desiccation tolerance and/or resistance. In arctic sawflies, he demonstrated that their abilities to survive low winter temperature and desiccation stress are co-adapted, that is, they are overlapping adaptations (see also Ring and Danks 1994, 1998). Similarly, Morewood (1999) studied the life history strategies and temperature versus development relationships of the high arctic woolly bear caterpillars (*Gynaephora* spp.) and their parasitoids at Alexandra Fiord, Ellesmere Island, Nunavut. Other contributions made in my laboratory towards an understanding of the adaptations of insects to the extreme temperature conditions of the arctic were by Winchester (1984) on arctic trichopteran larvae of the Tuktoyaktuk Peninsula in the western arctic, by Humble and Ring (1985) and Humble (1987) who studied the overwintering behaviour and adaptations of arctic willow sawflies and their parasitoids, and by DeBruyn and Ring (1999) on the overwintering behaviour and habitats of two species of diving beetles, *Hydroporus* spp. (Dytiscidae) in ponds at Alexandra Fiord, Ellesmere Island.

In the miscellaneous category, we find contributions from a variety of sources. At the top of the list I place G.G.E. Scudder, University of British Columbia (who has made three other contributions to this volume) and his collaborators who have made many insights into the ecological adaptations of water boatmen (Corixidae) that have successfully inhabited the saline lakes of Interior BC (Scudder 1976). With his students, he recognizes that many insects can, indeed, overcome the osmotic problems associated with these highly saline lakes – many of which are more saline than the sea – once again giving rise to that perennial entomological question "why have insects not re-invaded the sea?" Certainly not for the lack of osmoregulatory adaptations, according to this research. At the same time at UBC, J. Phillips and P. Hochachka were working on "pure" insect physiology. Nevertheless, much of their research also contributed knowledge towards our understanding of insect adaptations in the area of eco-physiology (see Hochachka and Somero 1973; Phillips 1975).

Ring (1978) studied the adaptive significance of spiracular gills in the pupae of the intertidal crane fly, *Limonia marmorata* (Tipulidae) (Fig. 1). This is a spectacular morphological adaptation which allows the pupae to respire both above and below water – an obvious advantage for any insect that lives in the intertidal zone. Other work that has taken place in the Ring laboratory on insect adaptations to the intertidal habitat is that of Morley and Ring (1972) on life history characteristics of intertidal chironomids, Parkinson and Ring (1983) on the osmoregulatory adaptations of these marine chironomids, and Topp and Ring (1988a, 1988b) on the adaptations of staphylinid beetles to both rocky shores and sandy beaches of the marine environment (Fig. 2). There then follows a paper (Ring 1991) that deals with insects that live in the natural hot springs of Hotspring Island, BC. These insects not only have to deal with wide temperature fluctuations but also with the associated osmoregulatory problems – the water of these natural springs is 2.5 times more saline than the sea. The chironomid midge larvae (*Thalassosmittia pacifica*) survive by being osmotic regulators in the surrounding medium rather than osmotic conformers. Other adaptations of marine chironomid larvae involve the up-take of dissolved organic nutrients from the surrounding seawater (Ring 1989). This is probably one of the least resolved but yet most intriguing questions in marine invertebrate zoology. My research has shown that these intertidal chironomids can utilize dissolved organic nutrients such as glucose, amino acids, etc. to enhance their nutrition. This is done by absorption through the cuticle of specialized areas in the intersegmental membranes of the larvae. This phenomenon may be more widespread among arthropods than was formerly recognized (see Chapman 1981).

Figure 1. Morphological adaptation – the spiracular gills of the pupa of the intertidal tipulid, *Limonia marmorata*. This structure allows the pupa to respire both above the water (low tide) and below the water level (high tide).

Figure 2. A typical view of the rocky intertidal zone on the west coast of British Columbia. Many insects exploit this habitat and show a whole suite of adaptations for survival in this extreme, inhospitable environment.

Another unexpected but interesting structural adaptation found among herbivorous insects going about their daily lives of eating plants, is the fact that many of them (if not all) incorporate metals into their already sclerotized mouthparts (mandibles) and claws. A good example of this can be found in Fontaine *et al.* (1991) where they demonstrated that zinc is prominent in the mandibles and claws of the mountain pine beetle (*D. ponderosae*), beetles which tunnel through bark as adults and as larvae mine tissues of the inner bark. Similar results were obtained from several species of coneworms (Lepidoptera: Pyralidae) where larvae mine cones and feed on developing seeds – all plant structures which have developed considerable toughness.

In summary, this paper provides, to the best of my knowledge, an up-date on the last 100 years of research in the adaptations of arthropods (mainly insects) in BC. It chronicles those papers dealing with various aspects of eco-physiology, but also includes work carried out on morphological/structural and behavioural characteristics. About one-third of the papers have been published in the Journal (or Proceedings) of the Entomological Society of BC. Please excuse me, reader, if I have not included your seminal work in this article!

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Insect population ecology in British Columbia

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The heydays of population ecology in British Columbia occurred during the 1970s and 1980s. Significant work was conducted by many people, and at several institutions, including: the University of British Columbia; Institute of Animal Resource Ecology; Simon Fraser University; Agriculture Canada, Vancouver Research Station; and the Canadian Forest Service, Pacific Forestry Centre. This paper reviews some of the work, from the viewpoint of the authors. The first section relates to agricultural insects and the second focuses on forest Lepidoptera in BC.

Population ecology of agricultural insects

Many researchers in BC have studied various aspects of population ecology. Rather than list these people and their contributions, this section focuses on the work of one research group – allowing detailed development of a story. The group was selected because it treated population ecology as a subject in its own right. This approach to ecological studies was prevalent in the 1960s-1980s, and is quite distinct from the approach that currently dominates, in which commercial problems drive much of the research. The title of this section reflects the current approach; the group being considered took quite a different view.

The research group consisted of Neil Gilbert (Associate Professor, Institute of Animal Resource Ecology), Andrew Gutierrez (Visiting Professor from Purdue University; later Professor, University of California, Berkeley), Bryan Frazer (Research Scientist, Agriculture Canada, Vancouver Research Station), post-doctoral fellows Rhonda Jones and Penny Ives, University of British Columbia graduate students, and summer students.

The researchers selected organisms with characteristics that facilitated quantitative study of ecological relationships. They then used a reductionist approach, quantitatively defining relationships and processes at lower scales and combining those quantitative relations in simulation models to explain population trends (Gilbert *et al.* 1976). A characteristic of the work was the constant interplay between experiments in the laboratory, sampling, observations and experiments in the field, and modeling, to achieve a realistic, dynamic picture of natural systems. The approach was logical, it worked, and it still applies today. However, the book, Gilbert *et al.* (1976) met with considerable criticism (Lawton 1977), largely because it took to task current and past approaches to population ecology. In particular, Gilbert *et al.* (1976) objected to ecological studies that focused on the organism rather than underlying ecological relationships that can be generalized among organisms. They also objected to laboratory-centred population ecology and theoretical approaches that are not tested under field conditions.

One of the first organisms selected by the group was the aphid *Masonaphis maxima* (Mason) (Frazer and Forbes 1968). This is a single-host aphid that appears on thimbleberry in sheltered locations in April, goes through 3-5 generations parthenogenically depending on plant quality and weather, and produces overwintering eggs in July. Because a special morph is needed to produce sexuals, and sexuals are necessary to obtain eggs, the aphid must be able to respond to changes in plant quality two generations in advance. A very good understanding of the population dynamics of the aphid has been achieved (Gilbert and Gutierrez 1973; Gilbert 1980), and the work - based on this non-commercial system - provided the seeds for many of the applied results obtained by Andrew Gutierrez and co-workers on cotton, coffee, alfalfa, cassava and other crops (e.g. Gutierrez and Baumgärtner 1984). In addition, the aphid, due to a peculiarity in its life cycle, provides a convincing proof for one function of sex. Sex is required to maintain dimorphic fundatrix aphids (Gilbert and Raworth 1998), and the dimorphism, a differential production of sexual forms at the end of the season, adapts the aphid to its heterogeneous and unpredictable environment. This is as yet, the only proven function for sex.

Movement is a key element in the population dynamics of an insect. To study movement, the group, which included Rhonda Jones, Michael Guppy and Vince Nealis chose to study the cabbage butterfly, *Pieris rapae* (L.) (Jones 1977). Rules were obtained for short-distance movement, and these rules were then used to predict long-distance movement (Jones *et al.* 1980). The butterfly also proved amenable for the study of other aspects of population ecology and resulted in a series of papers on the control of fecundity (e.g. Gilbert 1988) and a series of papers on insects and temperature, one of which, Gilbert and Raworth (1996), presents a general theory.

The effect of predation on population dynamics was studied using the pea aphid, *Acyrthosiphon pisum* (Harris) on alfalfa (lucerne) and ladybird beetles, *Coccinella* spp. The resulting Gilbert-Frazer predator-prey model represented a major advance in population ecology, and the work produced one of the first cases in which the population dynamics of an insect in the field were explained by quantitative assessment of predation processes at lower levels (Frazer and Gilbert 1976). A key result was that, contrary to current theory, the population dynamics of the aphid are intrinsically unstable, being determined largely by weather via its effects on predation. Having considerable experience with the system, the group conducted an interesting applied study when Visiting Scientist, Eric Charnov arrived in the mid 1970's. The researchers set up several types of fisheries within an alfalfa field (four different, constant rates, and two increasing rates, of exploitation) - the pea aphid played the part of the fish. Analyses of catches in the various fisheries showed how compensatory mortality within the system can affect catch-versus-effort data and result in overestimation of potential catches based on those data (Charnov *et al.* 1976). Penny Ives joined the group in the late 1970s conducting detailed work on the estimation of coccinellid numbers, beetle movement in the field, and the relationship between feeding rate and egg production. The work culminated in a collection of nine papers covering the complete predator-prey relationship (Baumgärtner *et al.* 1981).

In order to generalize about population processes it was necessary not only to compare studies of different organisms, but also the same organism in different parts of the world. This was done with many of the studies of *P. rapae*. In addition, David Raworth undertook studies of the population dynamics of the cabbage aphid, *Brevicoryne brassicae* (L.) (e.g. Raworth 1984), an aphid that had been intensively studied in Australia by Dick Hughes at CSIRO; and Vince Nealis undertook comparative studies of the ecology of *Cotesia rubecula*, a parasite of *P. rapae*, in Vancouver, BC and Canberra, Australia (Nealis 1985).

What were the circumstances that led to this group? The work arose from the interests and dedication of the people involved. Inspiration came from the three lead researchers: Neil Gilbert, who trained at Cambridge as a biometrician under R.A. Fisher; Andrew Gutierrez who trained in population ecology at UC Berkeley under R. van den Bosch; and Bryan Frazer, who trained in entomology at UC Berkeley under R. van den Bosch. It was Neil Gilbert's unique view of population ecology, his insight that focused on fundamental ecological questions, his rigorous approach in 'consulting the animals and plants', and his drive, that guided much of the work. C.S. (Buzz) Holling (Director of the IARE) recognized the importance of Neil's views and supported him in a research position that required little teaching - although many students will attest to the influence Neil had on their work. The group was influenced by other workers who were making important advances in quantitative population ecology at the time, for example: C.S. Holling had taken a quantitative, reductionist approach to predation processes (Holling 1965); and R.F. Morris produced a series of papers on the quantitative assessment of the population dynamics of fall webworm, *Hyphantria cunea* Drury (e.g. Morris 1971). Advances in computer technology very much facilitated the work. Government-funded summer employment programmes provided the many hands that are necessary to conduct field studies in population ecology. Finally, the research was driven predominantly by scientific considerations – this required a unique economic, and administrative climate.

The work is not finished. Long-term, science-directed studies in quantitative population ecology are still very much needed to gain further insights into the complex relationships and processes that result in the various scale-dependent patterns of insect distribution and abundance.

Population ecology of forest Lepidoptera

The history of forest entomology in British Columbia can be organized around the species of insect under study. In the mid-1950s W.G. Wellington moved to the Pacific Forestry Laboratory and began working on the western tent caterpillar, *Malacosoma pluviale californicum* (Dyar). In his previous work Wellington developed his ideas on the interactions between insects and weather. In BC he was welcomed to an outbreak of tent caterpillars on the Saanich Peninsula of Vancouver Island between 1955-57. Here Wellington monitored changes in both the numbers and frequency of tent types; elongate tents were thought to characterize active groups and compact tents sluggish groups (Wellington 1960, 1964, 1965). He described how simple behavioral tests could distinguish the "quality" of individuals and how the composition of families in terms of how many active or sluggish individuals occurred, could influence their success. He also related this to the impacts of climate, parasitoids, and disease. During the 1970s Wellington and colleagues at the Institute of Animal Resource Ecology at UBC (Ilan Vertinsky and Bill Thompson) explored the potential interactions between heterogeneity in larval quality, climate, and population density of tent caterpillars using simulation models. A recent review of the tent caterpillar work (Myers 2000) looks at which of the early observations have been repeatable in subsequent population cycles. Tent shape does not seem to be a good predictor of population condition, but a common observation is a sudden invasion of new habitat sites associated with peak populations. Work on the viral disease that occurs in peak populations has continued, as has work on the impacts of weather.

Wellington was a strong force in encouraging people to recognize that all individuals in a population are not the same and that those in increasing populations may be quite different from those in declining populations. The actual causes of population decline may be less important than the condition of individuals within the population. These ideas have important ramifications for the simple density-dependence approach to population ecology. In addition he emphasized how geographic variation in weather patterns could have long-term influences on insect populations and distributions. These ideas take on new relevance with the current interest in global climate change.

During the 1970s, outbreaks of both the eastern, *Choristoneura fumiferana* (Clemens), and western spruce budworms, *C. occidentalis* Freeman, attracted the attention of insect ecologists across the continent. C.S. Holling and Don Ludwig (Ludwig, *et al.* 1978) spearheaded modeling efforts to explore the dynamics of these species (McNamee, *et al.* 1981). This involved the development of both very complicated simulation models and very simple deterministic models. At this time there was considerable interest in catastrophe theory and the idea that there could be multiple stable states at low and high densities, with very rapid transitions between. Part of this idea was that insects could be maintained in a low-density "predator pit" until good conditions allowed them to break out and move to a new, high-density equilibrium.

Other work on the western spruce budworm was initiated from the Pacific Forestry Centre by Roy Shepherd. In the mid-1970s a prolonged outbreak of populations in the vicinity of Hope led to calls for a spray program. Like many spray programs this was controversial because the insect ecologists considered the populations to be on the verge of collapse. The newspapers were filled with controversial articles and Shepherd was on the hot seat. Shepherd's group did considerable work on the western spruce budworm including trials with viral sprays and Bt.

Douglas Fir Tussock moth, *Orgyia pseudotsugata* (McDunnough), is another forest defoliator with cyclic population dynamics, and a periodic pest in BC. Imrie Otvos and Shepherd initiated trials with a virus spray that showed that it was possible to stop an outbreak (Shepherd, *et al.* 1984). Viral sprays are still in the toolbox of potential controls for Tussock moth. These trials are excellent examples of applied insect ecology. Shepherd also carried out considerable work on monitoring tussock moth including developing pheromone systems to allow predictions of impending outbreaks.

The introduced winter moth, *Operophtera brumata* (L.), made a mark on insect ecology in BC starting in the late 1960s. By the early1970s what was thought to be an outbreak of the native Bruce's spanworm, *O. bruceata* (Hulst), continued to cause unsightly defoliation of oak trees in Victoria. Finally, studies by Dave Gillespie and Thelma Finlayson (Gillespie *et al.* 1981) on the parasitoids of the caterpillars led to the realization that this was an exotic species and therefore lacking in parasitoids. Winter moth had been successfully controlled in Nova Scotia by the introduction of a parasitoid fly, *Cyzenis albicans* (Fall.) and the experiment was replicated in Victoria. Within 5 years of the original fly introductions winter moth populations declined. Jens Roland did his Ph.D. research on this successful biological control program and showed through his experiments and observations how ground predators and parasitoids interact to maintain winter moth at densities higher than in their native habitat but much lower than during their initial outbreak (Roland 1988, 1994; Roland and Embree 1995). Studies continued when winter moth became a pest of blueberries on the lower mainland (Horgan *et al.* 1999). Imrie Otvos was given the keys to the city by an appreciative Victoria city council for the successful biological control of winter moth.

Gypsy moth, *Lymantria dispar* (L.), has also presented challenges to insect ecologists in BC. This exotic, European species, which is well established in eastern North America continues to show up in BC. The first discovery of the species was in the early 1900s when the Asian strain was found. However, it wasn't until 1978 that a major introduction was recognized in Kitsilano. The challenge of this species to insect ecologists has been to detect introductions and coordinate spray programs. Many introductions have either gone extinct or have been eradicated with *Bt* sprays (Myers and Rothman 1995). Again these spray programs have been controversial and have involved considerable attention of insect ecologists.

One of the fine aspects of population studies of forest insects was the Forest Insect and Disease Surveys that were done annually from the 1930s to the mid-1990s. These data bases provided valuable long-term information on population trends of many of British Columbia's forest caterpillars. That they have stopped just as the world is becoming increasingly interested in the impacts of global change is a shame.

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Behavioral and chemical ecology in British Columbia

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Behavior can be broadly defined as the response of an individual to a change in its environment. During the past 50 years many ESBC members have studied insect behavior both directly and indirectly. Below we chronicle two major schools of behavior, (1) basic studies and (2) research on aspects of pheromone production and response.

Behavior studies are represented in almost every volume of the past 50 issues of JESBC yet they are never common. In fact, excluding the pheromone-based studies, papers that deal directly with behavior make up just 6% (27/452) of all the papers published between the years 1968 and 2000. This low frequency may not be unique to JESBC. A survey of The Canadian Entomologist between 1980 and 1983 gives a nearly identical frequency of behavior-based papers (29/505).

Our survey focuses on papers that study behavior for its own sake. Many other papers have behavioral components or evaluate phenomena that are driven by behavior (e.g. trap captures - Vernon and Gillespie 1990). Either way, behavior-based studies that are published in the JESBC are drawn from a wide variety of insect taxa including, Hempitera, Homoptera, Thysanoptera, Hymenoptera, Diptera, Lepidoptera and Coleoptera. The topics range from oviposition preference in pear psylla (Stuart *et al.* 1989) to predator avoidance in fireworms (Fitzpatrick *et al.* 1994).

Behavioral ecology

There are five significant developments during the past fifty years in behavioral entomology in British Columbia. First, in the mid-1960s, Bill Wellington and C.S. (Buzz) Holling arrived at the University of British Columbia (UBC) from the Canadian Forest Service. Wellington's studies on the maternal effects on the behavior of forest caterpillars are classic while Holling's derivation (Holling 1966) of the functional response has spawned a veritable cottage industry. Additional UBC faculty with behavior based programs include, Ken Graham (behavior of bark beetles), Geoff Scudder (behavior of various hemipterans), Judy Myers (behavior underlying population processes), Bob Elliot (grasshopper feeding), Murray Isman (impact of natural products on insect feeding), John McLean (behavior of forest insects) and Bill John Richardson (behavior of aquatic insects).

The second major development was the formation of the Pestology Centre at Simon Fraser University (SFU) in 1967. Several members of the centre focused on behavior including, Bert Turnbull (predators), John Borden (host and mate-seeking behaviors), Peter Belton (acoustic and oviposition behaviors in mosquitoes), Manfred Bryan Beirne (behavior of biocontrol agents). Later additions to this group were Mark Winston (bee behavior), Bernie Roitberg (behavioral ecology) and Gerhard Gries (pheromone-based behaviors).

Third, the development of technology for identifying and synthesizing insect pheromones has had tremendous impact on research programs at BC universities and government research stations. A detailed history is provided below.

Fourth, the Behavioural Ecology Research Group (BERG) was established at SFU in the mid 1980s. Several members of the BERG used principles from evolutionary biology to study behavior of a range of organisms. These individuals include Bernie Roitberg, Mark Winston, Bernie Crespi (thrips), Larry Dill (aphids, phantom midge larvae and water striders) and Ron Ydenberg (bees).

Fifth, the 1990s will be remembered for the awakening of the biodiversity consciousness in this province. Led by Geoff Scudder and Richard Ring, the habits of lesser known and endangered species were studied in their native habitats. Of particular concern was the issue of habitat fragmentation and its impact on insect colonization and perpetuation. To get a handle on these important issues requires a good understanding of how insect behavior shapes habitat use.

Finally, behavior has featured in the research programs at government labs throughout the province (Table 1). In many cases, there has been a conscious attempt to link behavior to pest population dynamics. This approach is exemplified by Bryan Frazer and Neil Gilbert's (1976) seminal studies on the role of predator and prey behavior in the

Table 1

Government scientists and university researchers who have worked on insect behavior in British Columbia but were not mentioned by name above.

NAME	AFFILIATION	STUDY ORGANISM OR AREA OF STUDY
Nello Angerilli	Agriculture Canada	Orchard pests
Brad Anholt	U Victoria	Aquatic insects
Rene Alfaro	Forestry Canada	Forest insects
Robb Bennett	Ministry of Forests	Forest insects
Gerry Carlson	Phero Tech Inc	Forest insects
Alan Caroll	Forestry Canada	Forest insects
Joan Cossentine	Agriculture Canada	Orchard pests
Bob Costello	BC Government	Mosquitoes, greenhouse insects
Collin Curtis	Agriculture Canada	Mosquitoes
Don Elliott	Private	Parasites, predators
Doug Finlayson	Agriculture Canada	Root maggots
Henry Gerber	BC Government	Bees, wasps
Linda Gilkeson	BC Government	Biocontrol
David Gillespie	Agriculture Canada	Parasitoids, greenhouse insects
Jack Gregson	Agriculture Canada	Ticks
Staffan Lindgren	U Northern BC	Forest insects
Deborah Henderson	Private	Parasites, predators
Leland Humble	Forestry Canada	Forest insects
HR (Mac) MacCarthy	Agriculture Canada	Aphids
Dave McMullen	Agriculture Canada	Orchard pests
Lorraine Maclauchlan	Forestry Canada	Forest insects
Vince Nealis	Forestry Canada	Forest insects
Imre Otvos	Forestry Canada	Forest insects
David Raworth	Agriculture Canada	Insect predators
Les Safranyik	Forestry Canada	Forest insects
Ward Strong	Ministry of Forests	Forest insects
Robert Traynier	BC Research	Mosquitoes, turf pests
Fred Wilkinson	Agriculture Canada	Wireworms, biocontrol
Jerry Weintraub	Agriculture Canada	Warble flies
Paul Wilkinson	Agriculture Canada	Ticks
Ian Wilson	Phero Tech Inc	Forest insects
Neville Winchester	U Victoria	Tree canopy insects
Bob Wright	BC Research	Mosquitoes

population dynamics of pea aphids. In the next section, we discuss the role of behavior in chemical ecology studies on insect pests.

Chemical ecology

Studies in insect chemical ecology are devoted to promoting an ecological understanding of the origin, function, and significance of semiochemicals (message-bearing chemicals) that mediate interactions within and between organisms. Such relationships, often adaptively important, comprise the oldest and likely most prevalent communication systems in terrestrial and aquatic environments.

Research in Chemical Ecology in British Columbia began in the 1960s when Ken Graham (1968) at UBC explored the primary attraction of ambrosia beetles to Douglas-fir logs undergoing anaerobic metabolism. This research culminated in 1970 with the discovery by Henry Moeck of the Pacific Forestry Center (PFC, Victoria) that ethanol was the compound responsible for this phenomenon. Another pioneer was John Chapman (1966) of PFC who demonstrated in 1966 that a pheromone produced by female striped ambrosia beetles, *Trypodendron lineatum* (Olivier), was responsible for mediating secondary attraction to and mass attack of host logs.

Since the arrival of John Borden at SFU in 1966, studies in insect chemical ecology have been closely linked with, but not restricted to, faculty members at SFU. In 1981, interdisciplinary research in chemical ecology was formalized by establishing the Chemical Ecology Research Group (CERG) comprised of the entomologist John Borden, chemists Keith Slessor and Cam Oehlschlager, apiculturist Mark Winston and plant pathologist Jim Rahe. In 1992 Gerhard Gries joined the group. Group members have specialized on identification and development of pheromones to manipulate economically important insects in forestry, agriculture and stored products.

The list of achievements by CERG members is long and impressive. Particularly significant are the identification of bark and ambrosia beetle pheromones and their strategic deployment to alleviate the beetles' economic impact (Borden and McLean 1981; Borden 1990). Major accomplishments by CERG members and their students also include the identification of the honey bee queen's mandibular gland pheromone (Slessor *et al.* 1988), elucidation of pheromone biosyntheses (Plettner *et al.* 1996) and deployment of synthetic pheromone to manipulate the bees' behavior within and outside the hive (Winston and Slessor 1992). Gerhard and Regine Gries have used coupled gas chromatographic-electroantennographic detection (GC-EAD) techniques to identify new pheromones and kairomones for many insects, including the exotic orange wheat blossom midge (Gries *et al.* 2000).

Two 'semiochemical companies' are spin-offs of CERG's research activity. Phero Tech Inc., founded by SFU graduates in 1981, launched its commercial enterprise by offering a pheromone-based management program for ambrosia beetles. Today, Phero Tech offers a wide variety of semiochemical products, traps and services for North American and world-wide markets. Phero Tech Inc. also provides first employment for many graduates of the Master of Pest Management program at SFU. ChemTica Internacional, founded by Cam Oehlschlager and his wife Lilliana Gonzales in 1991 in Costa Rica, started out by marketing pheromones of palm weevils and rhinoceros beetles identified in CERG's laboratories. Like Phero Tech Inc., ChemTica now offers diverse semiochemical products, particularly in tropical regions.

Following the pioneering work of Chapman and Moeck, government-based scientists have also developed considerable expertise in the chemical ecology of insect pests in forestry and agriculture. In one of the earliest applications of GC-EAD technology (Struble and Arn 1984), Dean Struble (Agriculture Canada, Lethbridge Research Station) elucidated a number of lepidopteran pheromones. Roy Sheperd and Tom Gray of PFC

(1985) developed synthetic moth pheromones as a tool to monitor population densities of lepidopteran forest defoliators and to determine incipient outbreaks. Mike Hulme and Tom Gray of PFC (1994) successfully used pheromone-based mating disruption to control an infestation of the Douglas-fir tussock moth. Research by Sheila Fitzpatrick *et al.* (1998) of the Pacific Agri-Food Research Centre (PARC, Agassiz) on pheromone-based control of the blackheaded fireworm, a pest of cranberry, lead to 3M Canada's registration of the pheromone by the Pest Management Regulatory Agency. Gary Judd of PARC (Summerland) developed a research program aimed at integrating semiochemicals into orchard IPM systems and deciphering the mechanisms mediating pheromone-based insect control (e.g. Judd *et al.* 1997; Evenden *et al.*, 2000). Most recently, Bob Vernon of PARC (Agassiz) has implemented a mass-trapping program for the European wireworm in the Fraser Valley in an ambitious effort to save the local potato growing industry.

Current and future research by ESBC members in the fields of behavioral and chemical ecology of insects will continue to advance our basic knowledge about insects and to improve management of pest insects in commercial settings.

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Arthropods that attack man and domestic animals in British Columbia (1951 – 2001)

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INTRODUCTION

In 1951, the Dominion Livestock Insect Laboratory, built in 1938 on 32 acres of Mission Flats on the western outskirts of Kamloops, was the centre for Medical and Veterinary Entomology in the Province (Fig. 1). J.D. Gregson was in charge and ran the very successful tick laboratory that did much to reduce the incidence of paralysis of livestock, and the occasional human, caused by bites of the rangeland tick, *Dermacentor andersoni*. L.C. Curtis was in charge of the Household and Medical Entomology Unit until he retired in 1969. He was heavily involved in testing new post-war insecticides and repellents and many of our Society's photographs show him with a portable sprayer or fogger. G.P. Holland, who had been involved with Gregson in the biology and control of fleas, mosquitoes, warble flies and ticks, had just left the laboratory in 1948 to head the Systematics Unit at the Central Experimental Farm, Ottawa. He had been responsible for identifying many thousands of fleas sent in by the Plague (*Yersinia pestis)* Survey carried out during and after World War 2.

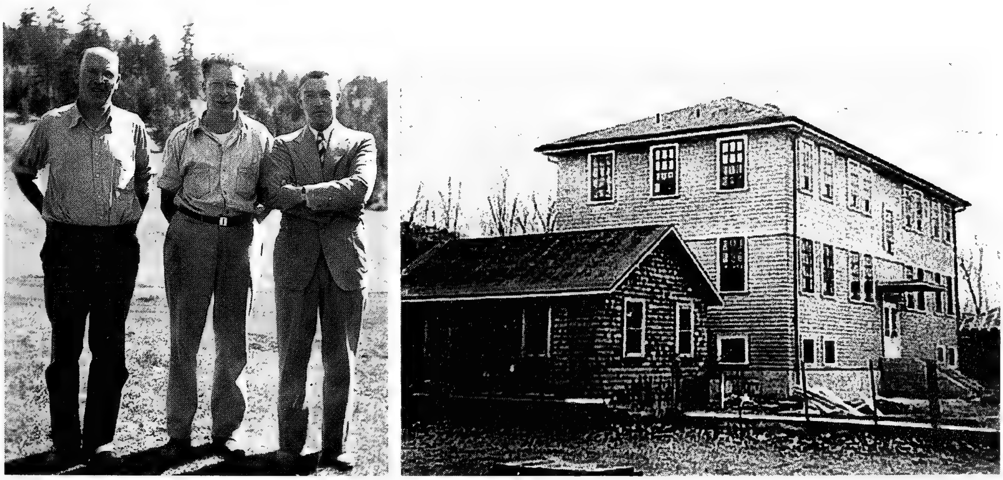

Figure 1. Left, Professor George Spencer, Ivor Ward and G. Allen Mail. Right, newly completed Kamloops Laboratory. In the 1940s, Mail had just taken over from Spencer as Officer-in-charge of the Lab. Ward shared an interest in grasshoppers with Spencer and later became Provincial Entomologist until his untimely death in 1947.

All three left milestone publications of their Federal work (Gregson 1956, Curtis 1967, Holland 1949). Holland was partly replaced by J. Weintraub who acquired a lasting interest in insects as a summer student at the Dominion Parasite Laboratory in Belleville. He was appointed in 1949 and quickly became a world expert on the ecology and physiology of warble flies. G.B. Rich also joined the Livestock Laboratory that year as a student assistant from UBC. He worked with Weintraub on the flight range of warble flies, and with Curtis surveying mosquitoes and controlling them at their breeding sites. He later became well known for his work with lice, and devised some of the early trials of systemic insecticides to control lice and warble grubs. His careful large-scale experiments showed that cattle grubs and lice could be eradicated over as much as 200 square miles of ranchland.

TICKS

Research on our ticks was continued by P.R. Wilkinson who studied their management, resistance, life histories and host relationships until the Livestock Insect Section was closed in 1971. Wilkinson then joined Weintraub who transferred to the larger Federal Research Station at Lethbridge, AB in 1953.

Ticks are potentially the most important vectors of human diseases in the Province. In addition to causing the paralysis that was responsible for at least 27 human deaths by the 1950s (Gregson 1956), they can transmit Powassen and Colorado tick fever viruses, Rocky mountain and Q fever rickettsias as well as the spirochaete bacteria that cause relapsing fever and Lyme disease. Relapsing fever was first reported as an outbreak in the Kootenays in the 1930s (Palmer and Crawford 1933) and bites from the fast-feeding tick *Ornithodoros hermsi* probably were, and continue to be, responsible (Gregson 1956).

Lyme disease, which made a sudden appearance in an epidemic at Old Lyme in the eastern United States in 1977, has a curious history. By 1990, 11 cases had been reported in British Columbia as well as 84 in Ontario and Manitoba (Anon.1991). The western vector, *Ixodes pacificus*, was a severe problem in the 1940s in West Vancouver, the Malahat on Vancouver Island and Harrison Bay and Cultus Lake in the Fraser Valley. At that time, however, it was not associated with disease but was known for its painful slow-healing bites that could be exacerbated if the long mouthparts broke when the tick was being removed. There is still some doubt whether Lyme disease is established in our Province. People travel freely across the continent and modern and extremely sensitive chromosomal diagnostic techniques may exaggerate its prevalence but, on the other hand, before these techniques were used, real cases of Lyme disease may have been misdiagnosed as arthritis from other causes.

Tick research in BC is still largely concerned with livestock and a Ministry of Agriculture entomologist at the Kelowna office, H. Philip, in collaboration with T. Lysik in Lethbridge is currently looking at immune responses to tick bites.

SPIDERS

In the last 50 years two types of spider bites have been reported. Western black widow spiders (*Latrodectes hesperus*) are not uncommon in southern BC. The females are large, about 2cm across the legs, and have a shiny black abdomen, with ventral red markings on most specimens. They can inject a neurotoxic venom with their bites which occasionally require medical treatment, but G.A. Mail, Gregson's predecessor at the Kamloops Laboratory found that the venom had no effect when injected into the leg muscle of a guinea pig. Perhaps encouraged by this, Mail tested it on his own arm, which became red, swollen and painful for about 4 days. When he heard of it, the Dominion Entomologist, Arthur Gibson told Mail firmly to restrict his experiments to the laboratory animals

(Riegert 2000). The symptoms can usually be treated successfully with calcium injections. The other type of spider bite seems to cause slow healing wounds. One of the earliest medical investigations of it in the Province was reported from Kamloops (Davies 1963). The patient was bitten on the thigh, she believed "during the night" and necrotic arachnidism was diagnosed although the spider was not found. Such bites are often attributed to *Loxosceles reclusa*, the brown recluse of the southern US, but R.G. Bennett (2002) has recently emphasised that this species, whose bite can cause serious necrotic injury, has not been recorded in BC (nor in Canada). Since the early 1980s there has been an increasing number of reports of such bites being blamed on the introduced agelenid hobo spider (*Tegenaria agrestis*) which can be found at various localities, and often in homes, in southern BC. In 1999 Dr.G.Willis of the Vancouver Poison Control Centre received 132 calls (but still less than 1% of her annual total) relating to spider bites. Bennett notes that reports of such bites claimed to be from *Tegenaria* species are seldom accompanied by the actual spider and are better explained by other factors. Binford (2001) gives some of these explanations and shows convincingly that the proteins in the venom of these introduced spiders are not significantly different from those found in Europe where necrotic bites from them have never been reported. A search for necrotizing enzymes like the sphingomyelinase D found in recluse spiders (Goddard 1999) might be worthwhile.

BITING MIDGES

A group of biting flies that were just considered a nuisance, the Ceratopogonidae (biting midges or no-see-ums), became important in 1975 when Bluetongue, a quarantinable virus disease of sheep and cattle, was reported for the first time in Canada near Osoyoos. Seven species including one thought to be a major vector, *Culicoides variipennis*, were known in the Province (Curtis 1941) but none had been collected in the south Okanagan valley. Agriculture Canada organized an extensive survey led by R.D. McMullen. They identified another 9 species of mammal-biting midges but no virus was detected in the many adults of *C. occidentalis* and other potential vector species tested (McMullen 1978). It is now certain that *C. sonorensis* is the major vector of Bluetongue virus and that it was previously misidentified in BC as both *C. variipennis* and *C. occidentalis* (Holbrook *et al.* 2000). A second surge of interest in these insects followed the recognition of their association with Sweet Itch, an allergic reaction of horses to midge bites. Fifteen cases, the first in Canada, were reported in southwestern BC (Kleider & Lees 1984) and a later survey by Anderson *et al.* (1988) showed that up to 26% of horses in the Province were affected becoming unrideable and unworkable. She trapped two new midge species bringing the total in BC to 18 (Anderson *et al.* 1993). Borkent (unpublished 2001) has now identified 31 species of these pests from the Province and suggests that another 11, found just across State and Provincial borders, may also be here.

BLACK FLIES

The start of our second half century was marked by an outbreak of another group of biting flies, the Simuliidae or black flies, in Cherryville in the Shuswap region (Curtis 1954). In 1952 the Provincial Entomologist, C.L. Nielson, was asked to investigate their control. He enlisted the help of L.C. Curtis who found many black fly larvae in Cherry Creek in March and used a control program based on the one perfected by F.J.H. Fredeen in Saskatoon (Riegert 1999). Treatment with 0.1ppm DDT cleared Cherry Creek, Eight-Mile Creek and the Shuswap River of black flies much to the satisfaction of local ranchers. The fly, at first thought to be a new species, was later identified by Fredeen as *Simulium defoliarti*, a large-mammal biting species less toxic to cattle than the prairie biter, *S. arcticum*. Nevertheless it seems to have caused some cattle deaths although our Province appears to be less affected than Alberta and Saskatchewan where *S. arcticum* can still cause toxic and allergic reactions and fatal stampeding.

MOSQUITOES

Mosquitoes are second only to ticks as carriers of human diseases. Two viruses, Western equine encephalomyelitis (WEE) and Snowshoe Hare (SSH), in the California group, have or can potentially cause clinical disease in BC. Two human deaths from WEE occurred in the Interior in 1971 and cases are reported in unvaccinated horses, presumably brought north by virus-infected migratory birds. SSH is endemic in the north but does not seem to cause disease in humans west of Ontario (McLean 1975). Some viruses with very high concentrations in the host's blood can be transmitted on the mouthparts of almost any biting insect. Fortunately mosquitoes have never been found to transmit Human Immunodeficiency Virus in this way but the fatal Myxoma rabbit virus is thought to be transmitted thus by mosquitoes in the western US and is a potential threat here. Human malaria has not been transmitted so far in BC by our indigenous *Anopheles* species although one of them, *An. freeborni* is a capable vector in the southwestern US. Mosquitoes can also transmit parasitic nematodes but the only one of concern in the Province is a heartworm restricted to dogs and the odd cat, perhaps only established in the dry interior (Slocombe 1999).

Curtis (1967) described 42 mosquito species in BC and listed five more that might be expected. Since then, two species new to Canada, *Aedes togoi* and *Ae. nevadensis*, and two of the species Curtis expected, *Ae. melanimon* and *Culiseta minnesotae*, have been found in the Province bringing the total to 46 (Belton 1983). *Aedes togoi*, first collected in Horseshoe Bay, is thought to have arrived by boat from Japan and is now known from rock pools in Cortes Island south to Fidalgo Island, WA, in the south and west to Bamfield on the Pacific coast, all of them close to harbours. In Asia, *Aedes togoi* is a known vector of both Japanese B Encephalitis and filarial nematodes.

OTHER BITING PESTS

In 1955 the Provincial Entomologist, C.L. Neilson, with the help of the Federal entomologists in Kamloops, kept agricultural workers up to date on the recommended control practices for other biting livestock insects with a duplicated "Handbook of the Main Economic Insects of British Columbia". He mentions female horse and deer flies that can consume their own weight in blood at each feeding and transmit tularemia in the Interior of the Province. He knew of 24 species in BC, all of which bite, most of them between June and September. Teskey (1990), who recently updated this number to 60 species, names another seven diseases of mammals that they can transmit in North America and pointed out that their painful bites make them likely to be dislodged while feeding and thus more likely to transmit infections to their next host. Snipe flies (Rhagionidae) like the horse flies to which they are related, can sometimes be troublesome human pests in woodland, even in greater Vancouver. Neilson also deals with horn flies, stable flies, keds, biting and sucking lice and poultry mites in his handbook and all of them can be found as biting pests of domestic animals today.

MANAGEMENT

In the 1950s and 60s DDT and methoxychlor were thought to have a relatively low toxicity but Neilson (1955) warned agricultural workers that DDT was eliminated very slowly by mammals and would "build up if not used wisely." Some of his recommendations were for rotenone, derris and pyrethrum – "almost non-toxic for man and animals." Some of the techniques he suggested were designed to limit the broadcast use of pesticides, for example setting up self-applied back-rubbers in pastures and paddocks to control lice and flies.

Curtis (1967) recognised that the removal of larval habitat was "the most important and efficient" method of mosquito abatement and this has been going on, consciously or not, since the first immigrant settled in the Province. He promoted larviciding with pesticides or by encouraging predators and parasites as the next best management technique "as the larvae are confined to their native water and cannot escape". He described adulticiding as "the method of last resort" to be used when larval treatment was not possible or when adults invaded from distant breeding areas. This advice can hardly be bettered although there is valid concern nowadays for the preservation of wetlands. Curtis wrote that at that time "the most spectacular, popular and expensive method" of controlling adults was by aerial spraying, covering large areas in a short time. Using persistent insecticides this technique provided immediate relief and often also a barrier to further invasion. Unfortunately in the mid-1960s there were several incidents where pesticides were misused. In Kamloops, for example, 45 gallon drums of DDT and 2-4-D were confused and an airspray defoliated most of the urban trees leaving a large population of adult mosquitoes unharmed. Adding insult to injury, many of the trees, which probably would have recovered, were cut down and replaced. Several such incidents lead to the drafting of new regulations for the old Pharmacy Act in 1969. Courses were taught and examinations required for licenses to resell and to use pesticides and for certification of individuals to dispense and apply them.

At that time a strong environmental lobby group, pioneered by SPEC, the Society for Pollution and Environmental Control, developed in the Province and there was considerable opposition to aerial adulticiding particularly in Coquitlam. Malathion, a short-lived organophosphate and Baygon, a longer lasting carbamate insecticide were registered for aerial application but in 1971 some of the residents showed their objection to this procedure by flying balloons in the path of the spray plane.

The New Democratic Party came into power in 1972 and ordered a Royal Commission on Pesticides and Herbicides. The commission recommended (14-III) "Aerial spray for mosquito (sic) should only be permitted if there is a real threat to human health or livestock. The decision to allow aerial spraying for adult mosquitoes should lie solely with the Minister of Health Services and Hospital Insurance. Aerial distribution of chemical larvacides should only be undertaken under permit from the proposed Pesticide Control Branch." It also recommended that Provincial Government leadership should be provided "to establish rational ongoing mosquito control programmes." At that time the Ministry of Agriculture employed a medical entomologist, R.A. Costello, but until 1974 he was in a Ph.D. programme at Simon Fraser University and unable to devote much time to mosquito control. However in 1976 the Minister of Agriculture, Don Phillips, approached P. Belton, an impartial academic with an interest in mosquitoes, to chair a Provincial Mosquito Advisory Committee. The committee included Costello, two medical doctors, a pesticide chemist, representatives from Environment Canada, Provincial Fish and Wildlife, a private consultant and (a masterstroke) Mrs. M. Doucette, the chair of SPEC. For just over 10 years, and with a few changes in membership, the Committee amicably prepared and revised a Mosquito Control Guide and generally advised the Minister of Agriculture on policies and procedures. In 1978 the new Provincial Pesticide Control Act came into force and by 1987 the Ministry of Environment had taken over the regulation of pesticides, following the recommendations of the Royal Commission, and the Ministry of Agriculture and Food no longer published the Guide. For several seasons mosquitoes had not been a great problem, partly because of low river levels associated with slow melting snow. Another reason was the improved management of the larvae of human-biting species, with better mapping of breeding sites and the intelligent use of the very effective and selective *Bacillus thuringiensis*, serotype H14 larvicide. In 1988 the Mosquito Advisory Committee quietly dissolved.

In the 21st century, most active control of biting flies is done by larviciding. Highly effective and specific bacterial toxins are applied to breeding sites, which can be mapped and located using satellite techniques. Door and window screens and repellents are often recommended as a first line of defence, but in most regions adults may be controlled on request, often requiring unanimous groups of local residents. One of the original controversial organophosphates, malathion, is still being used applied from the ground to control adult mosquitoes when their numbers warrant it. Unless there is a medical emergency, the malathion is applied as a low volume spray from trucks which can avoid residents who object to spraying and others likely to be affected, such as beekeepers.

CONCLUSIONS

Biting insects and arachnids in BC seem to have survived about 10 millennia of competition with humans. Our development of their habitat has undoubtedly reduced the numbers of some species, but others, for example, that can develop in ditches, irrigation runoff and containers, may have benefited. Dams may reduce seasonal flooding of rivers but often change their characteristics to the advantage of some species of black flies (Riegert 1999). Many species of ticks feed on several different hosts during their life cycle, and changes, for example in the population of lizards, mice or deer, might affect the numbers of ticks that could feed on humans. There is also valid concern that global warming, possibly related to the increase in human population might increase the population of disease-bearing species in what are now cooler parts of the planet. It might also prolong the life of some vectors, giving them more opportunity to transmit diseases.

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Forensic entomology in British Columbia: A brief history

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Forensic, or medicolegal, entomology is the study of the insects associated with a dead body, primarily to determine time of death. In its broadest sense, forensic entomology actually refers to any legal activity that involves insects or other arthropods. This includes urban entomology, involving insects which affect the human environment, such as structural damage by termites or carpenter ants and even spider bites (Haskell *et al.* 1997) and stored products entomology, involving the insects and insect residue in stored products such as grain and flour. However, it is the medicolegal or medicocriminal aspects that are most commonly referred to by the general term 'forensic entomology'.

Determining time of death is paramount in a death investigation. Knowing time of death focuses the police investigation into the correct time frame, can support or refute a suspect's alibi, helps in the identification of an unknown victim, improves efficacy of the police investigation and most importantly, is vital in determining time line prior to death, victim's whereabouts, associates seen with victim, *etc.* Determining time of death is, therefore, vital. Pathologists can estimate time of death based on several medical parameters (Henssge *et al.* 1995) but these are only valid for the first few hours after death, becoming less valuable as time passes and can usually not be used beyond about 72 h. However, homicide victims are frequently not discovered for days, weeks or months. Forensic entomology is the most accurate, and frequently the only method of determining time of death when more than a day or two have elapsed (Kashyap and Pillai 1989). It continues to be valuable up to a year or more after death. Forensic entomology also can be used to determine whether the body has been moved from one site to another, whether the body has been disturbed after death, the position and presence of wounds, *etc.*, but its primary use is to determine time of death.

A dead body, whether animal or human, is a rich but temporary and ephemeral resource, exploited by many organisms, primarily insects. Within minutes of death, assuming conditions are suitable, insects, primarily the Calliphoridae and Sarcophagidae, colonize a body, developing at predictable rates, based on environmental and meteorological conditions (Anderson and Cervenka 2001; Anderson and VanLaerhoven 1996). As the body decomposes it goes through rapid biological, chemical and physical changes, attracting a sequence of colonizing insects until nothing of nutritional value is left. This sequence of colonization depends on biogeoclimatic zone, habitat, season, microclimate *etc.* but is predictable within those parameters (Anderson 2000a). This predictable and sequential colonization of a body allows an entomologist to determine the tenure of the insects on the body, and therefore the minimum time since death.

The use of insects in death investigations dates back to 13th Century China (McKnight 1981) and came into some use from the mid 19th Century in Europe (Smith 1986; Yovanovitch 1888). This early interest led to a study on insect succession on human corpses in Quebec, Canada, in 1897 (Johnston and Villeneuve 1897). However, little forensic entomology was used in Canada after this time until the 1970s, when police interest in forensic entomology began to grow in North America, with interest developing in three major centres in North America: one of those was Vancouver, British Columbia.

In the 1960s and 1970s Peter Zuk, Vancouver Research Station, Agriculture and Agri-Foods Canada (then Agriculture Canada) was involved in several cases for the police, including the infamous Clifford Olsen cases. He was probably the first to present forensic entomological evidence in court in Canada, and certainly in British Columbia. In the early 1970s, police came to Dr. John Borden at Simon Fraser University wondering whether an insect found on a dead railway worker might be implicated in his death. John identified the insect as *Monochamus* species (Coleoptera : Cerambycidae), and stated that it could only be the cause of death if the decedent suffered from an extreme case of entomophobia! Forensic entomology at Simon Fraser University was born!

During the 1970s and early 1980s, Professor Thelma Finlayson, of the Centre for Pest Management at Simon Fraser University, received preserved specimens from several cases and was able to provide identifications and expertise. Cases were handled when a police officer had a specific question about insects involved in an investigation, but only on a sporadic basis, with Professor Finlayson, Dr. Borden and members of his lab providing the expertise. Other entomologists were also sometimes called in on a case by case basis. In the early 1980s, the BC Coroners Service approached John Borden about providing forensic entomology expertise on a more regular basis. John enlisted the aid of Akbar Syed, the head of the Simon Fraser University Insectary, and Akbar was involved in about a dozen cases until 1987. He attended crime scenes and autopsies and testified in court as an expert witness in forensic entomology (Skinner *et al.* 1988).

By 1987, police interest in the field was increasing, and case work and the need for court appearances was growing. I was just starting my Ph.D. in medical and veterinary entomology, with Dr. Peter Belton and Dr. John Borden at Simon Fraser University in the Centre for Pest Management. In late 1987, John Borden approached me and asked if I would like to take over the forensic entomology, as case work was increasing and Akbar Syed no longer wished to continue taking cases. Intrigued by the idea, I agreed. Although I immediately delved into the literature, nothing happened until August when I was thrown into the deep end with two cases arriving on the same weekend! One was a young man and another a single human thigh. I attended my first two autopsies on the same day! I determined the young man had been dead for a little over 3 weeks, based on the presence of Calliphoridae puparia and pupae, and the thigh had been colonized 3-4 days prior to discovery, based on Calliphoridae larval development. Both cases remain unsolved at time of writing. Although already an entomologist and continuing in my entomology training under John and Peter's guidance, I had no knowledge of forensic science, crime scene analyses, autopsies, court procedure *etc.* However I was fortunate to be kindly guided in this by then Corporal Bob Stair, (now Staff Sergeant, Retired) Royal Canadian Mounted Police (RCMP), Regional Forensic Identification Support Section (RFISS), Coroners Bart Bastien and Chico Newell of the BC Coroners Service Forensic Unit, and pathologists Dr. Sheila Carlyle, Dr. Laurel Grey and Dr. Rex Ferris. Everyone in the forensic field was extremely supportive and enthusiastic and I was hooked!

Case work was increasing every year and by late 1991 I was about to complete my graduate work. Therefore John Borden met with the Coroners office and the University and raised the money between the two to establish a position in forensic entomology at Simon Fraser University for me, which began in 1992. The Information and Identification Services Directorate and the Training Directorate, Royal Canadian Mounted Police (RCMP) later also supported this position.

It had become apparent to me during my case work that there was a desperate need for more research in this field: there had been no research in Canada since 1897 (Johnston and Villeneuve 1897), and none in BC. As a newly minted Ph.D. and professor I could now devote my research to forensic entomology. Analysis of maggot development, used in the early days and weeks after death, is based primarily on temperature, humidity and species so literature reports, although at the time few in number, could be applied. Insect succession over time, however, is much more dependent on local conditions and so literature reports from other areas, seasons, habitats *etc.* are not applicable. Therefore, the first research project in forensic entomology this century in Canada, and ever in BC was begun in 1992, funded by a small start up grant from SFU. I hired a keen young second-year year undergraduate student, Sherah VanLaerhoven and our first pig project began!

This first study looked at insect succession on carrion beginning in one season, summer, one scenario, direct sunlight, and was conducted in the Lower Mainland of BC, the Coastal Western Hemlock zone, using freshly killed pig carcasses. Pigs have long been accepted as the best model for human decomposition studies (Catts and Goff 1992) due to their similarity in skin type, gut bacteria, size, and relative lack of hair. Insect colonization on the carcasses was studied over a 10-month period. Results were dramatic. In previous studies in other temperate countries, with very similar climates to the Lower Mainland of BC, such as Britain, publications had suggested that key colonizing groups, such as Dermestidae (Coleoptera) and Piophilidae (Diptera) arrived months after death. Dermestidae were generally considered to be the last group to feed on the remains worldwide in temperate zones, with the majority of adults and larvae being collected in the final stages of decomposition when only skin and bones remain (Early and Goff 1986; Smith 1986; Rodriguez and Bass 1983; Payne and King 1970; Easton 1966; Reed 1958; Fuller 1934), although the actual post mortem interval varied with geographic region. Early colonization was only reported from much more tropical regions, such as Hawaii (Hewadikaram and Goff 1991; Early and Goff 1986). The only other report of insect succession on carrion in Canada states that Dermestidae, including *Dermestes frischii* Kugelman, were not collected on human remains until 3-6 months after death, despite compelling evidence of a case in which *Dermestes* sp. were found less than 5 weeks after death (Johnston and Villeneuve 1897). However, in the Lower Mainland of BC, Dermestidae larvae were first collected 21 days after death, and were commonly collected after 43 days post mortem (Anderson and VanLaerhoven 1996).

Piophilidae or skipper flies were similarly collected earlier than previously reported, with larvae being present 29 days after death. This confirmed case work in which I had collected Piophilidae from human remains 26 days after death (Anderson 1995). This initial study (Anderson and VanLaerhoven 1996) highlighted the need to conduct research in all biogeoclimatic zones, seasons and habitats in which forensic entomology is used. Such data are not necessarily transposable to other regions.

When large numbers of maggots congregate on a body, they form masses which generate high temperatures, affecting development rates. It had been previously assumed that although diurnal temperatures obviously fluctuated, internal carcass temperature fluctuated less, remaining at a higher, more constant temperature than ambient (Deonier 1940). Previous studies had measured maggot mass temperature daily but only at a single time each day (Shean *et al.* 1993; Early and Goff 1986; Payne 1965). In our experiments, we placed datalogger probes inside the carcasses, continuously recording internal carcass temperature, and found that although internal carcass temperature does increase considerably during active decay, there is greater fluctuation in internal than ambient temperature, with diel differences of more than 35°C (Anderson and VanLaerhoven 1996).

This study became the foundation for our future work. Research was needed in different geographical areas and situations as I was training police officers, in BC and across North America (Anderson *et al.* 1996; Anderson 1993a, b, 1991), so case work was increasing rapidly (Anderson 1995). I was also testifying in court as an expert witness, or my report was admitted as evidence in more and more cases.

Funding from the Canadian Police Research Centre (CPRC) allowed me to take on my first M.Sc. student, Leigh Dillon, and to expand the research into three biogeoclimatic zones, the Coastal Western Hemlock zone, the Sub-boreal Spruce Zone and the Interior Douglas Fir Zone. Although BC is divided into 14 biogeoclimatic zones, these three zones include the most populous areas, such as the majority of the Lower Mainland, Vancouver

Training police officers to collect insect evidence in a mock homicide scene.

Island, Prince George Region and the Okanagan, so consequently are the areas from which most forensic cases originate. This work again used pig carcasses as human models and insect succession was studied in the three zones, in spring, summer, and fall, in sun and shade.

Colonization times varied with season, habitat and biogeoclimatic zone, and occurred in a predictable sequence with similar species colonizing in each area, although colonization times varied (Dillon 1997; Dillon and Anderson 1996a, 1995). Some species were found in all areas, but in some areas certain species predominated. A distinct difference was noted between pigs in sun and shade, in species composition and abundance, as well as seasonal differences in both. Level of shade impacted decomposition rates, actual species attracted and arrival times. Pigs in shade were also scavenged more heavily by vertebrates, which impacted insect colonization (Dillon 1997; Dillon and Anderson 1996a, 1995).

This work generated excellent databases of insect succession on carrion for these biogeoclimatic zones and also confirmed our previous observations of earlier colonization times for many species in BC in comparison with some other regions, and the diurnal temperature fluctuations within the maggot mass. However, this work also showed that in some cases, primarily those in shade, or cooler seasons, the oldest maggots would enter the prepupal stage and leave the body before the high temperatures were generated by the maggot mass (Dillon 1997; Dillon and Anderson 1996b). This obviously has a major impact on determining time of death using maggot development. Maggot mass temperature is usually taken into account when determining age of the oldest maggots, but this work indicates that in some cases, the oldest maggots may not be impacted by the maggot mass.

However, early on in the research, although the pigs in spring and fall, and those in the shade in summer decomposed in a manner similar to the human cases I was analyzing at the time, we noticed that Leigh's summer, sun pigs decomposed much faster than a human body, with the skin and extremities actually mummifying (Dillon 1997; Dillon and Anderson 1995). We realized that, while the pigs that Leigh was working with were naked, the majority of the human cases I was involved with were clothed. We also noticed that the majority of my previous cases involved either clothed, partially clothed or wrapped bodies.

We postulated, therefore, that clothing might be having an effect on pig decomposition and insect colonization, as clothing absorbs body fluids, and provides habitats for insects. I sent a simple little electronic message to my departmental colleagues requesting donations of used clothing. The message somehow reached the media; to Associated Press and then went international! I received large quantities of used clothing from all over and we were able to clad our pigs! For years, I continued to receive disreputable packages of old clothing! However, some good did come of all this as although my work had received a tremendous amount of media attention prior to this, which continues to this day, it was this particular attention that was noticed by an entomology student in Ontario, Niki Hobischak, who became my third graduate student.

In 1995, a wildlife enforcement officer noticed this work and contacted me, asking whether forensic entomology could be applied to poaching cases. Bear poaching is a major crime in BC with animals being taken illegally as trophies and for body parts, primarily for the Traditional Chinese Medicine market. Most carrion insects are ubiquitous and do not discriminate between carrion species, except in the case of particularly small carcasses (Denno and Cothran 1975), and most species are more likely to colonize animal carcasses than human bodies, simply due to availability. However, although pigs are accepted as good models for human decomposition, it was not known whether they would be valid as models for bear decomposition. Therefore, supported by various wildlife organizations, including World Wildlife Fund and the Vancouver Foundation, we added several bear carcasses to Leigh's project. These were bears that had been killed as nuisance bears, which are normally incinerated. In 1995, they were donated to forensic entomology research! Obviously we could not get enough bears at the same time for a full experiment, but Leigh was able to compare bear decomposition and insect colonization with her extensive pig experiments (Dillon 1997; Dillon and Anderson 1997, 1996b). Leigh Dillon graduated in 1997 and is presently a coroner with the BC Coroners service.

In 1995, I was called into my first bear poaching case, in which two cubs had been killed for their gall bladders. The case involved first instar Calliphoridae eclosion rates and I testified in the court case in 1996 (Anderson 1999). The insect evidence indicated a time of death that successfully linked two suspects to the scene. Both defendants were found guilty of two counts of poaching under the Provincial Wildlife Act of Manitoba. They were sentenced to 3 months in jail per count. This was the first time in Canada where a jail term was secured for the actual poachers of the animals in question and has set a precedent.

By this time, the compilation of an extensive database was under way in BC for bodies found above ground, but many bodies are buried and there was little research worldwide on buried carrion, and no research for BC. This point was brought home when the body of a child was found in a shallow grave nearly two months after the child was last seen alive. I collected the insects from the grave and autopsy but had no direct database with which to compare. Sherah VanLaerhoven, my first forensic entomology research assistant, was completing her undergraduate degree with a small research project in my lab (VanLaerhoven and Anderson 2001) and decided that she would like to do her Master of Pest Management on insect colonization of buried bodies. Again funded by the CPRC, and with support from the RCMP, large numbers of clothed pig carcasses were buried in shallow graves in two biogeoclimatic zones, with above ground carcasses as controls. Three pigs were exhumed each time and their fauna analyzed at 2 and 6 weeks, 3, 6, 12 and 16 months. This work showed that burial encouraged some species and discouraged others. In particular, species in the family Calliphoridae, although present, were much rarer on buried bodies (VanLaerhoven and Anderson 1999; VanLaerhoven 1997; VanLaerhoven and Anderson 1996), than on above ground carcasses (Dillon 1997) and Muscidae were much more common, possibly due to the lack of competition with Calliphoridae. In some cases, the same species were present above and below ground, but at very different times. For instance, *Fannia* species (Diptera: Fanniidae) were found 6 weeks or more after death in above ground bodies (Dillon 1997), but were found within 2 weeks of death on buried bodies (VanLaerhoven and Anderson 1999; VanLaerhoven 1997; VanLaerhoven and Anderson 1996). Decomposition was also greatly slowed by even such shallow burial. As Calliphoridae were low in numbers, no maggot masses formed so carcass temperature remained very close to soil temperatures (VanLaerhoven and Anderson 1999; VanLaerhoven 1997; VanLaerhoven and Anderson 1996). This is quite different from data from Tennessee in human bodies (Rodriguez and Bass 1985), and also from our preliminary research in Alberta in which maggot masses did form, indicating major geographic differences. This work indicated that it is difficult if not impossible to extrapolate data from above ground research to buried victims. I used these data when I testified in both the preliminary and supreme court trials associated with the death that had prompted this research in the first place. Sherah went on to complete a Ph.D. in entomology at the University of Arkansas and has now returned to BC as an NSERC postdoctoral fellow at Agriculture and Agri-foods Research Station, Agassiz and Simon Fraser University with Dr. Dave Gillespie and Dr. Bernie Roitberg. This is coming full circle, as Sherah first became intrigued with entomology in Dave's lab as a volunteer at the research station when she was just 17!

We had developed databases for terrestrial environments, both above ground and buried. However, whenever I gave seminars to police officers, one of the first questions asked always concerned what happens to a body in water? So, in January 1996, Niki Hobischak began an MPM degree on the effects of freshwater submergence on a body, funded by CPRC. Pig carcasses were again used to model human decomposition and were compared with human deaths in similar habitats. Niki looked at decomposition and faunal colonization on carcasses in freshwater streams and ponds and found that variation in aquatic organisms occurred over time, based primarily on season but also on decompositional stage, with Trichoptera being the major scavengers. Calliphoridae also colonized when parts of the body were exposed, but were rarely successful (Hobischak and Anderson 2002; Hobischak 1997; MacDonell and Anderson 1997). The pig carcass research compared well with human death cases with known elapsed time since death in the same time period (Hobischak and Anderson 1999). Niki was a Coroner after completing her MPM in 1997, and is now the Research Coordinator for the Forensic Entomology Lab at Simon Fraser University.

In 1997, I moved to the School of Criminology at Simon Fraser University, and in 1999 received funding from the Ministry of the Attorney General of British Columbia, Proceeds of Crime Fund and the University, to build the first laboratory in Canada dedicated to forensic entomology. Through the lab, I am now coordinating research across Canada to develop databases of insect succession on carrion in several biogeoclimatic zones. This work involves extensive collaboration with entomologists, forensic scientists and students in several provinces.

Although by then data existed for the effects of freshwater decomposition on a body, no data were available for bodies in the marine environment. In talking with Cpl. Bob Teather, RCMP (retired) a distinguished police diver, I mentioned my desire to look at the effects of marine submergence on faunal colonization and decomposition rates of a body. However, this project was limited by a lack of resources such as boats, divers *etc.* Bob said "well, we have divers, we have boats!". So the marine project was born. Funding was provided again by the CPRC, but massive in kind support, including divers, boats, hovercrafts, field research facilities, safety equipment *etc.* was provided by the RCMP, Canadian Coast Guard, Canadian Amphibious Search Team and the Vancouver Aquarium Marine Sciences Centre. Pig carcasses were submerged in the waters off Vancouver shortly after death in both early summer and fall, and divers observed, photographed and sampled the carcasses every few days. In general Niki and I found that decomposition was much slower than in terrestrial environments, although the carcasses went through much the same stages. The tissue itself remained intact for much longer than on land, and decomposition was affected by whether the body was in contact with the sediment because the diversity of animals were limited when the body floated. A sequence of marine fauna colonized the remains, focusing at first on wounds but very shortly after, on non-wound areas, unlike terrestrial colonization where wounds and orifices are the focus (Dillon 1997; Anderson and VanLaerhoven 1996; Dillon and Anderson 1996a, 1995). Fauna included crustacea, mollusks, annelids and echinoderms (Anderson and Hobischak 2001). This work is ongoing.

Forensic entomology is now an established part of death investigations in Canada, as well as providing greatly needed knowledge on carrion ecosystems, an area which has often been sadly neglected in the past. It has extended into studying ancient human remains and a future collaboration will involve looking at Calliphoridae myiasis in live people for maggot debridement therapy for wounds. Present research includes extending our aquatic work into large bodies of freshwater and white water, the effects of commonly used human drugs, illicit and therapeutic, on insect development and the effects of several microclimatic features on insect development. Of course, the lab continues to receive many cases every year from BC and across Canada as well as from other countries. Each case is unique and often provokes more questions which will be addressed through the Forensic Entomology Lab at Simon Fraser University.

One of the most satisfying things about doing research in forensic entomology, for myself and my students is the knowledge that the data we generate can and will be used in a death investigation and a court of law, often very soon after it has been generated. In a case in Manitoba, I was testifying in the second degree murder trial of a man accused of murdering a teenage girl. Empty pupal cases of *Phormia regina* (Meigen) (Diptera : Calliphoridae) indicated that the insects had completed an entire life cycle on the body and I based my determination of a minimum elapsed time since death of 30 days (or 480.5 accumulated degree-days) on my lab generated data for this species (Anderson and Cervenka 2001; Anderson 2000b). During the preliminary trial, defense counsel argued that the data were lab generated and therefore could not be applied to a field situation. Although it was true that the data were lab generated, Calliphoridae larval development is primarily temperature driven, so lab conditions can simulate the main parameters involved. However, it was true that I did not have field data to back up my lab data. Just weeks before the supreme court trial, by sheer coincidence, Leigh Dillon's field work had been conducted in almost the exact same weather conditions as those in the case. She noted that it took the first specimens of *Phormia regina* exactly 30 days to complete development under those temperature conditions (Dillon 1997; Dillon and Anderson 1996a), confirming the lab data exactly. The defendant was convicted.

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Bees and pollination in British Columbia

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Bees co-evolved with flowering plants. Their wasp-like ancestors modified their diet and behavior in order to utilize the floral food resources that became available some 90 million years ago. In turn, plants were able to accelerate species diversification. The interdependency between flowering plants, especially fruit-bearing plants and insect pollinators became obligatory and in some cases developed into extreme specialization. In general, the abundance and species diversity of insect pollinators play a critical role in the ecology of many habitats in the world. Economic interests and demand for optimized yields in modern crop production systems have intensified the interdependency between crops and insect pollinators.

British Columbia's temperate environment and habitat diversity has facilitated the evolution of a rich pollinator fauna. The majority of its indigenous pollinators are solitary bees, characterized by the female establishing a nest on her own, and provisioning each cell with pollen, nectar and an egg. Many solitary bee species are gregarious and nest in the soil.

In comparison, only a small number of social bee species are indigenous to BC. These include bumblebees (*Bombus* spp.) characterized by one female (queen) having assumed sole responsibility of egg laying while all other individuals are sterile workers and males (drones). The vast majority of the offspring are workers responsible for food gathering, nest building, brood rearing and protection.

Winston and Graf (1982) identified six families of solitary bees in BC. These included *Halictus, Andrena, Auqochlora, Chelastoma, Melissodes* and *Xylocopa.* In 1987, Scott-Dupree and Winston (1987) examined the diversity of bees in Okanagan Valley orchards and found *Halictus spp.* most abundant, followed by *Andrena, Megachilidae* and *Anthophoridae.* Among bumblebees, *Bombus terricola* was most often recorded followed by *B. bifarius*, while at least ten additional species were noted. Mackenzie and Winston (1984) found *B. mixtus* the most abundant species in Fraser Valley berry crops followed by *B. occidentalis*, *B. terricola* and *B. flavifrons*.

Management of Bee Species for Crop Pollination

Although all bees play an important role in the ecology of most habitats, the development of agriculture in the province magnified the significance of their role (Matheson *et al.* 1996). John Corner, BC Provincial Apiarist from 1950 to 1983, assessed the suitability of using wild bees to improve pollination of various crops (Corner 1963). Corner selected the alkali bee *Nomia melanderi* for further trials. These bees were gregarious ground nesters from Oregon and were used in alfalfa pollination on a limited scale. Soil beds were established adjacent to alfalfa fields near Ashcroft and Kamloops and soil cores containing larvae were imported and successfully introduced. The bees became well established but the project was abandoned, as alfalfa seed production remained limited in the southern interior. Management suitability of *Bombus* spp. was also assessed in the Peace region for the pollination of red clover *Trifolium pratense*. The long-tongued species of *B. californicus* and *B. auricomis* were identified as most effective pollinators while *B.bifarius nearcticus* was deemed unsuitable.

Other trials involved the alfalfa leafcutter bee *Megachile rotundata* at sites in Creston, Vernon, Kamloops, Williams Lake and Peace River. Although leafcutter bee management proved successful under BC conditions, the alfalfa growers' unfamiliarity with seed production caused the abandonment of the projects in southern and central BC. Leaf cutter management proved a successful enterprise for some Peace operations specialized in alfalfa seed production.

Scott-Dupree and Winston (1987) noted a low count of the indigenous Blue Orchard Mason Bee *Osmia lignaria* in Okanagan orchards. This solitary and gregarious species had been previously identified for its manageability and excellent pollination characteristics under poor weather conditions. Scott-Dupree recommended this species be considered for management in BC's tree fruit and berry crops. In the same study, *B. occidentalis* and *B. nearcticus* were also suggested as candidates for commercial use. Since then, *O. lignaria* was never adopted as a significant pollinator in commercial crops, but it has gained considerable popularity among gardeners in urban settings in recent years.

Researchers have assessed the management and rearing suitability of a wide range of insect pollinators over many years. Pollinators with unique characteristics may still be selected for special crop pollination requirements in the future. Yet, of more than 4,000 insect pollinators identified in North America, only a few species have ever been managed in significant numbers for crop pollination purposes. These include the non-indigenous honeybee *Apis mellifera* L., two species of bumblebees (*B. occidentalis* and *B. impatiens*), the alfalfa leafcutter bee *M. rotundata*, and the Orchard Mason Bee *O. lignaria*.

Orchard Mason Bees

The Orchard Mason Bee (also called the Blue Orchard bee, Mason Bee or Osmia Bee) is the ideal 'urban bee'. During the 1990s, *O. lignaria propingua* became popular in urban garden settings because of its non-defensive behavior, low maintenance, and high pollinating efficiency in early blooming fruit bearing plants. Its popularization was further enhanced with the introduction of 'condominiums' or nest boxes that are now commercially available at garden centers and selected nurseries. Many initial enthusiasts were former beekeepers who no longer kept honeybee colonies following the introduction of the obligate parasitic mite *Varroa destructor* (formerly *V. jacobsoni* Oudemans).

The Osmia Bee has nesting behavior similar to *M. rotundata* where the gregarious female selects a tubular cavity where she lays up to 10 eggs in succession, each provisioned with nectar and pollen, and closed off with a plug. Since reproduction rates remain limited, this pollinator is not considered suitable as a primary crop pollinator in large-scale settings.

Bumblebees

Over 30 indigenous species of bumblebees (affectionately called 'Bumbles') have been identified in BC. The bumblebee tolerance to poor weather conditions has made this insect an ideal pollinator of early blooming plants. The characteristic 'buzzing' causes sticky, moist pollen grains to be dislodged, further enhancing the bumblebee's pollinating versatility. While honeybees have a complex communication system enabling them to utilize pollen and nectar sources over great distances, the bumblebee's solitary, non-directional food gathering limits its foraging range and makes it an ideal pollinator in the confined space of the greenhouse. Their smaller nests and comparatively low defensive behavior also reduces conflict with greenhouse workers. Bumblebees have become the principal pollinators in greenhouse tomato production providing higher crop yields, improved quality and earlier maturation at substantially lower costs than manual pollination. In BC, growers purchase nest boxes from eastern Canadian suppliers that include the indigenous *Bombus occidentalis* and the non-indigenous *Bombus impatiens*.

Honeybees

Honeybees are not indigenous to the Americas. They were first brought to North America from Europe in the 1600s. The first introduction of honeybees in BC was in the 1850s. Initially, these colonies were not prolific as most of the natural vegetation of the province did not offer sufficient nectar and pollen sources. As agricultural activities expanded in southwestern BC and the Okanagan, honeybees became well established.

The introduction of intensive agricultural practices in modern times has made the honeybee indispensable. Monocultural practices, pesticides, and the alteration of the soil and natural vegetation have contributed to the decline in the abundance and species diversity of wild insect pollinators (Matheson *et al.* 1996). Even with a natural abundance of pollinators, the pollination requirements of monocultural crop management systems can not be met. It has been estimated that an hectare of mature highbush blueberries produce 9 – 10 million flowers in spring when weather conditions are often not conducive to insect foraging activity. Only honeybee colonies with their large populations can meet crop pollination requirements at the time of bloom. The value of annual crop production in BC attributable to honeybee pollination has been estimated at over $161 million (Anon. 1999). For Canada, this value is estimated at approximately $700 million (Scott-Dupree 1995). In the USA with its milder climates, honeybee pollination has been valued at over $14 billion worth of agricultural production per year (Morse and Calderone 2000).

The first reference to using honeybees in pollinating crops for a fee was in the 1953 Annual Report of the BC Department of Agriculture. A total of 155 colonies were rented for tree fruit pollination at $2.50 - $6 per colony. By 1975, 5000 hive sets were recorded at an average pollination fee of $15 per colony. During the 1990s, 29,000 hive sets were rented each year with fees ranging from $50 in tree fruit orchards to $90 in cranberry *Vaccinium macrocarpon*. With the ongoing expansion of berry crops in the Fraser Valley and high-density plantings of tree fruits in the Okanagan, the demand for honeybee pollinating units has increased to 47,000 in 2001.

Honeybee Diseases and Pests

The perennial colony nest of honeybees offers ideal conditions to a range of pathogenic and non-pathogenic organisms. In 1586, Jacob of Germany first described American Foulbrood disease (AFB) caused by the spore-forming bacterium *Paenibacillus larvae* (formerly *Bacillus larvae* L.) (Otten 1999). The highly resistant spores remain viable for decades and pose a source of infection to bee brood in any infected hive equipment. Many countries in the world have enacted legislation to control the disease, which has traditionally involved the depopulation of colonies followed by burning of all the equipment. In the 1950s, antibiotics were introduced enabling beekeepers to control AFB effectively. However, the bacterial spores would not be killed but merely prevented of germination. The incessant use of antibiotics in beekeeping management has led to the development of antibiotic-resistant strains of *P. larvae* (r-AFB) in recent years.

Other bee brood diseases include European Foulbrood (*Bacillus alvei*), Chalkbrood (*Ascosphaera apis*) and viral diseases such as Sacbrood. Most of these ailments are stress related and can be managed relatively easily by the beekeeper. Nosema disease caused by the protozoan *Nosema apis* affects the midgut and ventriculus of adult bees, causing impairment in nutrient absorption. Effective control is obtained with the application of the antibiotic fumagillin.

With the arrival of parasitic mites, beekeeping changed radically. In 1986, the first infestation of the microscopic mite *Acarapis woodi* was confirmed in BC. Initially, the impact of this mite, affecting the tracheal tubes of adult bees, was much feared because of the widespread destruction of colonies that had been reported on the Isle of Wight in 1919. Since then, the tracheal mite has proven manageable for most beekeepers. Comparative studies on tracheal mite resistance in honeybees during the 1990s showed that resistant strains occurred in BC. Through selection, many beekeepers developed beestock with some level of tracheal mite resistance.

The first infestation of the highly destructive mite *Varroa destructor* was confirmed in 1990. Despite efforts to isolate the pest through colony movement restrictions, the mite eventually spread to most beekeeping areas in BC. *V. destructor* originated in Southeast Asia where it was a common pest of the eastern honeybee, *Apis cerana*. With the introduction of the western or European honeybee, the mite found a perfect host without defenses parasitizing brood and adult bees.

The high pathogenicity of *V. destructor* invariably leads to the demise of the colony if no controls are applied. In Canada, formic acid and the synthetic pyrethroid *fluvalinate* marketed under the trade name Apistan, have been registered to control this pest. The development of Apistan-resistant mites signals the end of the usefulness of this product. There are currently efforts to obtain an emergency registration of Coumaphos of Bayer, while other control methodologies are being sought at various research facilities in North America.

Use of Hive Products

Honey is the end product bees produce from the collection of floral nectar sources. While nectar is a sugary solution containing approximately 80% water, honey is a solution of enzymatically converted monosaccharides containing between 14 and 20% water. Its low water content prevents microbial growth and when kept airtight and in cool conditions, honey can be stored for many years. Virtually all stored honeys will undergo the physical process of crystallization over time. The rate or crystallization is determined by the relative abundance of the different sugars. Reversal to liquid honey can be accomplished through warming and stirring. In North America, honey is viewed as a fancy alternative sweetener to table sugar. In most other countries of the world honey is regarded as a scarce and valuable product to which many medicinal qualities are ascribed. While per capita consumption of honey in Canada is only 0.86 kg per annum, consumption in the Middle East exceeds 10 kg per capita per annum (Anon. 2001).

Pollen constitutes the primary protein source needed for brood rearing. Through special management, some beekeepers collect pollen for feeding to bees at a future date, for sale to other beekeepers, or for human consumption. Some of the pollen is also collected as a nutrient supplement for racehorses. The total amount of pollen sold for commercial purposes is limited.

Propolis (Pro – *for*; polis – *the community)* is a resinous material collected from floral and foliar buds. The material is used for plugging holes in the nest cavity, or encasing and mummifying foreign materials inside the nest that bees can't remove. Its strong anti-microbial and hydrophobic properties have long been recognized, from the ancient Egyptians to today's pharmaceutical industry.

Bee venom has long been used for controlling rheumatoid arthritis and various other ailments. A collection device has been developed where bees release their venom when exposed to a small electric charge. The pharmaceutical industry is the primary market although in recent years, the alternative medicinal practice of apitherapy has gained popularity.

Royal jelly is a protein-rich excretion of the hypo-pharyngeal glands in young worker bees. The material is the principal food source of the queen throughout her life. Worker brood is only fed small quantities of royal jelly mixed with honey and pollen during early larval development. High labor costs in colony management and harvesting have prevented commercial production of royal jelly in North America and Europe. The world's largest producers include China and Korea.

Queen and Honeybee Stock Production

Prolonged winter conditions have always been among the most important stress factors to honeybee colonies. Average winter mortality has been about 16% for the province but in some northern regions average losses have often been much higher. To replace winter losses and improve the quality of stock, beekeepers purchase queens or package bees (a cage containing approximately 8,000 bees and a queen) from breeders. In former times, large-scale commercial operators in the Peace region purchased thousands of packages from California each spring to stock their hives. These "package operators" killed off all their colonies after the honey harvest, as wintering was considered too costly and expensive. When parasitic mites were first discovered in the US, Canada closed its borders to the import of bees from the US, forcing Canadian beekeepers to winter their bees and rely on domestically produced beestock or bees imported from Australia and New Zealand. Most of the domestic bee breeders became established in coastal BC. Due to high production costs and late availability in spring, the growth potential of this sector remains limited.

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Fifty years of entomological research in orchard and vegetable crops in British Columbia

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British Columbia has seen tremendous advances and accomplishments in the broad field of entomology over the past fifty years. This is especially true in relation to the orchard and vegetable industries, where entomologists have played essential and often pivotal roles in the production, protection and sustainability of these crops. I have attempted to list as many of the entomologists (and their affiliations) working in orchards and field vegetables as I have been able to retrieve from memory and various archival sources. Unfortunately, to adequately summarize the specific endeavors of the many scientists involved would take more space than allotted for this article. For more in-depth information on the entomologists of BC and their various research specialties, the reader is referred to the joint Entomological Society of BC and Entomological Society of Canada publication 'Entomologists of British Columbia' compiled by P.W. Riegert in 1991. For this paper, I have chosen in part to present a number of the more highly publicized research programs and the entomologists involved that have played pivotal roles in the direction and advancement of entomology in certain orchard or vegetable crops. Since this year marks the 100th anniversary of the Entomological Society of BC, and the 98th Volume of the Journal of the Entomological Society of BC (JESBC), it also seemed appropriate in part to link certain aspects of this article towards key papers published in the Journal since 1951.

General Trends

Reviewing the past fifty issues of the JESBC was a tremendously educational and nostalgic experience, not only from an entomological point of view, but also as a general interest and historical exercise. Who could resist reading, for example, 'An authenticated case of black widow bite', by Carl and Perry in 1959, or so many of the other key articles that in retrospect helped capture our interest and shape our profession in BC. When I had gathered and summarized all of the papers pertaining to entomology in orchards and vegetables since 1951, I was greatly impressed by the diversity and efficacy of our Society's entomologists, both past and present, and by the ebb and flow of various research themes over time.

Volume 47 of the Proceedings of the Entomological Society of British Columbia, issued July 15, 1951, began with an ad by the Nichols Chemical Company congratulating the Entomological Society of British Columbia on its 50th anniversary. I found it interesting to note that there was a total of 8 pages of advertisements by various pesticide companies in that issue, most of which (Monsanto being a notable exception) are no longer in existence. One ad in Volume 49, 1953, had the ominous title 'Improved Controls for Entomologists', and on another page was a photo of two workers (possibly the entomologists referred to in the first ad) wearing no safety equipment, in short-sleeved shirts, applying pesticides in an apple orchard using hand-held sprayers (the chemicals advertized in that ad included DDT, parathion, and lead arsenate). Such photographs of course, are now used to illustrate how 'not' to apply pesticides, and these advertisements went the ultimate way of DDT following the 1954 issue.

The prominence of pesticide advertisements in the JESBC at that time reflected the prominence and influence of the pesticide industry on entomological research. The papers published in the Journal between 1951 and 1960 were heavily biased towards pesticide trials (including studies on efficacy, resistance, phytotoxicity, application technology, etc.), seemingly at the expense of general biological studies (general species descriptions, host range and damage, life history, insect ecology, behavior, etc.) and studies on alternative pest control methods (biological, cultural, natural, physical, mechanical, genetic, semiochemical or SIR) (Fig. 1). It is interesting to note that the number of pesticide-related articles published in the Journal has declined linearly from a high of 25 papers from 1951-60 to a low of 3 papers in the last decade. This probably reflected in part the gradual erosion in the number of existing and pending product registrations, as well as the reviving interest in insect biology and the development of integrated pest management (IPM) theory, tools and strategies (alternative controls, sampling and forecasting, economic thresholds, blended control strategies, etc.). The number of papers in the general biology category overtook pesticide articles in the Journal between 1961-70, and articles depicting IPM and alternative control approaches have also been gradually increasing (Fig. 1).

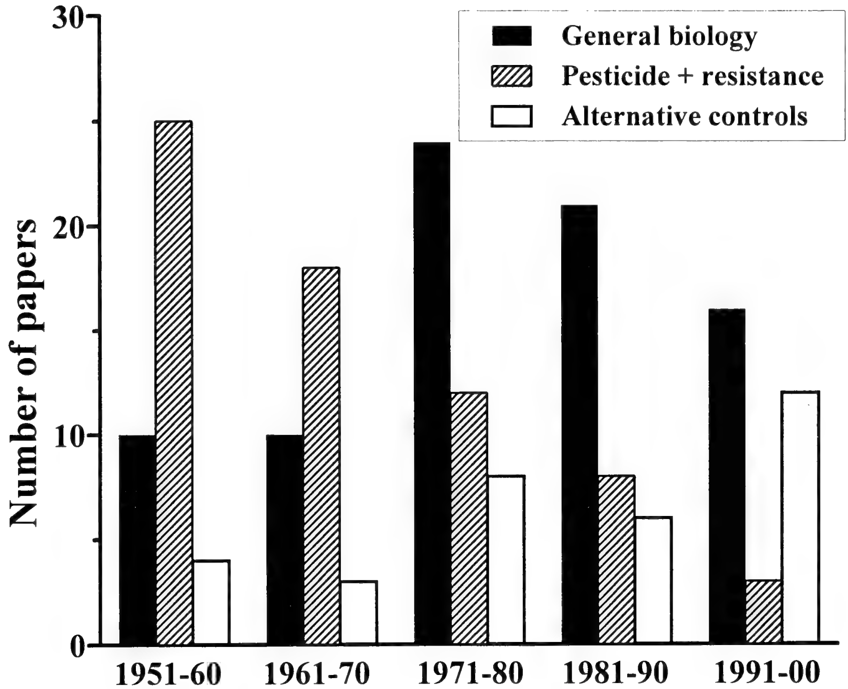

Figure 1. The number of papers published between 1951 and 2000 in Journal of the Entomological Society of BC relating to: general biological studies; pesticide studies; and alternative control methods of insects and mites in orchard and field vegetable crops.

Although the emphasis and general infrastructure of entomological research has changed dramatically in orchard and field vegetable crops over the past fifty years, the insects and mites involved have changed but little. The next sections chronicle the entomologists who have studied insects and mites in orchards and vegetables in BC, and a few examples of key pests that have demanded a relay team of entomologists and effort spanning the past fifty years are given. Since most entomological research in orchards and vegetables can be classed under biological, chemical or alternative IPM research, these will also serve as broad themes for the discussions to follow.

Entomology in Orchard Crops

The majority of orchard crops in BC, (primarily apple, pear, peach, apricot, plum or prune, and cherry) are grown in the Okanagan and Similkameen Valleys with some production in the Kootenays and more recently in the lower Fraser Valley. Most of the research in orchards over the past fifty years, however, has focused on the Okanagan and Similkameen areas, primarily by Agriculture and Agri-Food Canada scientists at the Pacific Agri-Food Research Centre (PARC) at Summerland (formerly the Summerland Research Station). An interesting and historic paper was published in the JESBC in 1953 entitled "A decade of pest control in BC orchards" by J. Marshall, senior entomologist at the Summerland Research Station. A buildup of federal and provincial staff at Summerland was occurring at that time and Marshall spoke of the facility as having struck a good balance between fundamental long-term biological studies and the chemical investigations that were considered a season-to-season necessity by the industry. In the 1950s, scientists at Summerland included: J. Marshall (specialty: pesticides); D.P. Pielou (specialty: aphids and resistance to insecticides); C.V.G. Morgan (specialty: Eriophyid mites and scale insects); M.D. Proverbs (specialty: codling moth irradiation) and; R.S. Downing (specialty: insecticides and mites). In the 1960s, W.H.A. Wilde transferred to Summerland from the Creston substation in 1961, retired in 1963 and was replaced by R.D. McMullen (their specialty: pear psylla bionomics) who transferred from the Harrow Research Station in Ontario in 1964. H.F. Madsen (specialty: integrated control) joined Summerland in 1964 and replaced Marshall (retired in 1963) as head of entomology. In the 1970s, F.L. Banham, formerly studying vegetable insects began orchard research in 1971 (specialty: stone fruit insects), and following the retirements of Morgan in 1974, Downing in 1979, and Proverbs in 1980, the entomology team at Summerland by 1982 consisted of McMullen, Banham, Madsen and newcomers N. Angerilli (specialty: orchard mite control, San Jose scale) and V.A. Dyck (specialty: management of codling moth). J.E. Cossentine (specialty: biological control) replaced the retired Madsen in 1985, and G.J.R. Judd was appointed in 1989 (specialty: insect chemical ecology and behavior). M. Smirle (specialty: resistance management) joined the station in 1990 and D. Thielmann (specialty: insect baculoviruses) transferred from the Vancouver Research Station upon its closure in 1996. H. Thistlewood transferred to Summerland from the Vineland Ontario Research Station in 1998, was temporarily seconded to the SIR program as general manager between 1998 and 2001 and is now at PARC, Summerland (specialty: insect ecology). Surrounding this core of research scientists have been many technical staff, including, C.J. Campbell, W.W. Davis, M. Gardiner, L.B. Jensen, C. Jong, C. Krupke, D.M. Logan, T.K. Moilliet, J.R. Newton, and J.M. Vakenti (only individuals, whose names have appeared in the literature as author or co-author are listed).

In addition to the federal government researchers mentioned above, significant contributions have also been made by entomologists from the Provincial Government (C.L. Nielson; J.C. Arrand; J. Corner; P.J. Procter; and H. Philip), private consultants (S. Haley; J.M. Vakenti; L. Edwards; F. Peters; D. Thomson) and the Okanagan-Kootenay Sterile Insect Release Program (K.A. Bloem and S. Bloem). Contributions to orchard entomology have also been made by the various BC universities, including UBC (D.A. Chant) and Simon Fraser University (J.H. Borden; B.P. Bierne; B.D. Roitberg; M. Mackauer; G. Gries;) which has had close ties to PARC, Summerland through the Centre for Pest Management (hosting the Master of Pest Management program (MPM)). The impact of SFU and the Centre for Pest Management on current research personnel at PARC Summerland is evidenced by the fact that three out of five current research scientists (Judd, Smirle and Thistlewood) as well as numerous technical staff (M. Gardiner, M. Claudius and C. Krupke) are former SFU graduate students. Numerous collaborations between SFU and PARC, Summerland scientists involving graduate students have also resulted in significant contributions to orchard pest management, and PARC, Summerland scientists have hosted the orchard pest management summer course in the MPM program since 1973.

General Biology

The list of insect and mite pests as well as the associated suite of beneficial organisms in orchard crops in BC is very long, and has provided entomologists with an abundance of challenging material for study over the years. Downing *et al.* (1956) compiled a list of 63 species of insects and 14 species of mites known to be economically (E) or sporadically (S) injurious to apples (28 E; 22 S); apricot (10 E; 12 S); peach (11 E; 14 S); pear (12 E; 15 S); plum or prune (15 E; 23 S); and cherry (12 E; 26 S). This list has grown since then, and I'm sure the next fifty years will see a number of major new introductions and challenges to the industry, the apple maggot, *Rhagoletis pomonella* (Walsh), for example, being an imminent threat.

Much of the attention of orchard entomologists over the past fifty years has focussed on: scale insects (e.g. San Jose scale, *Quadraspidiotus perniciosus* Comstock), mites, both pest (e.g. the McDaniel mite, *Tetranychus mcdanieli* McGregor, and European red mite, *Panonychus ulmi* (Koch)) and predators (e.g. phytoseiid mites including *Typhlodromus occidentalis* Nesbitt); lepidopterans (e.g. codling moth, *Cydia pomonella* (L.), obliquebanded leafroller, *Choristoneura rosaceana* Harris); pear psylla, *Cacopsylla pyricoli* (Föerster) and the western cherry fruit fly, *Rhagoletis indifferens* Curran. In addition to their popularity as research organisms, some of these species are also the focus of a number of success stories that will be highlighted below.

Insect and Mite Management

The introduction of organochlorine insecticides to the BC orchard industry in the 1940s had an immediate impact on the population dynamics of insect and mite populations, as well as on the job descriptions of many entomologists. The initial efficacy of these new products was so impressive, and the influence of the pesticide companies so great, that much of the research efforts in the 1940s, 50s and 60s were directed at evaluating various products against the key economic orchard pests present at that time. A number of the Summerland scientists mentioned earlier in the 1950s and 60s were very prolific in evaluating insecticides (Marshall, Pielou, Proverbs) and acaracides (Downing, Morgan). It was fortunate for the industry, however, that these entomologists were also aware of the drawbacks to indiscriminate pesticide use, and their concurrent biological and ecological observations and work with less toxic alternatives such as dormant oil sprays (Downing, Madsen) gradually gave rise to more discriminate pesticide use and ultimately to widely adopted IPM programs.

As early as 1953, the need for judicious use of chemicals in orchards in order to preserve beneficial organisms had been recognized by Marshall and others (Marshall 1953). Marshall published another important paper in JESBC a decade later (1963), entitled, "Background for integrated spraying in the orchards of British Columbia", which made reference to the recently published and "woefully biased" 'Silent Spring' by Rachel Carson in 1962 (also reviewed in JESBC by Marshall in 1962), and which essentially described the evolving concept of IPM in Summerland and other fruit growing areas of the world. Among other advances, Summerland scientists had recently shown that less spraying for insects and mites was possible without crop losses, and the use of more selective pesticides used only when necessary was being advocated for various regions of the Okanagan Valley. In apples, a number of breakthroughs in mite and codling moth control helped shape and direct the course of pest management related research in this major crop.

Much of our understanding of the life histories and distribution of the pest and predatory mites in BC orchards can be attributed to the early efforts of N.H. Anderson (e.g. Anderson *et al.* 1958), Morgan (e.g. Morgan *et al.* 1955), and Downing (e.g. Downing and Moilliet 1971) whose orchard survey and life history work formed the foundation for the integrated mite controls now standard throughout the industry. An important tool in the understanding and management of mites was the mite brushing apparatus, which was adapted by Morgan for use in Okanagan orchards (Morgan *et al.* 1955) and has been in standard use for about 50 years. This apparatus allowed researchers to study both phytophagous and predaceous mites, and with the development of accompanying action thresholds it has become a cornerstone of apple and pear IPM programs delivered by private consultants and packing houses. Along with the findings that dormant oil sprays could control the European red mite (and certain scale insects) without impacting predator mites, and that the predatory mite, *Typhlodromus occidentalis* had developed natural resistance to organophosphates such as azinphos methyl (Guthion), growers have been able to rely heavily on naturally occurring biological control backed up by surveillance-based miticide applications since the early 1970s.

The codling moth, *Cydia pomonella*, is the key insect pest of apples and pears world-wide and much of the general biology of this pest has been determined elsewhere, or pre-dates the current review. However, it is in the development of sophisticated IPM tools and strategies for codling moth management that a number of BC entomologists have distinguished themselves. In the Okanagan and elsewhere, codling moth could only be managed in the 1950s and 60s by repeated use of a variety of insecticides, however three major developments, including: autocidal control; pheromone trapping; and mating disruption, have irrevocably changed this tradition over the past 30 years.

Autocidal control, later to become known as the Sterile Insect Release (SIR) program, was initiated in Summerland in 1956 by M.D. Proverbs with the ultimate aim of eradicating codling moths from geographically isolated areas. Probably the most challenging aspect of this program was the development of an artificial diet and mass rearing facility for codling moth, the efficiency of which was evolved by Proverbs' team to the point that about 17 million sterile moths were eventually being reared and released annually. The rearing facility itself at the Summerland Research Station was an amazing example of what can be accomplished with ingenuity and a shoestring budget, and the larger present day facility near Osoyoos was modeled very closely after the original. The efficacy of SIR was demonstrated in a number of isolated orchards between 1964 and 1976, and from 1976 to 1978 was expanded to include 520 ha of apples and pears in the geographically isolated Similkameen Valley. By the end of the project in 1978, codling moth populations and associated apple damage had been virtually eradicated from the Valley (Proverbs *et al.* 1982), and no additional measures for codling moth control were required in any of the orchards until 1981.

Proverbs' SIR program had gained worldwide attention and recognition by his retirement in 1980, and in 1988 plans for the resurrection and expansion of the SIR program to cover the entire Okanagan and Similkameen valleys were established in a cooperative effort between the Summerland Research Station (V.A. Dyck) and the BC Fruit Growers' Association. In 1990, the Okanagan Similkameen SIR program was formally launched with the goal of eradicating codling moth from key growing regions of the Okanagan and Similkameen Valleys of BC by 1999. The hiring of staff, including K.A. Bloem as program manager (succeeded in 1998 by H.

Thistlewood), began in 1992, and releases of sterile moths began in 1994 in the south Okanagan (Summerland and Naramata south to the U.S. border), Similkameen (Cawston, Keremeos) and Creston regions (known as Zone 1 of the SIR). The program has since expanded to the central (Zone 2) and north (Zone 3) Okanagan regions. After 7 years of moth releases, populations of codling moth had declined dramatically throughout Zone 1, but functional eradication had only been achieved in those regions of the more segregated Similkameen valley where Proverbs did his initial work. Although the goals of the SIR program were shifted from eradication to area-wide suppression in 1999, the autocidal control approach has reduced codling moth populations over large areas to unprecedented low levels.

An interesting paper was published in the JESBC by Madsen and Davis in 1971 which described the use of female-baited traps as indicators of codling moth populations and apple damage. This paper was followed by another JESBC paper by Madsen and Vakenti in 1973, which recorded the initial use of traps baited with synthetic pheromones for codling moth and fruit-tree leafroller, *Archips argyrospilus* (Walker) in orchards in BC. Pheromone traps soon after became a widely used and indispensable tool in orchard IPM in BC, and provided an important cornerstone to the codling moth SIR program still under development at that time as well as in the current SIR program.

Possibly the most exciting development in apple IPM in the past decade has been the development of pheromone-based mating disruption technology for area-wide management of codling moth and other lepidopterous pests of apples and pears (i.e. *Choristoneura rosaceana* and *Pandemis limitata* (Kearfott)). This work, collectively, has been led by G.J.R. Judd at PARC, Summerland in association with industry (Pacific Biocontrol, 3-M Canada, and PheroTech Inc.) and colleagues at SFU, including professors J.H. Borden, B.D. Roitberg, and G. Gries and graduate students M.L. Evenden, N. Delury, H. McBrian and J.P. Deland. In 1992, Isomate-C was registered in Canada by Pacific Biocontrol (Vancouver, WA) as a mating disruption product for codling moth control, and has since been used in Canada and the USA for area-wide management of codling moth (e.g. Judd *et al.* 1996). Mating disruption has become the preferred method for reducing codling moth populations in the clean-up stage of both conventional and organic orchards in Zones 2 and 3 of the Okanagan Similkameen SIR program, and is now being rationally integrated with the sterile moth release program for non-chemical management of codling moth in Zone 1. Mating disruption has also been demonstrated for a number of leafroller pests in BC orchards, and eventual registrations for these additional mating-disruption products will further reduce the reliance of the industry on insecticides.

Entomology in Vegetable Crops

Commercial field vegetable crops are grown in many areas of BC, with the largest concentration of acreage historically being in the lower Fraser Valley and south central interior including the Okanagan Valley, Kamloops and Kootenay areas. As was observed in orchard crops, most of the published entomological research in vegetable crops up until the last decade has involved Agriculture and Agri-Food Canada scientists working out of various research stations or substations in the above regions. In the 1950s, entomological research in vegetables was strong in Kamloops (at that time the Dominion Field Crop Insect Laboratory), Victoria (Saanichton Station), Agassiz (formerly the Agassiz Research Station) and Vancouver (formerly the Dominion Laboratory of Plant Pathology at UBC). In Kamloops in the 1950s, scientists included: R.H. Handford (officer in charge); D.A. Arnott; H.R. MacCarthy; D.G. Finlayson; and F.L. Banham. At Saanichton, scientists in the early 1950s included K.M. King, A.T.S. Wilkinson and A.R. Forbes, however, vegetable research was phased out in the mid-1950s with the retirement of King in 1956, and the transfer of Wilkinson (specialty: soil insects and biological control of weeds) and Forbes (specialty: aphids and aphid morphology) to Vancouver. At that time, federal entomologists in Vancouver were located on the UBC campus in a building since converted into a cafeteria known as 'the Barn', and also included MacCarthy (specialty: virus vectors) who transferred from Kamloops in 1955. They relocated to the newly built Vancouver Research Station (VRS) at UBC in 1959, and were joined by Finlayson (specialty: root maggots; toxicology) who transferred from Kamloops that year. B.D. Frazer (specialty: aphid ecology) joined the VRS in 1967 and the group remained intact until the retirement of MacCarthy in 1976. In 1981, R.S. Vernon (specialty: vegetable insect IPM) replaced the retired Finlayson (1980), and D.A. Raworth (specialty: biological control) was appointed in 1984. Vegetable research at Agassiz was conducted by R. Glendenning until his retirement in 1953, as well as H.G. Fulton (specialty: vegetable insects), who was stationed at the Entomology Laboratory substation of Agassiz in Chilliwack BC (which later became a VRS substation) until his retirement in 1967. With the closure of the VRS in 1996, Vernon and Raworth (as well as small fruit specialist S. Fitzpatrick, specialty: semiochemicals) were transferred to Agassiz (now the Pacific Agri-Food Research Centre (PARC)) to join D. Gillespie (specialty: greenhouse vegetables), V. Brookes (specialty: minor use registration) and J.T. Kabaluk (specialty: geographic information systems and microbial control). In 1965, Banham transferred from Kamloops to Summerland and was their sole vegetable insect specialist until his specialty was changed to tree fruits in 1971. Excellent technical staff have complimented this core of research scientists, including, C.J. Campbell, C.K. Chan, T. Kabaluk, M. Knott, J.R. Mackenzie, R.R. McGregor and M.D. Noble (again, only individuals, whose names have appeared in the literature as author or co-author are listed).

As was observed above in orchards, additional professionals have contributed in various ways to entomology in field vegetables, including extension officers from the Provincial Government (H. Gerber, H. Philip, B. Costello, J.C. Arrand, T. Kluge, L. Gilkinson) and private consultants (R.S. Vernon, G.J.R. Judd, W.B. Strong, B.D. Henderson, S.Y. Li). Contributions to vegetable entomology have also been made by the various BC universities, including UBC (M.B. Isman) and Simon Fraser University (e.g. J.H. Borden; B.P. Bierne; B.D. Roitberg; M. Mackauer; G. Gries;), the latter again having close ties to the Vancouver and Agassiz Research Stations through the Centre for Pest Management. In fact, the development and implementation of many of the vegetable IPM programs in current use in BC has been through collaborative efforts between the Vancouver and Agassiz Research Stations and SFU staff and graduate students since the mid 1970s.

General Biology

Vegetable crops in BC include a multitude of plant families, species and cultivars, and as such the list of insects associated with these crops is also very long. It is interesting to note that many of the key pests of our more important vegetable crops are not native to Canada, and it is these pests that has demanded much of our attention over the past fifty years. Among the more important introduced pests to BC are: root feeding maggots (e.g. the onion maggot, *Delia antiqua* (Meigen), the cabbage maggot, *Delia radicum* (Bouche) and the carrot rust fly, *Psila rosae* (F.)); wireworms (e.g. the dusky wireworm, *Agriotes obscurus* (L.) and the lined click beetle *A. lineatus* (L.)); lepidopterans (e.g. imported cabbageworm, *Pieris rapae* (L.)); and aphids (e.g. the lettuce aphid, *Nasonovia ribis-nigri* (Mosley)). Other important pests are endemic to the USA and may have entered BC by natural avenues of dispersion or through man's activities (e.g. the tuber flea beetle, *Epitrix tuberis* Gent. and the Colorado potato beetle, *Leptinotarsa decemlineata* (Say)). Much of the research effort in BC vegetables has involved root maggots, tuber flea beetles and various aphids, and brief summaries of the research activities devoted to these pests are given below.

Root maggots. Root maggots are pests of many vegetable crops (i.e. all cruciferous crops, onions and carrots) in BC, and entire fields can be destroyed without adequate protection. Most of what is known about the general biology of root maggots attacking cruciferous crops in BC (particularly *D. radicum*) is through the independent or combined work of Forbes and Finlayson (e.g. Forbes and Finlayson 1957). From the 1950s to the 1980s the majority of research on *D. radicum* as well as on the onion maggot, *D. antiqua*, and carrot rust fly, *P. rosae*, involved the screening of a wide variety of insecticides (Forbes, Fulton, Wilkinson, Finlayson, Mackenzie, Vernon). The amount of spraying for these pests, however, had become excessive, and in the late 1970s to early 1980s a number of monitoring devices and threshold-based IPM programs were developed for onions and carrots through graduate studies at SFU by Vernon and Judd (under the guidance of J.H. Borden). These programs dramatically reduced insecticide use in these crops in the Cloverdale Valley, and formed the basis of BC's first grower-funded private IPM consulting company, Monagro Consultants, in 1979.

Flea beetles. The tuber flea beetle, *E. tuberis*, at one time was one of the most important pests of potatoes in BC, and all published literature on the biology of this insect has been through the efforts of MacCarthy, Banham, Finlayson, Fulton, Vernon and Thomson. As with root maggots, considerable research on this pest since 1950 has been devoted to establishing chemical controls, and growers had become accustomed to spraying their potato fields on a routine basis with broad-spectrum insecticides. This practice also established the need for routine sprays for aphids, largely due to the coincident elimination of aphid parasitoids and predators. In the early 1980s, a monitoring program was established through the efforts of Vernon and SFU graduate students K. Giles and M. Cusson, and this program has been provided to the majority of potato growers in BC since 1980 by private consultants (in particular by Monagro Consultants, and ES Cropconsult Ltd.). Since flea beetles enter potato fields from the field margins, it has been shown that early-season monitoring can detect when and where they first occur, and populations can generally be controlled for the entire season with one (or zero) carefully timed and placed edge spray. By not spraying the entire field on a routine basis, the control of aphid populations through the natural buildup of biological control agents is now common practice.

Aphids. Aphids are found as pests of many vegetable crops, and the efforts of entomologists at the Vancouver Research Station (until its closure in 1996) have been pivotal in determining their biology and control. The early work of H.R. MacCarthy, for example, helped build our understanding of the relationship between aphids and their ability to transmit various virus diseases to potatoes. There is no doubt, however, that the research of A.R. Forbes and his technician C.K. Chan has been most instrumental in building our base of knowledge on the biology and distribution of aphids in BC, many of them pests of vegetable crops. Their work, along with contributions by MacCarthy and Frazer, was published almost annually in a series of 21 papers in the JESBC between 1973 and 1993 (e.g. Forbes and Chan 1991). With the last paper published (Chan and Frazer 1993), this team had described 412 aphid species collected from 1243 different host plants and had identified 2434 aphid-host associations. The collective efforts of these entomologists helped set the stage for the development of management programs for several key aphid species (e.g. lettuce aphid, *N. ribis-nigri* and the European asparagus aphid, *Brachycolus asparagi* Mordvilko).

It is hoped that this paper has adequately portrayed the personalities, scope and at least some of the more public aspects of entomological endeavor in orchards and field vegetable crops in BC. The work of entomologists not profiled in the limited space available is of no less importance, and like a jigsaw puzzle, every piece is required to make the image complete. Assuming some of us will still be around in 2051, it will be interesting to see how much more of the orchard and vegetable entomology puzzle will have been completed when the next fifty years of entomology is reviewed.

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History of forest insect investigations in British Columbia

This three-part paper describes the history of forest entomology in British Columbia during the past century. The first part discusses programmes and personnel in the federal and provincial governments, private enterprise, and academic institutions. This section was co-authored by current or former employees of these agencies as a reflection of the close co-operation between them over the years ranging from insect management programs, research, and training of forest health personnel. The second part describes a unique federal entomology program, the history of the former Forest Insect and Disease Survey (FIDS) unit of the Canadian Forest Service. The third part is a brief history of the establishment and programmes of the federal Vernon Laboratory, the first permanent facility in British Columbia dedicated to forest insect investigations.

I. Forest entomology education, research, and insect management

a. Forest entomology in the British Columbia Ministry of Forests and private sector
b. Teaching and research at academic institutions
c. Research in the federal government

II. Forest Insect and Disease Survey in the Pacific region

III. The Vernon Laboratory and federal entomology in British Columbia

Throughout the history of forest entomology in BC, there has been substantial and productive interaction between provincial, federal and academic institutions. In addition, industry has supported major initiatives in research, e.g., on ambrosia beetles and bark beetles. Thus, there is unavoidable overlap when attempting to synthesize the contributions of each.

I. Forest entomology education, research, and insect management

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a. Forest entomology in the British Columbia Ministry of Forests and private sector

Background

"For several years reports have been received from various points in British Columbia indicating considerable loss from Bark-beetle attack to standing timber and logs. The lumber industry of the province is of such importance, and the destruction by forest insects in the States to the south has been reported as so serious in recent years, that it was thought advisable to make a survey of the actual conditions in regard to injurious forest insects in British Columbia forests. The Forestry Branch of the Department of Lands of British Columbia had in the meantime requested the Division of Entomology to undertake such an investigation. Accordingly, with the assistance and co-operation of the Provincial Forestry Branch, a survey was made during the summer of 1913 the object of which survey was to determine the location and extent of the chief forest insect injuries, and to decide upon proper control measures for the more serious outbreaks." (Swaine 1914)

And so began the history of forest entomology in British Columbia. Until relatively recent times, the British Columbia Forest Service (BCFS) did not employ entomologists or pest management personnel; it relied on the federal government and universities for this expertise. However, there were numerous instances where the BCFS continuing interest in forest insect impacts and management was shown.

The Chief Forester of British Columbia, Mr. H.R. MacMillan, made the initial request to the Division of Entomology and provided funding support to J.M. Swaine to carry out the survey. Subsequently, the BCFS utilized the expertise of federal entomologists such as R. Hopping in supervising a number of bark beetle control efforts utilizing crews for falling and burning infested trees and directed harvesting of infested stands and trees. These control programs were funded by the provincial Forest Service (Hopping 1921). As bark beetle infestations continued to arise, so did further control programs, still relying on federal entomologists for professional expertise (Hopping and Mathers 1945).

The vast and diverse forests in British Columbia result in a similar diversity of forest insects, many of which can cause damage that affects different forest resource values. However, timber losses have long been of greatest interest to management agencies and industry. Through the years, each decade presented the province with one or more major insect-related issues, most often in the form of extensive outbreaks of bark beetles, *Dendroctonus* spp., or defoliators.

Up until about the 1960s, much of British Columbia's forest industry was concentrated in coastal areas. However, the extensive stands of spruce, *Picea* spp., and lodgepole pine, *Pinus contorta*, in the interior of the province beckoned, and, as markets increased forest industry operations in the interior areas of the province expanded.

The modern era

A major step towards a provincially coordinated forest pest management program came in 1974 when the Forest Pest Review Committee (FPRC) was formed (Pearse 1976). This committee was chaired by the Chief Forester for British Columbia and was comprised of representatives from the Forest Service, other provincial and federal agencies, and industry associations. The purpose was to discuss specific insect and/or disease outbreaks and make recommendations as to management directions. Several issues in the 1970s made the committee relevant and very active:

- the beginnings of the Chilcotin outbreak of mountain pine beetle;
- mountain pine beetle outbreaks in the Prince Rupert Region and in the Flathead Valley in Nelson Region;

- the beginnings of the Bowron Lakes spruce beetle outbreak;
- a large scale trial of treatments against Douglas-fir tussock moth in the Kamloops Region carried out in co-operation with the US Forest Service;
- proposed spraying of a western spruce budworm outbreak in the Fraser Canyon; and,
- the first detection of gypsy moth in British Columbia found in Kitsilano.

In response to the major forest insect and pesticide related issues, Mr. ***J.M. (Mike) Finnis*** was hired by the Protection Section of the BC Forest Service to act as an in-house advisor and specialist in pest management issues. Mr. Finnis served primarily as a co-ordinator of activities and as liaison between provincial and federal agencies (most notably the Canadian Forestry Service). ***Paul Wood*** was hired by the Cariboo Forest Region in the mid-1970s to address the increasing mountain pine beetle outbreak. Additionally, the Forest Service routinely provided summer students to assist Canadian Forestry Service entomology researchers.

The report from the Royal Commission on Forest Resources was published in 1976 (Pearse 1976). This report made a series of recommendations to change how the forest resource was managed and administered in British Columbia. It set the stage for the creation of the Ministry of Forests Act (Anon. 1978a) and the Forest Act (Anon. 1978b). These legislative acts gave a mandate to the Ministry of Forests to "manage, protect and conserve the forest and range resources of the government, having regard to the immediate and long term economic and social benefits they may confer on British Columbia" (Section 4b, BC Ministry of Forests Act, 1978). The new legislation led to a large-scale reorganization of the British Columbia Forest Service in 1980.

Staffing up

By 1979 it became clear that the Forest Service required some in-house expertise, who were capable of training field staff, advising the Ministry Executive on forest health issues, and implementing large and small management programs. In early 1980, Mr. ***R.S. (Bob) Hodgkinson*** was hired as a forest entomologist by the Forest Service Protection Branch and based in, Prince George, to evaluate the use of trap trees for reducing losses caused by spruce beetle, and Mr. ***P.M. (Peter) Hall*** was hired as the regional forest entomologist for the Cariboo Forest Region, Williams Lake, BC.

The reorganization of the Forest Service progressed through the summer of 1980. For the first time, the provincial government staffed professionals in pest management positions. In Victoria headquarters, the positions of a Manager, Pest Management (***R.F. (Bob) Deboo***), Forest Entomologist (P.M. Hall), Forester (Mike Finnis) were filled. Later, a Forest Pathologist (***J.A. (John) Muir***) and a Pesticide Specialist (***J.F. (John) Henigman***) were added to the Pest Management Section at Protection Branch. Branch personnel are responsible for developing policy and procedures, advising the Ministry Executive and Government, providing co-ordination with other provincial, federal and private agencies, monitoring management programs at the regional and district level, and providing expert technical advice. The name of the Pest Management Section was changed to Forest Health in 1990 to reflect a shift in philosophy away from traditional pest control and towards more integrated forest management.

At the regional level, Pest Management Co-ordinators were staffed at each of the six regional offices:

Region	Location	Initial Pest Management Co-ordinator Positions	Subsequent Forest Health Forester Positions
Cariboo	Williams Lake	D. Doidge	M. Hamm*
Kamloops	Kamloops	R. Edwards	D. Calder*
Nelson	Nelson	A. Renwick	J. Monts E. Morris R. Stewart*
Prince George	Prince George	R, Cozens	S. Taylor*
Prince Rupert	Smithers	V. Barge	M. Geisler B. Young*
Vancouver	Vancouver	S. Raine	P. Wood R. Heath*

* the last to hold the position

The position of Pest Management Co-ordinator was eliminated in 1987 and was replaced in various regions with the position of Forest Health Forester. The latter position was not necessarily supervisory to the regional forest entomologist.

The regional entomologist position evolved from necessity in those regions experiencing a wide variety of issues. Staffing of this position occurred over a period of years, with the formal creation of the position in 1984:

		Forest Entomologist	
Region	Location	Initial*	Subsequent*
Cariboo	Williams Lake	P. Hall	R. Heath L. Rankin*
Kamloops	Kamloops	R. Chorney	T. Maher L. Maclauchlan*
Nelson	Nelson	D. Gray	E. Morris A. Stock*
Prince George	Prince George	R. Hodgkinson*	
Prince Rupert	Smithers	A. Stock	T. Ebata K. White*
Vancouver	Vancouver/ Nanaimo	E. Jeklin	D. Heppner*

*the last (current) to hold the position

Regional entomologists are responsible for providing expert technical advice to regional and district staff, co-ordinating and monitoring management programs, training, and liaison with other agencies, industry and the public. Regional forest pathologists were also hired in most regions.

Additionally, entomologists or pest management specialists were hired in other areas of Ministry of Forests operations:

Position	Specialist/Entomologist*
Nursery Pest Management Specialist	G. Shrimpton D. Trotter*
Cone and Seed Pest Management Specialist	D. Summers R. Bennett* (Victoria) W. Strong* (Vernon)

*the last (current) to hold the position

No specific pest management staff were placed in district offices at that time; the District Resource Officer – Protection, carried out the function of pest management. Since then, several districts with ongoing forest health issues have established a Forest Health officer position. Many of these staff have provided long-term continuity to insect management programs at the district (operational) level. District staff has contributed substantially to the development of management programs, and has been instrumental in ensuring that the BC Forest Service remains one of the best Forest Health organizations in North America.

Contractors and industry

The forest industry has usually depended upon the Canadian Forestry Service, the universities, and the BC Forest Service for professional entomological advice. They also regularly employ consultants and contractors to carry out specific studies or projects relating to forest entomology. There have, however, been instances where the industry directly employed entomologists, particularly to deal with issues such as ambrosia beetles which were beyond the mandate of the BC Forest Service. After his retirement from the Canadian Forest Service, H.A. Richmond consulted to MacMillan-Bloedel to deal with ambrosia beetle damage, and he was later employed as an in-house consultant to the Council of Forest Industries. He provided advice on a variety of forest insect issues (Richmond 1983). Further, Pacific Forest Products hired ***R. (Dick) Heath*** as a pest management specialist, Northwood Pulp and Timber hired ***T. (Tom) Maher***, and Finlay Forest Industries of Mackenzie, BC, hired ***D. (Darrell) Devlin*** to deal with pest management issues. At the current time, though, no BC forest company has an entomologist on staff.

Examples of companies that have provided a wide variety of products and services in forest entomology, are Phero Tech Inc., Delta, BC, and Bugbusters Pest Management, Prince George, BC. Phero Tech is one of the major North American companies providing commercial quantities of forest insect pheromones. Both of these companies, as well as other consulting companies, have employed numerous forest entomologists over the past 15 years.

The number of consulting entomologists and pest management specialists has increased dramatically in British Columbia since 1980. The increasing interest in and management of forest insects has created varied opportunities for individuals and companies with entomological expertise. Downsizing of federal and provincial agencies, as well as increased interest in the field by students entering graduate programs at universities, have contributed to a growing pool of talented individuals who have contributed to the development and refinement of management of forest insects in the province. A listing of individual contractors and companies is impractical in this publication and it would be impossible to ensure that all deserving individuals were included.

Milestones and accomplishments

The Ministry of Forests has accomplished a great deal in the area of forest entomology and management of the forest resource to reduce damage caused by insects. The Forest Service has evolved from an organisation primarily reacting to crisis to having ongoing integrated programs and staffing dedicated to dealing with all aspects of forest insect biology and management. Some of the accomplishments have been specific to a particular insect problem, while others have been in the realm of legislation and program integration and acceptance. All of the accomplishments have been achieved through the close working relationship between the forest entomology "team" of the Forest Service.

Some of what has been done is briefly noted in the following table:

Issue	Insect	Accomplishment
Legislation	All	Incorporation of forest health principles into all aspects of the Forest Practices Code of BC Act and Regulations (Anon., 2001).
Staffing	N/a	Forest Entomologists are in place in all 6 Forest Regions, Victoria headquarters, Cone and Seed Program, and Nursery Program. Several Forest Districts have dedicated Forest Health Officers.
Manuals and Publications	N/a	Management guidebooks for a wide variety of forest insects have been produced under the authority of the Forest Practices Code of BC Act. These include guidebooks for bark beetles, defoliators, terminal weevils and others. Extension literature and publications are now available. The Ministry of Forests website contains a great deal of information relating to forest entomology: http://www.gov.bc.ca/for/
Surveys	All	The Forest Service is now responsible for conducting the annual aerial overview survey formally conducted by the FIDS Unit of the CFS. The responsibility for this survey was assumed by the province in 1996 and has been fully implemented in 2001.
Support	All	The Forest Service has consistently supported research efforts by the Canadian Forestry Service and universities through direct funding or provision of logistical support.
Specific Management	Bark Beetles	The Forest Service was responsible for operationally implementing the use of aggregation pheromones for bark beetle management.

	Large-scale operational management programs for mountain pine beetle, Douglas-fir beetle and spruce beetle have been conducted periodically. Expenditures on these issues have exceeded $10 million annually.
	Province-level and landscape-level strategic planning frameworks have been developed and accepted by all levels of the Forest Service and industry.
	Ongoing support and encouragement for the development of predictive modelling techniques to improve understanding of population dynamics and the impacts of management efforts (e.g., SELES/MPBSIM)

The items noted in the table below show a small subset of the accomplishments in forest entomology achieved by the forest entomology professionals within the Ministry of Forests. This group has consistently worked co-operatively together and with others to ensure that management objectives are met and that impacts of forest insects are minimized.

Insect	Accomplishment
Douglas-fir tussock moth	The Forest Service was the first jurisdiction to use nuclear polyhedrosis virus operationally to terminate DFTM outbreaks. And the Forest Service has implemented an integrated detection, evaluation and treatment system for this insect. A true Integrated Pest Management System.
Spruce weevil	The Forest Service has actively supported the development of assessment models and identification and propagation of resistant genotypes of spruce.
Gypsy moth	The Forest Service has actively supported and participated in efforts to maintain British Columbia free of gypsy moth.
	Completed a detailed Risk Assessment for gypsy moth in British Columbia

Major issues

Currently, forest insect issues in British Columbia relate to the same insects as in the past: bark beetles, defoliators, ambrosia beetles, terminal weevils and regeneration problems, and others. However, new issues arise that deal with responsibility-sharing between government and industry, changing management objectives over time, new legislative initiatives, introduction of exotic, potentially damaging insects, encouraging and implementing new survey and management technologies, and, as always, trying to grapple with a class of organisms that often seem to be better at what they do than we are at doing what we do. Perhaps they just have more experience.

b. Teaching and research at academic institutions

Research on forest insects has been conducted at all major institutions in British Columbia. Some of the major contributions are listed in the next Table.

The earliest collections of insect damaged wood in the collections at the University of British Columbia bear the name of Dr. ***G. (George) Spencer.*** Materials he collected more than half a century ago are still in use at the Faculty of Forestry today. Forest Entomology has always been a core subject in the academic programs for students wishing to become professional foresters. The first full time professor of forest entomology was Dr. ***K. (Ken) Graham*** whose interests were in ambrosia beetles and bark beetles. He also wrote one of the first texts in Forest Entomology (Graham 1963). His successor in 1977 was Dr. ***J.A. (John) McLean*** who also was interested in the general biology of ambrosia beetles, especially the population surveys and mass trapping in sawmills with pheromone-baited traps as well as economic impacts of attacks on lumber values. His graduate students have contributed to our knowledge on ambrosia beetles, defoliators and leader weevils. Several of McLean's graduate students hold prominent positions with the BC Forest Service and the Canadian Forest Service, Victoria, BC. Several other UBC professors have also contributed to forest entomology studies, especially in the areas of population modelling, Dr. ***C.S. (Buzz) Holling***; in tent caterpillar and biological control studies, Dr. ***J. (Judy) Myers***; as well as in insects and weather, Dr. ***W.G. (Bill) Wellington***. In recent years concerns for sustainable forest management have centered on biodiversity studies of carabids, sucking insects and bark beetles by Dr. ***G. (Geoff) Scudder*** and riparian insects by Dr. ***J. (John) Richardson***. Dr. ***M.B. (Murray) Isman*** studied the effects of botanical insecticides, e.g., neem, on many insects, including forest seedling nursery pests and the mountain pine beetle.

A strong chemical ecology research group was established by Dr. ***J.H. (John) Borden***, along with chemists ***K.N. (Keith) Slessor*** and ***A.C. (Cam) Oehlschlager***, at Simon Fraser University (SFU) in the 1970s. Many of Dr. Borden's graduate students, who over the last 35 years have completed the Master of Pest Management program, as well as more traditional Masters and Ph.D. programs, now contribute professionally to forest entomology in BC and are mentioned elsewhere. The SFU team, led by Dr. Borden, and graduate students have made milestone contributions to the chemical ecology of forest insects. Over the years, they have identified numerous forest insect pheromones, many of which have been put to use in pest management applications.

Issue	Significant contributions
Bark beetle ecology and management	Significant contributions in the field of chemical ecology and basic biology of numerous important bark beetle species. Development of applications. Ongoing investigations in the role of anti-aggregation pheromones and non-host odours.
Ambrosia beetle ecology and management	Identification and synthesis of semiochemicals for the most important species, and development of applications, many of which are commercially available. Important findings regarding economic impact to coastal industry.
White pine weevil ecology and management	Important discoveries on host selection and host resistance mechanisms in collaboration with CFS.
Seed and cone insect ecology and management	Development of semiochemicals and investigations on the ecology and impact of significant seed and cone insects in collaboration with BCFS and CFS.

Dr. ***G. (Gerhard) Gries*** is currently very active in the area of identification of semiochemicals in forest insects. Drs. Borden and Gries teach graduate courses in forest pest management and forest entomology at SFU. In the early program at Simon Fraser, Dr. ***B. (Bernie) Roitberg*** supervised several graduate students studying mate selection behavior in bark beetles. Dr. ***A. (Bert) Turnbull*** wrote on biological control (Turnbull and Chant 1961), ***T. (Thelma) Finlayson*** described many hymenopterous parasites, and Dr. ***J. (John) Webster*** studied interactions between nematodes and insects, especially the pinewood nematode.

Forest entomology is taught as part of a Forest Health course at the University of Northern British Columbia by Dr. ***B.S. (Staffan) Lindgren***, whose major interests are in forest insect ecology and management. At the University of Victoria, extensive studies on the biodiversity of insects in the tree crowns of mature coastal rain forest have been conducted by Drs. ***R. (Richard) Ring*** and ***N. (Neville) Winchester***.

Technicians trained at the Technical Institutes and colleges in British Columbia have received their forest entomology education from a number of instructors over the years, and it would be impractical to name all of them here. Suffice it to say that forest entomology is taught at every major college and University College in BC. As well, teachers and researchers at these institutions have made important contributions to forest insect biology and management.

c. Research in the federal government

The following is a brief overview of entomology research conducted by the federal Government in British Columbia. We have listed the scientists grouped approximately by the decade in which they commenced permanent employment. For each scientist, we give a brief description of the main subject area(s) of work and/or the highlight of accomplishments. We do not give a complete list of laboratory and research directors as this list is available elsewhere. Instead, we listed only those managers who were trained entomologists and did some forest entomology research during their careers. We made an effort to provide a complete list of all scientists who, at least some time during their careers, were permanently employed by the federal government and worked at one or more of the three entomology labs (Vernon, Vancouver, Victoria). We sincerely apologize for inadvertent omission of any names. In compiling this information we drew upon our personal knowledge and the following references: Richmond (1983); Riegert (1991); and Swaine (1918).

The early years

Significantly, organized forest insect investigations in British Columbia by the dominion government were started in response to extensive outbreaks by bark beetles during the first three decades of this century. The following quote from C. Gordon Hewitt, Dominion Entomologist in Ottawa described the bark beetle problems that existed up to 1917 as follows.

" The bark-beetles constitute the chief insect enemies of our coniferous forests, and it is impossible to give even an approximate estimate of the enormous annual loss caused by their depredations throughout Canada. Much of the dead timber whose destruction is attributed to fire is the result of outbreaks by bark beetles; this is particularly true in British Columbia."

To this day, bark beetles affecting mature pines, spruces, Douglas-fir and sub-alpine fir collectively remain the most important cause of tree mortality from forest insects in the Province.

Although not residing in British Columbia, ***J.M. Swaine*** was the first dominion government entomologist to carry out major investigations of forest insect biology and management in the Province. During these early years, there was a lack of information on the taxonomy, bionomics, and methods of coping with, destructive bark beetles. In response to the urgent need for this basic information, and the constant demand by lumbermen, foresters and others for practical methods of control, J.M. Swaine, Assistant Entomologist in charge of Forest Insect Investigations, undertook a study of the Canadian bark beetle fauna. This work culminated in the publication in 1917-18 by the Dominion of Canada, Department of Agriculture of the two-part Bulletin No. 14 entitled Canadian bark-beetles. It describes several new species from British Columbia. In 1918 The Commission of Conservation, Canada Committee on Forests published Forests of British Columbia which included a chapter by Swaine on injurious forest insects. He described outbreaks of bark beetles affecting ponderosa, western white and lodgepole pine, Engelmann and sitka spruce, western hemlock, lowland and alpine fir. Most of these outbreaks were occurring in the southern interior and the southern Rockies.

The beginning of organized research

R. (Ralph) Hopping was hired from California by the Federal Government in the late 1910s to organize suppression programs against outbreaks of the mountain pine and the western pine beetle in ponderosa and lodgepole pines in the Nicola-Aspen Grove-Merritt areas. The Provincial Government financed the control operations. In 1923 J.M. Swaine established the first dominion government forest insect laboratory in Vernon and R. Hopping was appointed to undertake a program of forest insect investigations in British Columbia and Alberta. Initially, the total staff of the Vernon laboratory consisted of four persons: R. Hopping in charge; his son ***G. (George) R. Hopping,*** assistant: ***H. (Hec) A. Richmond*** and ***W. (Bill) G. Mathers***, research assistants. For the next two decades, these entomologists made significant contributions to our knowledge of bark and ambrosia beetle biology and control, and the biology and control of some important wood borers (e.g., the red cedar borer) and defoliators (e.g., the hemlock looper, blackheaded budworm). ***H. (Hugh) B. Leech*** collaborated with W.G. Mathers on aspects of bark beetle research. In his Masters thesis, H.A. Richmond produced the first morphologic description of adult mountain pine beetles. G.R. Hopping became an authority on the North American bark beetle genus *Ips*.

Expansion of entomology investigations

The early 1940s saw a great proliferation of defoliator outbreaks in the coastal regions of the Province. Dr. ***M. (Malcolm) L. Prebble*** was transferred from Fredericton to British Columbia and established a forest insect laboratory in Victoria. He was joined by Dr. ***K. (Ken) Graham*** and together they carried out detailed investigations of the nature and causes of outbreaks in the coast hemlock forests by a number of defoliating insects such as the blackheaded budworm, the hemlock looper, the hemlock sawfly, and the rusty tussock moth. These investigations included the nature of natural control and considerations for chemical treatment. ***D. (Don) N. Smith*** and ***G.R. Wyatt*** assisted with various phases of this work as well as with subsequent studies by M.L. Prebble and K. Graham on the biology and damage caused by ambrosia beetles in softwood lumber on Vancouver Island. D.N. Smith's main research areas involved nursery and regeneration insects and insect pests of wood in service. In 1948 K. Graham became professor of forest entomology at UBC and M.L. Prebble transferred to Sault Ste. Marie, Ontario. Dr. ***M. (Margaret) R. MacKay*** worked as a taxonomist at Vernon until 1949 when she was transferred to Ottawa.

E.D. (Dave) A. Dyer and ***J. (Jim) M. Kighorn*** both joined the entomology laboratory in Victoria in 1946 as student assistants and later (1950) as permanent staff. Over a long, productive career that spanned three decades, J.M. Kinghorn made major contributions to our knowledge of hemlock looper biology, especially the effect of stand conditions on its epidemiology; ambrosia beetle management, and chemical control of the mountain pine beetle. During the last decade prior to retirement, he switched careers and pioneered development of containerized production of seedlings for reforestation. E.D.A. Dyer and Dr. ***J. (John) A. Chapman***, who joined the entomology lab in Victoria in 1952, were among the first scientists to demonstrate pheromone production in ambrosia beetle and spruce beetles. E.D.A. Dyer also made significant contributions to the biology and management of the spruce beetle. Other scientists that joined the entomology lab in Victoria during the late 1940s were ***S. (Stu) Brown, M.G. Thomson***, and ***J. (Jack) Walters***. S. Brown worked on population change in the mountain pine beetle and, in collaboration with J.A. Chapman and J.M. Kinghorn, ambrosia beetle biology and management. M.G. Thomson and J. Walters conducted one of the first investigations in the Province on spruce beetle biology; the former also worked on hemlock looper and ambrosia beetle problems.

Dr. ***W. (Bill) G. Wellington*** joined the Victoria lab in 1953. He made fundamental contributions to the field of bio-meteorology and insect ecology, especially studies of insects and climate, and individual differences among insects as factors in population dynamics. ***R (Ray) R. Lejune*** replaced H.A. Richmond as officer in charge of the Victoria lab in 1955 as the latter started a highly successful career as an entomology consultant; he was the first entomology consultant in the Province. ***A. (Al) F. Hedlin*** moved to Victoria from the Indian Head station in 1954. He worked on seed and cone insects, became an international authority on the subject and authored and co-authored a number of definitive publications on seed and cone insects and their management in Canada and North America. Dr. ***L. (Les) H. McMullen*** joined the forest insect lab in Vernon in the early 1950s and moved to the Victoria lab in 1954. In collaboration with Dr. ***M. (Mike) D. Atkins***, who joined the Victoria lab in the mid 1950s, Dr. McMullen carried out the first comprehensive investigations of the ecology of the Douglas-fir beetle in British Columbia. These studies included flight capacity and dispersal, brood mortality in relation to natural factors, and the effects of stand conditions and harvesting practices on beetle populations. This work has lead to the development of the highly effective "Douglas-fir beetle clauses" in the early 1960s which were written into timber sale licenses in high beetle hazard areas in the BC interior to ensure sanitary logging practices and treatment of logging residue. Dr. McMullen has also contributed to studies of mountain pine beetle dispersal and the sitka spruce weevil biology and management, being the major author of the first computerized model of spread, intensification of damage and direct control. ***M. Seger*** and ***S. (Sergei) F. Condrashoff*** joined the Victoria lab during the early 1950s. Mr. Seger, an insect pathologist, investigated disease associations of damaging forest lepidoptera. Condrashoff worked on the biology of needle and leaf-mining insects and regeneration pests such as the weevil *Steremnius carinatus*. Dr. ***D. (Doug) A. Ross*** joined the Forest Insect and Disease Survey (FIDS) unit at Vernon in 1950. The main areas of his research were wood borer biology and control. ***D. (Dave) Evans*** joined the FIDS as a taxonomist in the early 1950s. The main areas of his research concerned the life histories of forest insect pests and introductions of exotic natural enemies for controlling forest defoliators. Dr. ***G.T. (Tom) Silver*** replaced E.D.A. Dyer as FIDS Survey Head in 1953. Dr. Silver made important contributions to several fields including the biology of several species of forest defoliators, sitka spruce weevil biology, and sample survey methods. Dr. ***D. (Don) K. Edwards,*** insect physiologist, joined the insect lab in Victoria in the late 1950s. A productive scientist, Dr. Edward's work was centered on techniques for measuring activity rates and rhythms in insects such as the effects of electrical fields or acclimatization, and development of sampling techniques to measure defoliator density.

The new forest research laboratory was opened on Burnside Road, Victoria, during the early 1960s and all subsequent entomology work was done out of this facility with the exception of a few entomologists working with the FIDS who remained in Vernon until 1970 when that laboratory was closed. Dr. ***C.S. (Buzz) Holling*** worked at the Victoria lab during the 1960s. His main interest and work concerned basic principles of insect predation and process modelling in insect ecology. He was recognized internationally as an authority on these subjects. In 1960, Dr. ***O. (Ozzie) N. Morris*** succeeded M. Sager as insect pathologist. He investigated, and produced a catalogue of insect pathogens associated with forest lepidoptera in British Columbia. Drs. ***J.R. (Rod) Carrow*** (entomologist), ***D.B. (Bir) Mullick*** and ***G. (George) S. Puritch*** (plant physiologists) joined the entomology research group in the mid-1960s. Their research focussed on the nature and effects of resistance in true firs to the balsam wooly aphid, and induced physiological and biochemical changes in the tree as it affected aphid establishment and survival. Dr. ***J. (John) W.E. Harris*** who joined the FIDS unit in 1964, collaborated with assessment of natural enemy complexes associated with the balsam wooly aphid. Other accomplishments included the biology of the poplar and willow borer, development of survey methodology, including remote sensing, and assessment of the effectiveness of introduced parasites and predators in controlling the larch sawfly, the larch casebearer and other forest insects. Dr. ***T. (Tara) S. Sahota***, insect physiologist, joined the entomology research group in 1967. He made important contributions to several fields including hormonal regulation of metamorphosis and reproduction in bark beetles, and quality of individual insects as affecting numerical changes in populations. Currently semi-retired, his work during the past 5 years concerns the reproductive physiology and behaviour of the spruce weevil as affected by host factors. ***D.R. (Ross) Macdonald*** moved to PFC from the Fredericton lab in 1968 to become Section Head, Forest Entomology. In 1969 he became Program Director for Forest Protection. After serving as Director of the Forest Protection Branch in Ottawa, Mr. Macdonald became Director General, Pacific and Yukon Region (1980-87), Canadian Forest Service (CFS), a post from which he retired. Mr. Macdonald's research experience and expertise included spruce budworm ecology and the effects of spray operations on budworm natural enemies. Dr. ***R. (Roy)F. Shepherd*** moved to Victoria from the Edmonton lab of CFS in 1969 to undertake researches on the population biology and management of defoliating insects. This research has lead to development of sampling methods for several defoliators, development of pest management methods for the Douglas-fir tussock moth and the black army cutworm, monitoring systems for endemic populations with pheromone traps, and prevention of outbreaks through early treatment with nuclear polyhedrosis virus.

Dr. ***H. (Henry) A. Moeck*** joined the bark beetle research group in Victoria from the Forest Products Laboratory in Vancouver in 1970. His field of research involved primary attraction in bark and ambrosia beetles and assessment of native and exotic natural enemies of bark beetles as potential biocontrol agents. Dr. ***S. (Steve) Ilnytzky*** joined the entomology group at PFC in the early 1970s. His main research concerned the use of pesticides in insect control. He developed bioassays of insecticide residues in soils and investigated phytotoxicity of pesticides to forest seeds. ***C. (Cliff) E. Brown*** moved to PFC from Ottawa in 1972 to become a Program Manager and Deputy Director, positions from which he retired. The focus of Mr. Brown's earlier work concerned the development of automated recording of FIDS data at regional and national levels. Drs. ***M. (Malcolm) D. Shrimpton*** (tree physiologist), ***H.S. (Stu) Whitney*** (plant pathologist) and ***L. (Les) Safranyik*** (insect ecologist) were transferred to Victoria from the Edmonton lab of CFS in 1972 in order to concentrate bark beetle research in CFS at the Victoria lab as these insects continued to be the most destructive in the forests of British Columbia. Based largely on previous research in the East Kootenays by this team and colleagues from Alberta, they produced two milestone publications on the mountain pine beetle in 1974: "An interpretation of the interaction between lodgepole pine and the mountain pine beetle with its associated blue stain fungi in Western Canada" and "Management of lodgepole pine to reduce losses from the mountain pine beetle" The first paper describes the nature and affects of the three-way interactions among the host, beetles and fungi and their role determining the course of infestations. The second paper, intended for practicing foresters and forest health specialists, emphasizes that in order to effectively cope with the beetle the focus of management should be logepole pine and not the beetle. This publication was an all time "best seller" in Canada and the United States; two printings of a couple thousand copies each are sold out. Other major publications followed on the population dynamics of the spruce beetle. Dr. Safranyik's current research involves a population dynamics model of the mountain pine beetle, competitive exclusion of the mountain pine beetle, and spruce beetle ecology. Dr. ***A. (Al) J. Thomson*** joined PFC in the late 1970s. An insect ecologist but not formally part of the entomology research group, Dr. Thomson does much work of entomological nature such as a landscape-level model for mountain pine beetle, collaborative work on bark beetle population quality with Dr. Sahota and a mountain pine beetle model with Dr. Safranyik. ***H. (Howard) A. Tripp*** succeeded Dr. Silver as FIDS Survey Head in 1973. His interests were biological control and seed and cone insects. Dr. ***C.D. (Doug) F. Miller*** moved to PFC from Ottawa to become Research Program Manager in 1978.His entomological work was done in agriculture concerning the taxonomy of ants, wasps and parasitic insects. Dr. Miller has published several monographs on the classification of these insects.

Dr. ***G. (Gordon) E. Miller*** joined PFC to take over seed and cone insect research following the retirement of A.F. Hedlin in 1980. Dr. Miller's research work was centered on the population ecology and management of cone and seed insects and produced over 30 scientific and technical papers on these subjects. Since 1986 he pursued a career in management and is currently Director of Research for CFS in Ottawa. Dr. ***I. (Imre) S. Otvos*** moved to PFC from the Newfoundland lab of CFS in1981. His main work at PFC centers on the use of natural enemies (predators, parasitoids, fungi, bacteria and viruses) for controlling defoliating insects. Some major accomplishments include assessment of the potential of introduced parasitoids and fungal pathogens for the control of the hemlock looper; pioneering the concept of creating epizootics of naturally occurring pathogens to control defoliators, and co-developing with Dr. R.F. Shepherd a management system for Douglas-fir tussock moth. Dr. ***R. (Rene) I. Alfaro*** joined the FIDS program in 1980 and was assigned to entomology research full time a few years later. The main foci of his research are quantification of damage caused by forest pests, management and ecology of the spruce weevil with emphasis on the nature of host resistance and host-insect interaction. His comprehensive research on insect impacts has enabled private and provincial pest management agencies to measure potential losses and to justify control programs. Continuing work on weevil-host interactions resulted in numerous scientific and technical papers concerning the nature and effects of host resistance, and the dynamics of intensification and spread of infestations at the tree, stand and landscape levels. Dr. ***M. (Mike) A. Hulme*** joined PFC from the Eastern Forest Product Laboratory in 1982. The main area of his work involves biological control. Dr. Hulme co-edited the book entitled "Biological control programs against insects and weeds in Canada 1969-1980". Other accomplishments include demonstration of pheromone-based mating disruption in Douglas-fir tussock moths, a first in this field, and showing that host phenology has a major affect on resistance to the sitka spruce weevil. Dr. ***T. (Terry) L. Shore*** transferred from the FIDS to bark beetle research in 1985 following the retirement of Dr. L.H. McMullen. His main areas of research are development of hazard-risk rating systems and decision support systems to enable forest managers to develop effective and efficient programs of managing destructive bark beetles. A system for rating lodgepole pine susceptibility and risk of loss from mountain pine beetle developed by Drs. Shore and Safranyik is included in the bark beetle management guidelines section of the Forest Practices Code for the province, and is being widely used by forest protection staff in industry and government in BC as well as in neighbouring states in the USA. Dr. ***H. (Hugh) J. Barclay***, an insect ecologist, joined the growth and yield program at PFC in 1982. Although his research assignments were, and continue to be, in a field other than entomology, he has authored and coauthored a number of scientific papers on entomological subjects. Significant contributions include the mathematical treatments of sterile males, inundative releases of natural enemies, for controlling insects, and contribution to the development of interactive models of spruce beetle and mountain pine beetle population dynamics. Dr. ***L. (Lee) M. Humble*** joined FIDS in 1985 as an insect taxonomist. In addition to the taxonomic work, his main areas of research include insect biodiversity, specifically the diversity of canopy-dwelling insects in the boreal forest, and the establishment and biology of introduced insects.

Following program reorganization in CFS during the mid-1990s two entomologists transferred to PFC from other CFS establishments: Dr. ***V. (Vince) G. Nealis*** from Sault Ste. Marie and Dr. ***A. (Allan) L.C. Carroll*** from St. John's, Newfoundland. Dr. Nealis is developing a program on the population ecology of spruce budworms in British Columbia. The focus of Dr. Carroll's current work involves investigations of the ecology of mountain pine beetle populations in the endemic state.

Technical support

The contributions of technical support staff to all phases of research and development are highly important and impressive. Some technicians, owing to special skills and or experience gained on the job, had their own research projects which they conducted semi-independently from the research officer in charge. For example, W. (Bill) W. Nijholt has made substantial contributions to ambrosia beetle management and pioneered the use of pine oil for controlling bark and ambrosia beetles and, with H.A. Richmond, water-misting of log decks in dry-land sorts to reduce ambrosia beetle damage. Some others who worked in similar manner are T. (Tom) G. Gray on pheromone-based monitoring of defoliators and R. (Bob) Duncan in insect taxonomy. Still others co-authored an impressive list of scientific and technical papers.

Trends in research

Of necessity, much of the research conducted during the first 25 years or so involved identification, taxonomic description, geographic distribution, and exploratory work on the biology and control of injurious forest insects. Due to shortage of manpower and expertise, often a single scientist was assigned to work on several problem areas involving several insect species in different taxa. With an increase in the number of scientists assigned to forest entomology, research became specialised. Scientists normally worked in a single field such as physiology, population ecology and often with one or a few related species such as the budworms. There was an emphasis on studying insect populations under outbreak conditions. Research projects, however, were still mainly headed up by single scientists. This general trend continued to the beginning of the 1970s. From this time on, gradually there was a change from studies of epidemics to studies of factors affecting populations in the endemic state. As well, there was more emphasis on insect management through cultural practices and natural enemies. Multidiscipline team approaches to tackling difficult problems became more prevalent. These trends continue today but with greater emphasis on development of practical decision support systems that are based on a solid ecological foundation. There is increased need for understanding the interactions of insects with their host trees and the host environment at the landscape level and the consequences of natural and man-made disturbances, including insect management actions, on biodiversity and sustainability of forest management.

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II. The Forest Insect and Disease Survey in the Pacific Region

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The combined Forest Insect and Disease Survey (FIDS) originated with the 1962 unification of the pre-existing Forest Insect Survey and the Forest Disease Survey. FIDS was an early national network within the Canadian Forestry Service, and its predecessors, to detect and monitor insect and disease conditions in Canada's forests. Responsibilities among the six regional units, such as the British Columbia and Yukon unit, included monitoring forest pest conditions, keeping records to support quarantines and make predictions, supporting forestry research with records, and disease (herbaria) and insect collections, testing and developing survey techniques, and providing advice on insect and disease conditions.

FIDS and pest surveys were an early and integral part of the Canadian Forest Service in its various forms and departmental associations. Dr. J.M. Swaine was appointed as the first full time forest entomologist in Canadian government service in 1912. He conducted numerous inspections (surveys) and collecting trips in western Canada and published "Canadian Bark Beetles" in 1918.

In 1922 the Canadian government established an insect laboratory at Vernon to investigate forest insect problems in the BC interior, the Rocky Mountain National Parks and the east slopes of the Rockies. The four staff sharing an office in the Vernon courthouse included Ralph and George Hopping, Bill Mathers and Hec Richmond. Initially efforts focused on extensive bark beetle infestations in pine stands in south central BC and in Banff National Park, where from 1941-1943 more than 27,000 infested trees were cut and burned to prevent an outbreak of the mountain pine beetle from developing to epidemic proportions. Although the Vernon establishment was made a sub-lab administered from the Victoria centre in 1945, by 1951 the 18 staff were accommodated in a new office building on British Columbia Forest Service land on Pleasant Valley Road. An insectary and large garage-shop was added by 1954. When the Vernon lab was closed and staff transferred to Victoria in 1970, the facilities were sold to the British Columbia Forest Service for $1.00

A sub-laboratory for insect and disease studies in the coastal forests was opened in Vancouver in 1925 in conjunction with the Forest Products lab.

In 1928, Dr. J.M. Swaine strongly urged the establishment of an "insect intelligence service" for a survey of forest insects because of the severe outbreaks of budworm, sawfly and bark beetles. This was supported by representatives of forest industries through the Canadian Pulp and Paper Association and the Canadian Society of Forest Engineers. In 1931, The Division of Forest Insects of the Entomological Branch of the Department of Agriculture organized the "Forest Insect Intelligence Service" A number of circulars giving popular accounts of the principal forest pests were prepared. These circulars, together with questionnaires were sent to industrial organizations and forest services, with the request that they be filled out by forest workers. In 1936 the Forest Insect Survey was established as a permanent, independent unit and 528 insect samples and records from eastern Canada reached Ottawa for identification and recording. In 1937 forest insect surveys from Vernon commenced as part of a survey which had national scope by 1939. To process the collections being sent to Vernon a Forest Insect Survey insectary was built nearby at

Trinity Valley in 1937. Mind you, this was only after obtaining direct approval from Dr. J.J. de Gryse, Chief, Forest Insect Investigations in Ottawa (and workers today think they are tightly controlled). Labor was to be at 70 cents an hour with total costs not to exceed $300. With closure of the Vernon lab, and following some vandalism and a fire in 1968, the Trinity Valley site was turned over to the Department of Education about 1971 for outdoor studies.

The nation wide survey project was administered on a regional basis, coordinated through a headquarters at Ottawa, initially with the following objectives:

1. Conduct a year-to-year survey of the status of potentially destructive insect species.
2. Accumulate information relating to the many thousands of species affecting forest trees:
   - the characteristics of their attacks on the trees;
   - their distribution throughout Canada;
   - the tree species attacked in different parts of their range;
   - the parasites, predators and diseases which attack the insects;
   - the relation of the development of destructive insect populations to forest composition, age and other environmental factors.

These objectives were updated periodically, to include forest disease surveys in 1952, and damage appraisal, survey methodology and remote sensing in the Pacific Region, in 1966.

A permanent forest insect centre was established in 1940 in Victoria firstly in the "old, old" Post Office building (now the Customs and Immigration Building on Government St. and Wharf St.). About this time two wood-walled tent-covered frames at Lake Cowichan/Mesachie Lake Experimental Station were refurbished by Drs. Prebble and Graham (entomology) and Dr. Buckland (pathology). These were upgraded, although still far from being luxurious, by Survey ranger staff from 1947-1949. They along with a 1960s laboratory (now a meeting centre) served as a field station for research by Federal staff until 1983 when they were turned over to the British Columbia Forest Service.

After World War II permanent ranger staffs were assigned to the Forest Insect Survey with their first offices in Victoria in the Central Building on View Street before moving to the old post office. R.L. (Lew) Fiddick was taken on staff in the spring of 1945 as the first federal insect ranger in the Pacific Region. The first assignment under the direction of Dr. M.L. Prebble was an assessment of a western black-headed budworm outbreak on north Vancouver Island in the Holberg Inlet-Port Alice area. A spray program had been organized, but a very labor intensive egg survey on numerous, large, hand-felled trees showed the infestation had collapsed due to natural causes. Over the next 30 years FIDS was to be involved in forecasting and assessing population levels, forest damage and control efficacy for more than 25 infestations of numerous different defoliators (see Appendix). It contributed to the development of aerial spray technology applicable to the unique and challenging conditions of BC. Effective dosage levels were progressively decreased and the more acceptable biological insecticides were introduced and tested.

By 1949 the Department of Agriculture was advertising for additional Forest Insect Rangers, Grade 1 at the annual salary of $2160-$2460. Expense account allowances were: breakfast 70 cents, lunch 85 cents, supper $1.15 = $2.70/diem. The midnight ferry from Victoria to Vancouver was fare $3.50, truck $6.00 berth $4.50. At its peak a total of 16 Forest Insect Survey Rangers were assigned to individual districts throughout BC.

In 1948, to undertake surveys of the more than 11,000 km of shore line at a time when there were virtually no roads, an 18 m (60 foot) vessel was purchased from War Assets and converted to a floating laboratory, the J.M. Swaine. Cramped quarters existed for the skipper, a cook, engineer and two or three survey rangers or assistants. The vessel served the coastal areas until 1953 when it was sold and replaced by the smaller two-man vessel, the Forest Biologist. With somewhat improved road access and increased usage of aircraft the Forest Biologist was last used in 1968, although smaller one-person trailered boats continued to be used for sampling on smaller islands and along the lower coast. In 1968, a new ranger hired from the second graduating class of British Columbia Institute of Technology forest technicians, Peter Koot, had his first "sink or swim" summer surveying from Jervis Inlet to Smith Inlet using "The Okalla Queen". This was a V6 powered plywood, 6.4 m (21 foot) cabin cruiser/tub built by the "very experienced" boat builders from Okalla Prison. It would only get up and plane with a nearly empty gas tank, very little food on board, no water in the bilges (a rarity because it always leaked) and preferably without the student assistant.

Also in 1948 a Forest Insect Survey insectary and rearing facility in Langford was completed by the versatile Survey staff. In 1965 with the new Pacific Forest Research Centre research facilities in Victoria the old insectary building was turned over to the municipality and is now the offices of the Capital Regional District and part of Mill Hill Regional Park.

Between 1950 and 1963 a network of seasonal Forest Insect Survey field stations was built including Kye Bay (1950), Cultus Lake, Lakelse Lake (1951), New Denver, Christina Lake (1953), Wasa Lake (1954), Williams Lake (1952), Prince George, and Babine Lake. In following years additional stations were moved to or acquired at Terrace (1959), Kamloops, Agassiz, Powell River (1963), Smithers and Summerland. With the long-term and conspicuous involvement in many communities throughout the province the Survey became one of the most visible parts of the Canadian Forest Service and maintained a reputation for consistent service to the forest community. The cabins greatly reduced accommodation costs during the 4 decades of service and greatly appreciated in value compared to the average cost of construction (Cultus Lake $3418; Kye Bay $2937; Lakelse Lake $3855; Williams Lake $4045; Wasa Lake $4359; Babine Lake $5804 - costs were said to be higher here because of local shortages due to the ongoing construction of the Kitimat aluminum plant). Minimizing operating costs is a regular government mantra, but consider the extent in the 1950s: in July 1957, B.M. McGugan, Co-ordinator, FIDS in Ottawa wrote Ray Lejeune, Officer-in-charge, Forest Biology Laboratory, Victoria, "policy regarding ranger cabin furnishings will not allow the purchase of refrigerators". And in 1959, $4.40 per month for a phone was considered too high to consider in the budget.

Remember at this time the paved roads ended at Clinton, the Hope-Princeton Highway was just being opened and the Rogers Pass and Kaslo-Salmo highways didn't exist. Initially the Survey organization "inherited" army surplus 4-wheel-drive vehicles called Heavy Utility Personnel Carriers (HUP's). Only slightly suitable for rough overland travel at slow speeds they were clumsy, noisy, dusty, right-hand drive and subject to break-down. When eventually new 1950 Ford vans were delivered to Victoria they didn't have heaters, Ottawa considered them unnecessary.

A Forest Disease Survey was formally organized in 1952 to include a survey of tree diseases. For both the Forest Insect and the Forest Disease Survey, a standard punch-card system of recording and sorting insect and disease records was established across Canada ("as many as 12 columns simultaneously and 400 cards per minute" were processed using Remington Rand sorting machines).

Annual forest insect and disease surveys in the Yukon were started in 1952, although a special survey for mosquitoes had been conducted in 1948 with an Ottawa-based scientist and support staff from Victoria (they certainly didn't collect them all!). The annual Yukon surveys by FIDS from the Pacific Forest Research Centre continued until 1965, and then again from 1974 to 1996. From 1966 to 1972 the Yukon surveys were conducted from the Northern Forestry Centre in Edmonton. Initially an older house trailer in Whitehorse was used during the Yukon surveys before being replaced by a roll-up, sectional camper and then a modern hard sided truck mounted camper. One year, the FIDS ranger sleeping in the camper awoke suddenly to find a mother and two cub bear faces pressed against the window only inches away from his own. Being a sectional camper, one good shove would have separated the sections; fortunately the bears climbed down from the hood of the truck and departed, probably followed quite quickly by the ranger. Another time a bear climbed into the back of the truck while the ranger was away collecting, and then... but there are so many bear stories.

Although the first sketching of infestation boundaries from an aircraft was published as early as 1920, and periodic mapping was done for major outbreaks, it wasn't until the early 1950s that aircraft availability and cost was reasonable enough that organized annual overview flights and mapping of the major defoliators and bark beetles was initiated on an annual basis. Federal Government austerity always seemed to exist and there was seldom much money for aerial surveys. Acknowledgement is made of the considerable provision of flying time and cooperation by the British Columbia Forest Service and forest industry. The considerable amount of flying time provided to FIDS from other agencies annually for many years speaks well for the negotiating skills of the ranger staff and for the value of the information they provided. Without the many excellent contacts and cooperation established and maintained by the rangers the several decades of aerial detection and damage records would not have been as extensive.

Cooperation was not limited to just flying time, but included information, lodgings, assistance and loan of equipment. One courtesy provided in 1958 to ranger, Norm Alexander in the remote West Prince Rupert District was the loan of a large box "portable" radio which required that the antenna be thrown up over a branch then back away the 30.5 m (100 foot) length to make your call (hardly today's cellular phone).

Aircraft and pilot reliability was a somewhat different matter at times. e.g. One pilot refused to fly about 300-500 m above the ground necessary to distinguish and map damage. He was dubbed "sky blue Lou" and probably fortunately, was always on days-off when other FIDS flights were scheduled. On the other hand there was the pilot who, after mapping mountain pine beetle damage, bypassed the refueling facilities at McBride and headed for Prince George. The FIDS ranger made a few enquiries about running out of fuel and sure enough over Purden Lake the engine sputtered. Abrupt rocking of the plane kept the engine alive for a few moments, but not for long and elevation was being lost. Gliding silently over Tabor Lake, boaters were seen making hasty retreats to the shore and even into the lake. Fortunately the glide carried far enough for a relatively smooth landing in a hay field just beyond the lake. A different plane and pilot, but the same FIDS ranger finished mapping later that week and continued doing so for years.

Other enjoyable(?), memorable flights: En route to Sandspit, dark oily spots started appearing on the window and increased until visibility was nearly nil. Upon landing, smoke curled up from the engine cowling and the engine bust into flame. Luckily the pilot anticipated this (had it happened before?) and doused the flames with an extinguisher. Another incident occurred on an early 1970s flight made from Campbell River in a Beaver on floats. After dodging the many anglers in the harbor and just about to lift off, the engine died, causing a near nose dive into the chuck. These were the joys of a new pilot on a plane just brought back to Canada from the Peruvian Air force with an instrument panel still in Spanish and the gas tank switches opposite to those of other Beavers (the pilot had switched to an empty instead of full tank). Most rangers had hair-raising experiences of flying in marginal weather using fish boats and lighthouses for navigation, float-plane landings hitting rough seas, logs or even basking sharks, and very tight turns in narrow or dead end (not a nice term) valleys. Invariably, they would comment "If it had been any other type of plane but a noisy Beaver, it would not have continued flying."

In 1960 the Forest Biology Division, Science Service, Department of Agriculture was joined with the Forestry Branch, Department of Northern Affairs and Natural Resources to form the Department of Forestry.

The Forest Insect Survey and the Forest Disease Survey were unified in 1962 as the Forest Insect and Disease Survey (FIDS).

While the Honourable J.R. Nicholson, the Minister of Forestry may have laid the cornerstone in August 1963 for the new Forest Research Laboratory on Burnside, it was FIDS rangers in 1957 who laid the more important first culvert and driveway for access to the site. This included hauling gravel from Goldstream in the back of the panel trucks because of government spending constraints. Guess who got the most press!

On February 15, 1965 the new Pacific Forest Research Centre on Burnside Road was opened, and for a short while the entire coastal unit of FIDS were together along with the herbarium and insectary. Then, after the 1969 austerity review, the Vernon lab was closed and all projects and personnel were transferred to Victoria (10 transferred, 2 quit and 2 positions were terminated). Along with staff transferred from the Calgary/Edmonton lab the Burnside lab became crowded and offices and labs were created for FIDS in the old headerhouse which had been constructed in 1957-1958 along with a separate greenhouse. (The herbarium cabinets stood just about where the Christmas luncheon is tabled). Although slightly separated from the main lab it was only a wet run away during coffee breaks and FIDS staff maintained a strong team unity (only the screams from the serious table tennis players in the silviculture group's annex next door shattered the noon-hour peace). With the addition of the "new wing" in 1985, the herbarium and all FIDS staff returned to the third floor again in association with the insectary. The new greenhouses were then built attached to the headerhouse.

Forest insect and disease punch card records were computerized in 1967 and new collections were recorded on a revised enclosure slip. Data processing was centralized in Ottawa.

In 1975 the FIDS unit at PFC led a national task force on Damage Appraisal and Pest-Caused Losses. The approaches developed were the basis for loss estimates contributed to Statistics Canada for the next couple of decades and used widely by the British Columbia Forest Service and others.

In 1979 there was another A-Base Review and a task force was struck by Canadian Forest Service Headquarters to review the FIDS program. Based on interviews and correspondence with over 150 individuals in federal departments, provincial agencies and the forest industry, the task force concluded: "there are sufficient and compelling reasons why the FIDS should be maintained as a national program". It also recognized that the transfer of FIDS from Agriculture to Forestry without provision for a mandate to replace the Plant Quarantine Act, and the de-emphasis of the national aspects of the program in the 1969 reorganization, required action to readopt and reaffirm the original strong rationale for a FIDS to provide essential data input to federal forestry programs and to federal policy and decision making. It was recognized that the demand for pest information was certain to grow at an increasing rate over the next decade, but periodic funding reviews would continue to target programs as large as the national Forest Insect and Disease Survey.

In 1984 FIDS at the Pacific Forest Research Centre began developing a computerized mapping and analysis geographic information system (GIS). It was up-graded in 1992 when the system was standardized nationally. GIS is now commonly and nationally utilized and the historical distribution and infestation records are available on the internet.

The Forest Insect and Disease Survey celebrated 50 years of service in 1986. Over this period of time and beyond, the motivation and self-reliant nature of FIDS staff was key to many accomplishments. They undertook annual in-service training programs most winters and tested and embraced new tools. Funds were found for 2-way radios in 1983 after Leo Unger walked more than 33 kms from a mud hole. Pheromone trap monitoring for gypsy moth detection was used since 1978 and pheromone monitoring systems for numerous other forest insects were tested and calibrated. Satellite tracking geographic positional systems and electronic field data recorders were added early in the 1990s.

From 1985-1996, FIDS provided information, undertook special surveys, developed and tested protocols and served on Science/Policy panels concerning the pinewood nematode and its effect on the export of Canadian lumber.

In 1995, after (yet another) program review and reorganization of the Canadian Forest Service, which included a 30% cut in resources, the decision to discontinue annual, operational surveys of important forest pests on a national basis was announced. Several provinces, including BC, felt that they could not politically accept the "off-loading" of what had been a Federal activity, or did not have the resources to continue the surveys. Subsequently the FIDS units were disbanded through early retirements, other packaged departures, and transfers to the various research networks that were established within the Canadian Forest Service.

PERSONNEL

FIDS has been an early and integral part of the history of the Canadian Forest Service in Canada and in BC/Yukon. Over a period spanning almost 6 decades many staff gained and shared an expertise and knowledge of the forests and its diseases, insects and natural control factors. More than 70 men and one woman served as Forest Insect and Disease Survey Rangers. Some remained only for a year or two but for many it was a long and dedicated career. Ranger staff in the Pacific Region with more than 25 years service included: Stan Allen, Dick Andrews, Cliff Cottrell, Lew Fiddick (the most senior with more than 37 years service, first as an insect ranger and then Chief Ranger), Jim Grant, Colin Wood, Roly Wood, and Bob Erickson, Peter Koot and Leo Unger who are still contributing as Forest Health network technicians. More than 50 other scientists and technicians have worked with FIDS in the herbarium, insectary, damage appraisal and methodology studies. Those with more than 25 years service included: George Brown, Don Collis, Al Dawson, Dave Evans, Ab Foster, John Harris, Daphyne Lowe, Alec Molnar, Erika Pass, Doug Ross, Dave Ruppel, Allan Van Sickle, Emil Wegwitz and Wolf Ziller.

Numerous others contributed and received a good foundation in FIDS before transferring to other projects in the Canadian Forest Service or to other aspects of forest pest management including (but not limited to): Norm Alexander, Rene Alfaro, Dennis Beddows, Clare Farris, Brenda Callan, Dennis Clarke, Don Doidge, Bob Duncan, Lee Humble, Rich Hunt, Ernie Morris, Doug Ruth, Terry Shore, Tom Silver, and Tad Woods. In addition, many casual employees and students, while working with FIDS to earn funds for further education, also gained an increased awareness of forest insects, diseases or geographic information systems, and the experience of federal government employment.

FIDS is indebted to the secretarial staff (Evelyn Andrews, Nancy Mason, B. Sugden and T. Gabriel at Vernon; Pat McLean, Heather Murchison, Francis Douglas, Susan Ticknor, and Joan Strobbe at Victoria), who patiently deciphered near incomprehensible telephone messages and hand writing; and to the many other technicians and scientists, regionally, nationally and internationally who worked closely with, and contributed greatly to the many accomplishments of FIDS.

MAJOR ACCOMPLISHMENTS OF FIDS

For more than 5 decades Forest Insect and Disease Survey staff provided expertise and a strong liaison for the Canadian Forest Service with the British Columbia Forest Service, the Yukon Territory, as well as with forest industry, universities and technical schools, provincial and federal parks, the public and other agencies. This was a time of growing awareness and concern about forest pests, their life cycles and control factors, both natural and chemical.

From the 1940s to the 1980s, FIDS staff undertook, often in cooperation with the Council of Forest Industries, or participated with research staff in the assessment and monitoring of more than 25 forest insect control projects. In numerous additional cases, careful assessments of population trends and natural control factors indicated that direct control was not required.

FIDS developed and implemented practical sampling and survey methods and frequently provided collections, information and assistance to other scientists across Canada and internationally.

The FIDS collections and associated data established the extensive data base of more than half a million records of forest diseases, insects and beneficial natural control agents from the forests of the Pacific Region of Canada. The curated permanent reference collection of more than 66,000 insect and 35,300 disease specimens is critical for accurate identification of native and exotic pests. An extensive photo and color slide collection was also assembled. Some of this information has recently been made available on the internet. It has also provided the basis for some biodiversity studies.

Many assessments of the natural biological control factors of forest insects were also conducted by FIDS. A data base of more than 20,000 records was compiled from collections and insectary rearings to better understand and predict the effects of natural occurring parasites and disease on insect infestations. Biological control experiments started as early as 1931 when parasites from Japan were caged with hemlock sawfly from the Queen Charlotte Islands. As well as monitoring the larch casebearer from its first detection in BC in 1966, FIDS initiated and participated in parasite introductions and assessments from 1969 to 1984. Other successful parasite releases and introductions were made for balsam woolly adelgid, the winter moth, larch sawfly and apple ermine moth.

In 1975 FIDS led a national task force on damage appraisal and pest-caused losses, developing the approach and providing estimates of forest insect and disease losses in the nation's forests for reporting by Statistics Canada for the following decades. These quantifications increased awareness of the major impacts of forest insects and diseases as well as identified areas needing further study and support. Damage appraisal, remote sensing of pest-caused damage, and statistically based sampling studies started first in FIDS before becoming separate studies.

Extensive biological surveys (insects, diseases, parasites and predators) were conducted up to 1969, after which emphasis was more on commercially important pests with increasing attention to introduced insects and diseases of potential risk to Canada's forests. An increased level of awareness and concern for the latter continues. FIDS provided both an annual and an historical perspective of forest pest conditions throughout BC and the Yukon. This was well documented in a great many timely reports and publications (even videos) and through participation in regional, national and international meetings.

FIDS first implemented a geographic information system (GIS) for the maintenance and reporting of insect infestations and disease distributions in 1984. Portions of the historical aerial survey outbreak maps and disease distributions are available on the world wide web.

An informative and popular Forest Pest Leaflet series describing the life cycles, damage and activities of more than 60 common forest insect and diseases was created and maintained by FIDS. These were also presented in PFC's first CD release (HFOREST - Hypermedia Forest Insect and Disease Knowledge Base and Diagnosis).

APPENDIX

Early aerial control trials of forest defoliators in BC.

Date	Insect	Location/area	Insecticide
1929	western hemlock looper	Burrard Inlet/45ac	calcium arsenate
1930	western hemlock looper + black-headed budworm	Stanley Park/800ac	calcium arsenate
1930	western hemlock looper	Seymour Creek/800ac	calcium arsenate
1946	western hemlock looper	Nitinat	DDT
1948	western false hemlock looper	Windermere Valley /11,200ac	DDT
	(First time in Canada to use non-fixed wing aircraft, Bell 47 helicopter, in an operational forest pest control program)		
1956	black-headed budworm	Pt. McNeill/360ac	DDT
1956	phantom hemlock looper	Burnaby, Central Pk /200ac	DDT
1957	phantom hemlock looper	Burnaby, Central Pk /200ac	DDT
1957	phantom hemlock looper	New Westminster Queens Pk /75ac	DDT
1957	black-headed budworm	Pt. Alice-Pt Hardy /156,000ac	DDT
1959	western hemlock looper + greenstriped forest looper	Stanley Pk/550 ac	DDT
1960	black-headed budworm	QCI Moresby Is /160,000ac	DDT, Bt
1960	saddleback looper	Kitimat/1,800ac	DDT
1961	saddleback looper	Kitimat /9,800ac	DDT, Dibrom, Phosphamidon, Bt
1961	pine butterfly	Cameron Lake/1,500ac	DDT
1962	Douglas-fir tussock moth	Okanagan Valley/160 ac	DDT, malathion, NPV
1964	western hemlock looper	Enderby/50ac	Phosphamidon
1964	greenstriped forest looper	QCI Pt Clements/1,600ac	Phosphamidon
1965	hemlock needleminer	Holberg/1,000ac	Phosphamidon, Dimethoate
1973	western false hemlock looper	Salmon Arm/400 ac	Dipel
1973	black-headed budworm	Pt. Alice/28,000 ac	Fenitrothion
1974	Douglas-fir tussock moth	Kamloops/25 ac	NPV
1974	western false hemlock looper	Chase/120 ac	Dipel, juvenile hormone, Zoecon
1975	Douglas-fir tussock moth + western false hemlock looper	Kamloops/31,000 ac	Dipel, Orthene, Bt, NPV
1976	Douglas-fir tussock moth	Kamloops/20,000 ac	Orthene, Bt

III. The Vernon Laboratory and federal entomology in British Columbia

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Over its fifty years of existence the personnel of the Vernon forest entomology laboratory conducted scientific research on B.C.'s insect species, battled epidemics that threatened commercial timber, and monitored their populations. Between 1920 and 1970, first as part of the Department of Agriculture and more recently within the Canadian Forestry Service, the facility provided tangible evidence of the federal government's interest in the provincial forest economy. Prior to the 1930 transfer of natural resources to the provinces Ottawa's stake in the Railway Belt provided sufficient reason for such a presence, perhaps, but the laboratory survived after B.C. claimed complete jurisdiction over timberlands in the province. Transcending provincial boundaries, forest insect problems were an appropriate area of Dominion scientific inquiry.

An early twentieth century bark beetle epidemic in the southern interior created the motivation for Ottawa and Victoria to cooperate in control projects that operated each spring and summer during the 1920s. Ralph Hopping directed that effort, and stayed on to head the laboratory's small staff until passing the reins to his son George in 1938. The facility remained B.C.'s major centre of forest entomology until losing its research orientation to a new federal installation in Victoria in the 1950s, then closed entirely in 1970. Ironically, soaring interior bark beetle populations have lowered the value of vast stretches of timber in subsequent decades.

Forest entomology in Canada began to emerge from its amateur origins in 1909, with the hiring of C. Gordon Hewitt as Dominion Entomologist. Hewitt, in a refrain entomologists would repeat often in coming decades, observed that the depradations of insects received much less attention than fire in Canadian conservation circles. Some research had been conducted on larch sawfly and spruce budworm outbreaks, but their significance paled in comparison to the damage caused by several species of bark beetles which had yet to receive any scientific attention. The first step in correcting this situation came with the 1912 appointment of J.M. Swaine, a graduate of Cornell and recognized North American bark beetle authority, as Assistant Entomologist for the study of forest insects in the Department of Agriculture's Entomology Branch. Swain took charge of the new Division of Forest Insects, and immediately undertook a study of bark beetle outbreaks in Canadian forests.[1]

A cooperative agreement between the Dominion Department of Agriculture and the B.C. Forest Branch took Swaine to the west coast in the summer of 1913 for a survey of forest insect damage. Swaine covered the Kootenay, Okanagan, Similkameen, lower coast, and Vancouver Island regions. His preliminary investigation found the coastal forests relatively free of extensive outbreaks, but in the southern interior pine beetles were

[1] M.L. Prebble, "Forest Entomology," *The Canadian Entomologist* 88 (July 1950), p. 351; D.R. Wallace, "Forest Entomology or Entomology in the Forest? Canadian Research and Development," *Forestry Chronicle* 66 (Apr. 1990), p. 120 [hereafter *FC*]; "Will Study Forest Insects," *Canadian Forestry Journal* 8 (Jan. – Feb. 1912), p. 26 [hereafter *CFJ*]; C. Gordon Hewitt, "Investigations on Forest Insects, and Forest Protection," *CFJ* 8 (Mar. – Apr. 1912), p. 36.

inflicting serious losses to yellow pine stands. Conditions were particularly acute in the Princeton area, where an outbreak had killed much valuable timber. "The clumps of "red tops" may be distinguishing upon the mountain-side and in the valleys for many miles," he noted in a report on the infestation.[2]

Swaine returned in the summer of 1914 to discover that the Okanagan infestation had spread as far west as Princeton. On Okanagan Lake the hillsides appeared "as though swept by a great fire," with only isolated patches of Douglas fir surviving. In other areas beetle attacks were decimating the white pine, and authorities noted the relationship between the slash left by logging operations and beetle outbreaks. Hewitt advocated the adoption of "vigorous control methods" to prevent the spread of beetles from fresh slash to standing timber. "It should be a settled policy in British Columbia to burn all pine slash each season between October and May, as an aid to bark-beetle control," he wrote.[3]

The infestation continued running its course over the next few years, with Swaine investigating outbreaks and pressing the provincial government for funds to control the devastation which threatened the province's white and yellow pine. Infested trees should be logged and handled in a manner that destroyed broods contained in the bark, reducing beetle populations to an extent that they would find sufficient breeding material in slash rather than standing timber. U.S. Bureau of Entomology control projects had demonstrated that the removal of 75 percent of infested trees would check an outbreak. Floating logs in water killed some of the broods, barking trees and burning the debris was another option, but if profitable utilization was not possible simply burning infested timber provided the cheapest means of control. Finally, in 1919 Swaine and B.C. Forest Branch officials entered into serious negotiations aimed at developing a cooperative effort to control the bark beetle menace. By this time the epidemic around Princeton had died out after killing about 130 million feet of yellow pine, but a new outbreak had emerged around Merritt.[4]

Swaine's discussions with B.C. authorities produced an agreement to establish a laboratory at Vernon, and he asked Ralph Hopping, then employed by the United States Bureau of Entomology in California, to take charge. Regarded as one of the "leading students of forest-insect life on the west coast," Hopping accepted the position as Dominion Forest Entomologist for B.C., settled in at the Vernon courthouse in December 1919, and prepared to launch what Minister of Lands T.D. Pattullo called the province's "war on the pine beetle." It would prove to be a significant campaign, occupying Hopping's energies for much of the next decade.[5]

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[2] H.R. MacMillan, "In British Columbia," *CFJ* 9 (July 1913), p. 106; H.R. MacMillan, "British Columbia Forest Work," *CFJ* 9 (Oct. 1913), p. 156; J.M. Swaine, "A Forest Insect Survey in British Columbia," *CFJ* 9 (Nov. 1913), pp. 166-67; J.M. Swaine, "The Economic Importance of Canadian Ipidae,"*Proceedings of the Entomological Society of British Columbia* (1913), pp. 41-43.

[3] C. Gordon Hewitt, "Forest Insect Investigations in British Columbia," *CFJ* 10 (Oct. – Nov. 1914), pp. 102-3.

[4] "Fighting Forest Insects," *CFJ* 11 (Mar. 1915), p. 42; J.M. Swaine, "Problem of the Bark Beetle," *CFJ* 11 (June 1915), pp. 89-92; "Beetles are Killing the Yellow Fir in B.C.," *Western Lumberman* 16 (Oct. 1919), p. 49 [hereafter *WL*]; R.H. Hopping, "Annual Report for 1923, Forest Insect Control, Pacific Forest Centre Library [hereafter PFCL].

[5] Kenneth Johnstone, *Timber and Trauma: 75 Years with the Federal Forestry Service, 1899-1974* (Ottawa: Minister of Supply and Services, 1991), pp. 106-7; "Fighting Pine

A provincial allotment of $10,000 permitted direct control operations to begin during the spring of 1920 in the Midday Creek valley, a tributary of the Coldwater River. In the Railway Belt, a Dominion Forest Service crew under D. Roy Cameron worked in the Spius Creek valley about fifteen miles south of Canford. Designated men first inspected infested areas, marking trees for cutting. A working party followed, cutting down the trees, peeling the bark, and burning both bark and limbs. By starting projects early in the spring Hopping hoped to destroy the beetles before they matured and took flight. "The epidemic can be practically eradicated," he declared, given the allotment of sufficient funds to undertake a comprehensive control program. The province had made admirable progress in its fire suppression program, but fiscal support for handling the insect menace remained insufficient to the task. The control effort was "successful as far as it has gone with the limited funds," but Hopping had no illusions about his capacity to cope with the ecological and economic consequences of unregulated cutting. Winter logging operations left an abundant supply of cull logs and limbs to become infested the following June and July. Lacking fresh slash that summertime logging would have provided, the beetles attacked standing trees after emerging. Another winter's cut simply added impetus to the outbreak, fuelling an epidemic capable of spreading even in standing timber by virtue of the immense populations. "The removal of slash and infested standing timber is absolutely necessary if we are to reduce the loss to the minimum, and prevent a state of chronic menace to our forests," he warned.[6]

The cooperative project had three distinct components: direct control, involving cutting and burning of infested trees; timber sales in areas accessible to mills; and a preventative emphasis on the burning of slash and cull logs. Hopping supervised all three phases of the operation, overseeing the work of control crews, inspecting timber sales worked by Nicola Pine Mills of Merritt, and instructing operators about proper logging methods. Swaine described the first season's work as "remarkably successful," but estimated that some $20-$40 million worth of yellow pine remained at risk.[7]

Four control projects involving forty-eight men worked between April 1 and June 30 the following year in the Vernon and Kamloops Forest District. Crews at Kingsdale, Spius Creek, Midday Creek and the north end of Adams Lake cut and burned thousands of trees, but funds were inadequate to keep pace with the infestation. Hopping requested a doubling of the provincial allotment to $20,000 but held out little hope that the increase would be granted. The *Pacific Coast Lumberman* supported his argument that the province should make a small immediate investment rather than suffer heavier future costs.[8]

Provincial expenditures rose to $15,500 in 1922, enabling Hopping to place three crews in the field around Merritt. Together with a federal project on Spius Creek, they treated over 8,000 trees. "We have found that direct control work on infestations reduces the infestations 80 percent," Hopping reported. An untreated epidemic, on the other hand,

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Bug in British Columbia," *WL* 17 (Mar. 1920), p. 40; R.C. Traherne, "A Further Review of Applied Entomology in British Columbia," *Proceedings of the Entomological Society of British Columbia* (1921), p. 144.

[6] "Epidemic of the Bush Beetle," *WL* 17 (May 1920), p. 49; "Fighting Bark Beetle in Pine Forests," *WL* 17 (June 1920), pp. 35-36; Ralph Hopping, "Control of Bark Beetle Infestations," *Pacific Coast Lumberman* 5 (Nov. 1921), p. 77 [hereafter *PCL*].

[7] J.M. Swaine, "Bark Beetle Successfully Combatted," *WL* 18 (Mar. 1921), p. 28.

[8] R.H. Hopping, "Annual Report, 1921," PFCL; "The Bark Beetle Menace," *PCL* 5 (Nov. 1921), p. 22.

would increase by 100 to 150 percent, or even more in certain conditions. Thus, work conducted during the 1922 season saved over five million feet of timber, worth perhaps $8,000. Encouraged, he suggested that another year or two of direct control would reduce the infestation sufficiently to permit a much lower annual expenditure.[9]

Five projects – four in the Merritt area and one at Adams Lake – involved eighty-five men during the 1923 season at a cost of over $20,000. Hopping again expressed regret that insect control, which had destroyed about 200 million feet of timber around Princeton and Merritt at a loss to the province of perhaps $6 million, did not receive the same support accorded fire prevention and suppression. He also stressed repeatedly that the balance of nature had been disrupted by lumbering. "Promiscuous cuttings, unless regulated by the government, upset the natural balance and cause such outbreaks as we are having at the present time," the entomologist observed in 1923. The provincial and Dominion governments then doubled their allotment to about $45,000 for direct control during 1924. The provincial share amounted to $35,000 in support of five large fifteen to thirty-six man projects and several smaller "flying crews," that treated 19,000 trees. Federal crews continued to work small infestations at Spius Creek and Adams Lake. With a temporary staff of four, including H.H. Thomas, Kenneth Auden, Norman Cutler and son George, Hopping found himself short-handed during the hectic summer season. Although epidemic infestations in controlled areas had been reduced by 90 percent as a rule, the expansion of lumbering around the province contributed to the rise of new outbreaks, "tremendously increasing the work of the personnel." The Vernon laboratory, Hopping declared in a blunt plea for additional help, "finds that it has been impossible to properly carry on."[10]

The appointment of Hector Richmond and William Mathers as Pest Inspectors in 1925 permitted an expanded research effort. Hopping had initiated cage experiments earlier in the decade in an effort to determine when the emergence of beetles began, peaked, and ended, and to identify parasites and predaceous insects. Richmond and Mathers were assigned to this work, felling, bucking, and limbing infested trees and constructing cages over the trunk and stump. Richmond inspected the cages daily, collecting and preserving in alcohol the insect material that emerged. Study of the cedar borer also began during this period at the Vancouver Forest Products Laboratory under George Hopping, and Mathers commenced an investigation of the life history of the spruce budworm.[11]

Ralph Hopping declared victory in the war against the bark beetle in the yellow pine stands around Merritt early in 1928. "The control measures have been entirely successful," he reported, "no epidemic now existing in the yellow pine of British Columbia for the first time in over fifteen years." He estimated the saving to the province at $5 million, attributable to the "100 percent method" of cutting and burning every infested tree and periodically recleaning infested areas. Over 50,000 trees had been treated in this manner

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[9] R.H. Hopping, "Annual Report for 1922," PFCL; "Saving Yellow Pine," *PCL* 6 (Aug. 1922), p. 64.

[10] R.H. Hopping, "Annual Report for 1923," PFCL; Ralph Hopping, "Forest Entomology," Proceedings of the Entomological Society of British Columbia (1923), p. 187; R.H. Hopping, "Annual Report, Entomological Laboratory, Vernon, B.C., 1924"; Ralph Hopping, "Forest Insect Problems of British Columbia and Their Importance," *WL* 22 (Sept. 1925), p. 60.

[11] R.H. Hopping, "Annual Reports, Vernon Forest Insect Laboratory, 1925,"; Hector Allan Richmond, *Forever Green: The Story of One of Canada's Foremost Foresters* (Lantzville: Oolichan Books, 1983), p. 20.

since the start of the campaign, at a cost of approximately $100,000. The situation in lodgepole pine, however, was less bright. Mountain pine beetle infestations had devastated vast areas of this commercially unimportant species, moving so rapidly that control operations had little hope of success even if funding had been available. The laboratory would also continue to monitor the steady growth of Douglas fir beetle infestations, the spruce budworm, and other forest insects.[12]

By this time Hopping had achieved some success in educating National Parks Service and Dominion Forest Branch rangers to the importance of identifying and reporting incipient outbreaks, but had made no such progress with B.C. Forest Branch personnel. "The unconcern of forest rangers and others of the Forest Branch with regard to forest insect infestations throughout the Province, has been strikingly apparent to us for some time," he informed Chief Forester P.Z. Caverhill. Many outbreaks had not been reported for two or three years after their onset, a situation he hoped to correct by having an information package sent to each Ranger and making lectures by Division of Forest Insect officers a feature of annual meetings. An educational campaign of visits to Ranger headquarters around the province went into effect in 1928, permitting joint inspections of forest districts. Officials hoped that this sort of cooperation would foster prompt reporting of outbreaks and eliminate the need for costly control projects.[13]

The Vernon laboratory conducted only one small control project in lodgepole pine during 1928, reflecting the gradual shift to a focus on education and research. The following year Hopping requested funds for a crew to take action against a lodgepole pine infestation in the Railway Belt, but the species had too little commercial value to justify the expenditure. George Hopping broke new ground on the coast, however, overseeing B.C.'s first airplane dusting project on a small area around the Wigwam Inn resort on Burrard Inlet. Undertaken in part to demonstrate the feasibility of the technique to Dominion and provincial forestry officials, the experiment against the hemlock looper saw a Western Canada Airlines Boeing flying boat dust forty-five acres with calcium arsenate. Mathers studied a spruce budworm infestation at Barkerville that summer, work that would contribute to his discovery of the budworm's two-year life cycle in the area. The younger Hopping took charge of a sub-laboratory at the University of British Columbia in 1930, and oversaw larger dusting projects on Stanley Park and Seymour Inlet that June. These endeavours involved three Boeing flying boats at a total cost of over $10,000. [14]

The onset of the Great Depression had an immediate impact on the activities of the Vernon laboratory. Unable to secure funds for control of growing bark beetle infestations in Douglas fir and lodgepole pine, Ralph Hopping did spend $5,000 that spring in response

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[12] R.H. Hopping, "Annual Report, Forest Insect Laboratory, Vernon, B.C., Fiscal Year 1927-1928;" J.M. Swaine, "Progress in Forest Insect Control in Canada," *FC* 4 (Feb. 1928), np.

[13] R.H. Hopping to the Chief Forester, 14 Nov. 1927, copy included in 1927-28 Annual Report; J.M. Swaine, *Forest Entomology and its Development in Canada* (Ottawa: King's Printer, 1928), p. 12.

[14] R.H. Hopping, "Annual Report, 1928," PFCL; J.M. Swaine, "Forest Insect Investigations in Canada, 1928," *FC* 5 (June 1929), pp. 37-38; R.H. Hopping, "Annual Report, 1929," PFCL; G.H. Hopping, "An Account of the Western Hemlock Looper, *Ellopia Sominaria* Hulst, on Conifers in British Columbia," *Scientific Agriculture* 15 (Sept. 1934), pp. 24-28; W.G. Mathers, "The Spruce Budworm in British Columbia," *FC* 8 (Sept. 1932), pp. 154-57.

to a massive beetle attack at Aspen Grove, one of the original project sites. But a cash-strapped B.C. government curtailed allocations for fire protection in the early thirties, and in this fiscal context Hopping had no hope of beetle control funding. Federal budget cutting in April 1932 led to layoffs of all temporary staff at Vernon. Richmond and the others continued working in the hopes that their positions would be renewed, receiving a six-month extension in May accompanied by a 10 percent pay cut that reduced Richmond's monthly salary to $112.50.[15]

Despite the need for direct control of further beetle outbreaks in the yellow pine stands around Merritt during the early 1930s, the laboratory was confined almost entirely to research. Richmond conducted bark beetle studies at Aspen Grove during the summer months, devoting the autumn to surveys of damage inflicted to interior forests. Hopping's confident assertions of victory in the bark beetle campaign appear to have been misplaced, then. According to Richmond beetle populations subsided during the mid-1930s due to several factors, primary among them the exhaustion of mature pine stands. The laboratory enjoyed greater success, apparently, in combatting an infestation of the European larch sawfly around Fernie during this period. A 1933 inspection by Mathers discovered an outbreak of some seventy miles in extent, and a parasite obtained from the Dominion Parasite Laboratory at Belleville was released over the next two years. This early instance of biological control in B.C. forest entomology had a beneficial impact on sawfly populations, saving extensive larch stands from the defoliator.[16]

In 1934 J.J. De Gryse took over as Director of the Department of Agriculture's Division of Forest Insects from Swaine, who became the agency's Director of Research. De Gryse would go on to initiate many important organizational developments, beginning with the nation-wide Forest Insect Survey. Swaine had taken a step in this direction in 1931 with the establishment of the Forest Insect Intelligence Service. In addition to publishing a number of circulars dealing with Canada's principal forest insects, Swaine had these distributed to industry organizations and forest services along with a request that field men submit reports on outbreaks in their districts. But after an initial favourable response Intelligence Service activities waned under the impact of the Depression, leaving the program moribund.[17]

De Gryse's effort to revive the initiative began in December 1934, with an Entomological Branch conference at Ottawa. Industry and Dominion Forest Service attendance at sessions dealing with forest insect problems prompted discussions of the need for cooperation to gather information on the threat posed by the European spruce sawfly to spruce stands in eastern Canada. A committee organized under the auspices of the Canadian Society of Forest Engineers and headed by De Gryse rounded up support among heads of protection organizations, corporations, and wildlife departments in Ontario and Quebec, and developed procedures for the collection and submission of insect

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[15] R.H. Hopping "Annual Report, 1930," PFCL; Hector Allan Richmond, "A History of Forest Entomology in British Columbia, 1920-1984," Pt. I, *B.C. Forest History Newsletter* 9 (Nov. 1984), p. 5.

[16] R.H. Hopping, "Annual Report of the Vernon Forest Insect Laboratory, 1932," PFCL; R.H. Hopping, "Annual Report, 1933," PFCL; R.H. Hopping, "Annual Report of the Vernon Forest Insect Laboratory, 1934," PFCL; Richmond, *Forever Green*, pp. 102-3; George R. Hopping, "A Forest Insect Problem in British Columbia," *FC* 11 (Dec. 1935), pp. 258-61.

[17] Prebble, "Forest Entomology," p. 352; Wallace, "Forest Entomology," p. 121.

samples to the Division of Forest Insects. In 1936 about eight hundred cooperators participated, examining trees in their areas to determine the presence of the sawfly and other destructive pests. They were provided with collapsible boxes for mailing samples, instructions, report forms, relevant circulars, and asked to make monthly reports between June and September. The Ottawa laboratory received 512 samples in 1936, the first stage in fulfilling De Gryse's vision of a national forest insect intelligence system.[18]

The Forest Insect Survey expanded to the Maritimes and B.C. in 1937, with the Vernon laboratory serving as headquarters for activities in the west. The B.C. Forest Branch and National Parks Branch participated the first year, field men making collections by placing a canvas ground sheet beneath a tree and "shaking it vigorously or hitting it with an axe" to dislodge larvae. Although the Vernon laboratory received no sawfly specimens in 1937, three hemlock looper outbreaks were brought to light in this fashion. The number of cooperators increased steadily over the following years, along with the volume of material sent in for analysis and rearing. De Gryse's establishment of a corps of trained forest insect rangers added to the survey's effectiveness. By 1947 seven rangers operated in B.C., divided evenly between the coast and interior districts. Surveying of the coastal forests reached a new level of efficiency that year with the commissioning of a sixty-foot boat, the *J.M. Swaine*.[19]

After supervising the survey through its initial stage, Ralph Hopping retired in December, 1938. He died at his Vernon home only two years later, acknowledged as one of the foremost forest entomologists in North America. His son George took over as director at the Vernon laboratory, now part of the Entomology Division of the Department of Agriculture's Science Service after a 1937 reorganization. The younger Hopping's leadership coincided with the establishment of a summer field station and insectary at Trinity Valley. Plans were also in the works that resulted in a similar facility for coastal studies at the B.C. Forest Branch's Cowichan Lake Experiment Station. By this time the most pressing problem facing the Vernon staff involved a massive beetle outbreak in Kootenay National Park. Infestation of the park's lodgepole pine stands began in the early 1930s, and covered seventy-two square miles by 1937. Ralph Hopping had recommended control measures to contain the outbreak, a proposal that fell victim to Depression-era budget constraints.[20]

A major restructuring of the Science Service's western forest entomology organization in 1940 brought a new laboratory at Victoria into existence. M.L. Prebble was transferred from Fredericton to head that facility, which took over the equipment from the UBC sub-

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[18] Canada, *Annual Reports of the Forest Insect Survey, 1936-1937-1938* (Ottawa: King's Printer, 1939), pp. 1-2; J.J. De Gryse, "Cooperation in Forest Insect Studies Relating to Conservation," *Journal of Forestry* 36 (1938), pp. 983-86.

[19] Canada, *Annual Reports of the Forest Insect Survey, 1936-1937-1938*, pp. 26-33; R.H. Hopping, "Annual Report of the Vernon Forest Insect Laboratory for the Fiscal Year Ending March 31, 1938," p. 2; Canada, *Annual Report of the Forest Insect Survey, 1947* (Ottawa: King's Printer, 1947), p. 91.

[20] R.H. Hopping, "Annual Report of the Vernon Forest Insect Laboratory for the Fiscal Year Ending March 31, 1937," PFCL; R.H. Hopping, "Annual Report of the Vernon Forest Insect Laboratory for the Fiscal Year Ending March 31, 1938," PFCL; "Ralph Hopping (1868-1941)," *Proceedings of the Entomological Society of British Columbia* 38 (1942), pp. 3-4.

unit. Kenneth Graham moved west from Vernon, while William Mathers returned to Vernon from the now defunct Vancouver branch. The new Victoria research centre took responsibility for forest and shade tree insect problems in the coastal area. The shuffle confined Vernon's jurisdiction to B.C. forests east of the Cascade range and all of Alberta with the exception of the province's southeast corner, to be administered from the Science Service's laboratory at Indian Head, Saskatchewan.[21]

Canada's entry into World War II forced funding restrictions at Vernon, where the insect survey and research on the larch sawfly dominated activities. George Hopping discontinued work on some of the less pressing research projects, but by 1941 the bark beetle problem had become acute on the Kootenay and Banff National Parks. By the end of that year an estimated 400 million board feet of lodgepole pine had been destroyed on the former, and Banff had become the scene of a large, unrelated outbreak in 1940. Hopping and Mathers attributed the mountain pine beetle infestations to several years of below-average precipitation that diminished the vigour of the mature lodgepole pine stands covering extensive areas in both parks.[22]

Since the situation on Kootenay National Park was beyond repair, officials decided to concentrate control efforts at Banff, where the outbreak was in its early stages. Fortunately, given the severity of wartime labour shortages, the Parks Branch succeeded in securing a supply of Alternative Service Workers for the project. Three forty-man camps for the conscientious objectors were established during the fall and winter of 1941, the crews working until late spring. Three or four men from each crew served as a cruising party, the remainder cutting, decking, and burning the infested trees. They covered 5,725 acres during the 1941-42 season, treating 9,192 trees. Crews resumed after the 1942 fire season, completing control work in the Bow valley. This effort, in conjunction with low temperatures in January 1943 that killed a high percentage of broods above the snow line, left only a small area to work the following season. Hopping and Mathers praised the conscientious objectors who, with few exceptions, "proved to be reliable workers rapidly acquiring proficiency in control procedure." Thanks to prompt action and the availablility of the Alternative Service Workers, the Banff project stands out as a rare success in the direct control of a bark beetle infestation, saving the park from a "major catastrophe."[23]

Federal government support of forest entomology increased in the immediate postwar period as wood products assumed greater importance in the economic boom. In late 1945 Reconstruction Minister C.D. Howe announced the creation of a Forest Insects Control Board, comprised of federal, provincial, and industry representatives, to coordinate entomological research and control measures across the country. In B.C., growing recognition of the threat insects posed to commercial forestlands was reflected in the establishment of an industry-endowed chair in forest entomology at UBC. George Hopping received a leave-of-absence from Vernon to initiate the course of instruction

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[21] M.L. Preeble, "Forest Insect Investigations, Victoria Unit, Report for 1940," PFCL; G. Hopping, "Annual Report, Vernon Forest Insect Laboratory, 1940," PFCL; Hector Allan Richmond, "A History of Forest Entomology in British Columbia, 1920-1984," Pt. II, *B.C. Forest History Newsletter* 10 (Mar. 1985), p. 3.

[22] G. Hopping, "Annual Report of the Vernon Forest Insect Laboratory, 1940," PFCL; G. Hopping, "Annual Report of the Vernon Forest Insect Laboratory, 1941," PFCL.

[23] George R. Hopping and W.G. Mathers "Observations on Outbreaks and Control of the Mountain Pine Beetle in the Lodgepole Pine Stands of Western Canada," *FC* 11 (June 1945), pp. 98-108; G. Hopping, "Annual Report, Vernon Forest Insect Laboratory, 1942," PFCL; G. Hopping, "Annual Report of the Vernon Forest Insect Laboratory, 1943," PFCL.

during the 1947-48 academic year. Industry figures also met with De Gryse in 1948 to discuss the development of insect control strategies on the west coast. Prebble left Victoria to take charge of a new research centre at Sault Ste. Marie that same year, bringing Richmond to Victoria as his replacement. That laboratory became the headquarters for forest entomological work in B.C. in 1948, relegating Vernon to sub-laboratory status.[24]

The Vernon laboratory, with a staff of fifteen during the summer months, remained responsible for the forest insect survey in the interior. By 1950 there were eleven forest insect rangers in the interior and nine on the coast. The establishment of permanent sample plots around the province made for more systematic collections, and the introduction of a punch card system of data entry in 1952 facilitated rapid analysis at the laboratories. By this time 171 permanent sample plots had been established in the vast interior of B.C. Insects sent to Vernon were sorted, and immature forms reared at the Trinity Valley field station near Lumby for the determination of life histories and host-parasite relationships.[25]

Airborne chemical attack on defoliators involving the application of D.D.T. captured the enthusiasm of forest entomologists during the postwar decades. Scientists at the Victoria laboratory studied an alarming incidence of attacks by the black-headed budworm and hemlock looper in coastal forests during the 1940s. The Division of Entomology cooperated with the B.C. Forest Service and industry in the first aerial spraying with D.D.T. on 12,000 acres in the Nitinat valley in 1946 to control a looper infestation. No effort to examine the impact on aquatic life accompanied this project, but the conflict between D.D.T. spraying in defence of timber values and the consequences for the fisheries resource would come to play a major part in limiting use of the insecticide. Vernon entomologists participated in the first aerial spraying of D.D.T. in the interior in 1948, when a false hemlock looper infestation threatened the Christmas tree crop in the Windermere valley.[26]

The most extensive application of D.D.T. in B.C. occurred in 1957 in response to a black-headed budworm infestation on northern Vancouver Island. By 1956 the outbreak covered some 3,000 square miles. Representatives of firms with holdings in the area collaborated with Forest Service and Forest Biology Division officials in developing a control project designed to save timber valued at $300 million. An experimental spraying that summer proved effective, and plans went ahead to spray 156,000 acres the following

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[24] Johnstone, *Timber and Trauma*, p. 138; "Destruction of Canadian Timber By Forest Insects Attains "National Disaster" Proportions, Says Minister Howe," *British Columbia Lumberman* 29 (Dec. 1945), p. 30 [hereafter *BCL*]; Richmond, *Forever Green*, p. 131; "Forest Entomology Vital Study, Says Expert," *BCL* 31 (Dec. 1947), p. 114; "Forest Entomology," *FC* 24 (Dec. 1948), pp. 293-94.

[25] "Forest Insect Survey in Interior B.C. Extended," *BCL* 34 (Feb. 1950), p. 103; B.C., *Report of the Forest Service, 1948* (Victoria: King's Printer, 1949), p. 55; B.C. *Report of the Forest Service, 1949* (King's Printer, 1950), p. 72; H.A. Richmond, "Forest Insect Surveys," *Proceedings of the Entomological Society of British Columbia* (1953), pp. 28-30; George Hopping, "Forest Insect Laboratory at Vernon Responsible for Control in Huge Area," *BCL* 31 (July 1947), pp. 112, 114.

[26] M.L. Prebble and K. Graham, "The Current Outbreak of Defoliating Insects in Coast Hemlock Forests of British Columbia,"*BCL* 29 (Feb. 1945), pp. 25-27, 42-48; "Forest Insect Conditions and Research in 1946," *FC* 23 (Mar. 1946), p. 89; H.A. Richmond, "Forest Insect Problems in British Columbia," *BCL* 32 (May 1948), p. 76; "Helicopter Fighting False Hemlock Looper Attack," *BCL* 32 (July 1948), p. 141.

summer with costs shared equally by the B.C. Loggers Association, federal, and provincial governments.[27]

By this time some evidence of fish mortality from D.D.T. spraying in New Brunswick had been accumulated, and officials of the B.C. Game Commission and federal Department of Fisheries participated in the planning process. Industry's Pest Control Committee turned down requests to have some fish- producing areas eliminated from the project. The fisheries biologists were also denied when they asked that the D.D.T. dosage be cut by half, to one-half pound per acre. Forest Biology Division representatives ruled that the reduced dosage might not be effective, in rejecting the proposal. The Committee did agree, however, to make some adjustments in flight patterns to minimize damage to fish populations. The project was declared a success from an entomological standpoint, although Richmond observes that budworm populations declined simultaneously on untreated areas in the following years. More significantly, the project resulted in considerable mortality in cohoe salmon populations. One industrial forester involved warned that if D.D.T. spraying was to be continued, it must be on the basis of non-lethal concentrations or public opinion would forbid its use altogether.[28]

The 1957 disaster influenced procedures followed in 1960 on Moresby Island, when a black-headed budworm infestation promped another D.D.T. control program. This time forestry officials agreed to reduce the dosage to one-quarter pound per acre, resulting in negligible salmon mortality. But studies carried out in conjunction with the project indicated that even this concentration was lethal to salmon fry, supporting other research that prompted a general outcry against use of the insecticide in North America. Awakening to the need for acceptable alternatives, the Forest Biology Division and B.C. Loggers Association initiated tests of a bacterial insecticide on the Queen Charlotte Islands in 1960.[29]

Bark beetles remained the major problem confronting entomologists in the interior during the early 1950s, although increasing spruce budworm populations also caused concern. Large outbreaks of the mountain pine beetle developed in the Columbia valley, and the Douglas fir bark beetle caused significant losses in the Quesnel region. Scientists studied the efficacy of ground-spraying insecticides such as D.D.T. in an effort to develop a faster and less costly method of controlling pine beetle epidemics, but such operations were themselves considered too expensive for widespread use in the province.[30]

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[27] B.C. *Report of the Forest Service for 1956* (Victoria: Queen's Printer, 1957), p. 79; B.C. *Report of the Forest Service for 1957* (Victoria: Queen's Printer, 1958, p. 70; G.S. Brown, A.P. Randall, R.R. Le Jeune, and G.T. Silver, "Black-Headed Budworm Spraying Experiments on Vancouver Island, British Columbia," *FC* 34 (Sept. 1958), pp. 299-306.

[28] E.G. Marples, "Significance of Fish Mortality in Forest Spraying Operations," *Proceedings of the Western Forestry and Conservation Association* (1957), pp. 44-55; R.A. Coulter and E.H. Vernon, "Effects of Black-Headed Budworm Control on Salmon and Trout in British Columbia," *Canadian Fish Culturalist* 24 (1959), pp. 23-40.

[29] I.S. Todd and K.J. Jackson, "The Effects on Salmon of a Program of Forest Insect Control with D.D.T. on Northern Moresby Island," *Canadian Fish Culturalist* 30 (Dec. 1961), pp. 15-27; Hector A. Richmond, "A New Look at Aerial Spraying in Forest Resource Protection," *Proceedings of the Western Forestry and Conservation Association* (1960), pp. 30-32.

[30] B.C., *Report of the Forest Service for 1951* (Victoria: King's Printer, 1952), p. 85.

Jack Walters of the Victoria Biological Laboratory and UBC forest entomologist Ken Graham worked on the Douglas fir beetle problem, investigating the factors contributing to recent outbreaks. One rewarding study at Douglas Lake involved the felling of "trap trees" and release of beetles to determine their flight patterns and the types of trees most vulnerable to attack. By the late 1950s it had been demonstrated that the presence of felled logs in a stand induced attacks on surrounding timber, insight that informed a silvicultural control project involving Western Plywoods, the Forest Service, and Forest Biology Division. This early effort to merge forestry and entomological principles into forest management planning sought to draw Douglas fir beetles into pre-selected areas with attractive logs, then remove these along with nearby infested trees in an attempt to lower populations.[31]

Vernon's status as a centre of entomological research declined during the 1950s, as the Victoria laboratory became the hub of federal government biological science. By 1955, when D.A. Ross replaced William Mathers as officer-in-charge at Vernon, the staff numbered twenty-one permanent employees concerned primarily with carrying out the insect and disease survey in the interior. Five years later the Forest Biology Division became the Forest Entomology and Pathology Branch of the new Canada Department of Forestry under director M.L. Prebble, and by 1963 the Vernon staff had dwindled to fifteen. Opening of the Department of Forestry's new $2.5 million forest research laboratory at Victoria in 1965 further undermined the Vernon station's prospects.[32]

During the same period forest insect problems in the interior became, if anything even more serious. During the early 1960s the central interior experienced the most serious spruce bark beetle outbreak ever recorded, and damage from the Douglas fir and mountain pine beetles increased in the southeastern part of the province. Between 1961 and 1965 the spruce beetle destroyed over 500 million cubic feet of timber in central B.C., an outbreak presumed to be caused by abundant slash, warm summers, and mild winters. Research on these infestations was carried out from Victoria, while the B.C. Forest Service supervised large-scale salvage operations in damaged timber.[33]

The end for the Vernon sub-laboratory came in 1970, when an economizing federal government closed the facility. Most of the staff members transferred to Victoria laboratory, now the centre of federal forestry science and base of the insect and disease survey for the entire province. Federal authorities insisted that the closure would not impair entomological work in any way, claiming improved efficiency for its entire B.C. operation. Nevertheless, Ottawa's decision to terminate activity at Vernon has been questioned frequently. Indeed, expansion of the pulp and paper industry in the central and southern interior since the 1960s has given these forests greater economic importance than the coastal stands that provided the raw material for the province's early lumber industry.

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[31] K. Graham, "The Bark-Beetle Problem in Douglas Fir of the Interior," *BCL* 36 (July 1952), p. 42; "Bark Beetle Spreads," *BCL* 36 (Aug. 1952), p. 100; H.A. Richmond, "Douglas Fir Bark Beetle in B.C.," *BCL* 37 (May 1953), pp. 43, 90-92; B.C., *Report of the Forest Service For 1958* (Victoria: Queen's Printer, 1959), p. 68.

[32] Miles Overend, "Intelligence Service Battles Bugs,"*BCL* 47 (May 1963), p. 38; Dr. D.A. Ross, "Forest Entomologist, Retires," *Truck Logger* (Jan. 1967), p. 23.

[33] Canada, *Department of Forestry Annual Report, 1963-1964* (Ottawa: Queen's Printer, 1964), pp. 33-35; "Spruce Beetle Damage Studied," *BCL* 51 (Jan. 1967), p. 66; Canada, *Department of Forestry Annual Report, 1964-1965* (Ottawa: Queen's Printer, 1965), pp. 33-35.

Moreover, bark beetles remain a significant obstacle to rational forest management in these areas. In recent years Ralph Hopping's old enemy the mountain pine beetle has re-emerged with great intensity in the Okanagan and Cariboo regions, thanks to favourable climatic conditions and the advance in postwar fire protection techniques that brought extensive lodgepole pine stands to maturity. Hopping would also be familiar with government's modern response to these epidemics, if not the precise techniques. Although entomologists now rely on sophisticated computer mapping systems to trace the progress of epidemics, salvage harvesting is the primary control technique. Much damaged timber now finds its way to the sawmill or pulp mill, and the use of trap trees and pheromones show promise in slowing the spread of outbreaks. But the magnitude of recent spruce and pine beetle infestations leave forestry officials no alternative but to concentrate logging operations on the most severely affected areas, an approach which in principle differs little from Hopping's early twentieth century control projects.[34]

Journal Abbreviations in footnotes

BCL	*British Columbia Lumberman*
CFJ	*Canadian Forestry Journal*
FC	*Forestry Chronicle*
LSJ	*Logging and Sawmilling Journal*
PCL	*Pacific Coast Lumberman*
PFCL	Pacific Forestry Centre Library
WL	*Western Lumberman*

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[34] "Dr. D.A. Ross," pp. 36-37; Hector Allan Richmond, "A History of Forest Entomology in British Columbia, 1920-1954," Pt. II, *B.C. Forest History Newsletter* (Mar. 1985), p. 3; "Northwood Confronts Beetle," *Logging and Sawmilling Journal* 14 (Nov. 1983), pp. 16-18 [hereafter *LSJ*]; L. Ward Johnson, "Chasing the Pine Beetle," *LSJ* 21 (July 1990), pp. 14-16; "Beetle Attack Prompts AAC Increases," *LSJ* 23 (Oct. 1992), p. 7; Jim Stirling, "Going to War," *LSJ* 31 (Feb. 2000), pp. 5-7.

Implications of using development rates of blow fly (Diptera: Calliphoridae) eggs to determine postmortem interval

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ABSTRACT

This research examined the eclosion times of blow fly eggs to determine whether eggs begin to develop at the time of oviposition, or *in vivo*. Eggs were obtained from laboratory colonies of *Calliphora vicina* Robineau-Desvoidy, *Phaenicia sericata* (Meigen) and *Eucalliphora latifrons* (Hough) and observed at 2-h intervals. All three species had eggs eclose earlier than the expected minimum of 22 h at 21°C. Precocious egg development occurred for 75% of the *C. vicina* egg mass, while 100% of the *E. latifrons* and *P. sericata* egg masses developed early. Subsequently, we denied an oviposition medium to fresh *C. vicina* and *P. sericata* colonies for 7 and 14 d and compared the eclosion times with that of eggs from colonies with a continual access to beef liver. In both species, no precocious egg development was observed as the eggs eclosed 3-4 h after the expected minimum time of eclosion in both treatments and control. Finally, we examined eclosion times of eggs laid by blow flies in the wild. Eggs laid in the wild by *P. sericata* and *C. vicina* also took 1-3 h longer to eclose than the expected minimum time of eclosion. Our first experiment demonstrated that eggs laid by a single female at one time, can eclose at a wide variety of times, ranging from 2 h to the expected 22 h after oviposition at 21°C. Our inability to repeat the early eclosion in the laboratory with new colonies, despite the denial of oviposition media, or in the wild under natural conditions, is reassuring to those using egg development and eclosion to determine elapsed time since death. Clearly this phenomenon is not common, and may be explained as an artifact of laboratory colonies that do not have a regular influx of wild blow flies.

Key words: forensic entomology, medico-legal entomology, elapsed time since death

INTRODUCTION

Forensic entomology, or the use of insects to determine the elapsed time since death of a homicide victim, is a technique that has been employed in many homicide investigations worldwide (Goff 1992; Leclercq and Vaillant 1992; Lord *et al.* 1994; Anderson 1995). It is the most accurate and often the only method available to determine elapsed time since death after 72 h. However, it also is used during the first 72 h after death, particularly in high profile crimes, to confirm pathological parameters, or when only a portion of the body has been recovered. Traditionally, medical parameters are used to determine time since death in the first hours after death, but these involve many variables (Henssge *et al.* 1995) and pathologists are often reluctant to offer an opinion on time since death when more than

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a few hours have passed. Thirty percent of forensic entomology cases in Canada in 1995 involved blow fly (Diptera: Calliphoridae) egg evidence alone and this trend has continued (Anderson and Cervenka 2001). Although the cases were mainly homicide, they also included one poaching case where blow fly egg development evidence was vital in connecting time of death of bear cubs with the perpetrators at the scene (Anderson 1999).

Since blow flies usually arrive and begin laying eggs within minutes of death (Anderson and VanLaerhoven 1996), an analysis using the eclosion times of blow fly eggs will provide an estimate of the minimum time since death in the early postmortem interval. This method requires accurate research on the developmental rates of eggs. Previous research indicates that the time necessary for blow fly eggs to eclose depends on the species and the temperature (Kamal 1958; Nuorteva 1977; Greenberg 1993; Anderson 2000). However, these developmental rates and times of eclosion assume that egg development begins after oviposition and that the eggs do not begin to develop within the adult fly. Our laboratory research has indicated that this may not always be the case. If *in vivo* development does occur, this would change the estimate of elapsed time since death by as much as 24 h. We hypothesized that female flies which have a suitable oviposition medium available, will oviposit eggs which eclose after the normal length of time, after oviposition; whereas flies which are denied a suitable oviposition medium may have eggs developing *in vivo*, thereby decreasing the length of time between oviposition and eclosion.

The objectives of this research were to: determine whether insect eggs laid on a homicide victim begin to develop at the time of oviposition, or *in vivo*, as we have observed occasionally in the lab; and to determine whether early eclosion occurs in the wild or is an artifact of laboratory conditions.

MATERIALS AND METHODS

We examined egg eclosion under laboratory conditions at 21°C for three species of blow fly: *Calliphora vicina* Robineau-Desvoidy, *Phaenicia sericata* (Meigen) and *Eucalliphora latifrons* (Hough). All three species were reared in laboratory colonies descended from wild specimens collected locally in the Lower Mainland of British Columbia. They had been under laboratory conditions for approximately a year. On 5 March 1994, beef liver was presented to gravid females and after several hundred eggs were laid by ~10 females over a 30 min period, the liver was removed from the cages. Each egg mass was examined for eclosion immediately after oviposition and at 2 h intervals until eclosion.

The experiment was repeated at 21°C with new colonies of blow flies, this time varying the availability of an ovipositional medium. Fresh wild caught *C. vicina* and *P. sericata* colonies were established. On 1 May 1995, newly emerged adults of each species were exposed to fresh beef liver for 24 h to ensure that all received a protein meal for the development of ovaries and testes (Erzinclioglu 1996). The adults were then divided into three groups. The first group was given immediate and continuous access to beef liver as an oviposition medium. The second group was given only water and sugar for 7 d after the females were gravid, and was then given fresh beef liver as an oviposition medium. The final group was given water and sugar but was denied an oviposition medium until 14 d after the females were gravid. A minimum of 75 males and 75 females of each species were used, with one cage per species per treatment. Five females were dissected each day to determine the time taken until eggs were mature. The delayed access to an oviposition medium was timed after the females were gravid. After each group was presented with beef liver, and eggs were laid over a 30-min period, the egg mass was removed from the cage and observed every 2 h until all the eggs had eclosed.

We also tested eggs laid by blow fly females in the wild. Petri dishes with approximately 250 g of fresh beef liver were exposed in partially sunny locations in Coquitlam, BC. The experiments were conducted between 17-25 September 1996 and 2-10 June 1997. At all times, blow flies were abundant in this mild region. The experiment was replicated 15 times. After oviposition of at least 100 eggs in a 30-min period, the petri dishes were covered to prevent further oviposition and moved indoors. Each egg mass was examined for eclosion at 2-h intervals until eclosion.

Ambient temperature was recorded at 30-min intervals throughout each experiment using a double channel datalogger (SmartReader 1®, Young Environmental Systems, Richmond, BC). Temperatures cited are means of records from the time eggs were laid until eclosion was complete.

RESULTS

All three species had eggs eclose earlier than expected at 21°C (Table 1). Precocious egg development occurred for 75% of the *C. vicina* egg mass, while 100% of the *E. latifrons* and *P. sericata* egg masses developed early (Fig. 1).

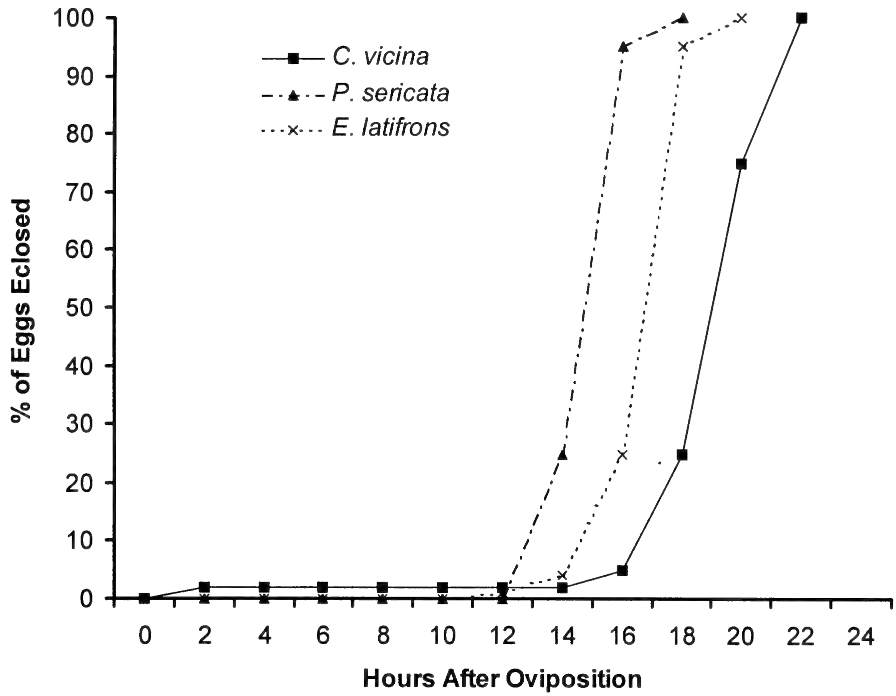

Figure 1. Percent of eggs eclosed from egg masses of three laboratory colonies of blow flies.

When new colonies of *P. sericata* and *C. vicina* were established, no precocious egg development was observed (Table 2), despite the lack of ovipositional media. *Phaenicia sericata* and *C. vicina* females took 3 d at 21°C to develop mature eggs in their ovaries.

In the field experiments, no precocious egg development was observed for eggs laid by *P. sericata* and *C. vicina* (Table 3). The mean temperature was 20°C for the September experiment and 23°C for the June experiment.

Table 1

Egg eclosion from egg masses of laboratory colonies of blow flies compared to expected minimum times of eclosion at 21°C (Anderson 2000).

Species	Minimum Time of Eclosion (h)	
	Expected	Observed
C. vicina	22	2
P. sericata	21	14
E. latifrons	22	12

Table 2

Egg eclosion from egg masses of laboratory colonies of blow flies: held continuously with oviposition media available; held 7 d without oviposition media; and held 14 d without oviposition media, compared to expected minimum times of eclosion at 21°C (Anderson 2000).

Oviposition media	Species	Minimum Time of Eclosion (h)	
		Expected	Observed
Available	*C. vicina*	22	26
Available	*P. sericata*	21	24
7 d	*C. vicina*	22	26
7 d	*P. sericata*	21	24
14 d	*C. vicina*	22	26
14 d	*P. sericata*	21	24

Table 3

Egg eclosion from egg masses of wild blow flies compared to expected minimum times of eclosion (Anderson 2000).

Mean Temperature	Species	Minimum Time of Eclosion (h)	
		Expected	Observed
20°C	*C. vicina*	26	28
20°C	*P. sericata*	25	26
23°C	*C. vicina*	21	24
23°C	*P. sericata*	21	24

DISCUSSION

It is currently accepted that blow fly eggs do not generally develop in the female fly, but only begin to develop after oviposition. Therefore, a measure of the developmental stage can be used to predict the age of the egg, and the time of eclosion can be used to count backwards to determine the time of oviposition. However, our first laboratory experiment demonstrated that eggs laid at the same time can eclose at a wide variety of times, ranging from 2 h to the expected 22 h after oviposition.

Early eclosion of blow fly eggs has been described in the literature, although it is rare (Auten 1934; Reiter 1984; Erzinclioglu 1990). It is possible that female flies may delay oviposition until a suitable site is found (Auten 1934). One recent study examined internal egg development of *Phormia regina* (Meigen) and stated that only one developing egg can be withheld by females, as this one egg enters the oviduct and is fertilized, whereas, the rest do not enter the oviduct until oviposition (Erzinclioglu 1990). Another study examined *Calliphora terraenovae* Macquart, *C. vomitoria* (L.), *C. vicina* and *P. sericata* (Meigen) and found precocious egg development of at least one egg within all four species (Wells and King 2001).

The trigger for development within the female remains unknown. Our inability to repeat the early eclosion in the laboratory with new, wild-captured colonies, despite the denial of oviposition media, or in the wild under natural conditions, is reassuring to those using egg development and eclosion to determine elapsed time since death. Clearly this phenomenon is not common, and may be explained as an artifact of lab colonies that do not have a regular influx of wild blow flies; it may even have been an artifact of those specific colonies, although this seems unlikely. In fact, in a large number of other experiments conducted over several years, in which eggs were observed every 1-2 h until eclosion, not once was this phenomenon observed (Anderson 2000). As well, many other researchers who have performed similar experiments have not mentioned early eclosion (Melvin 1934; Kamal 1958; Nuorteva 1977; Nishida 1984; Greenberg 1993).

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Observations on the behavior of *Monochamus scutellatus* (Coleoptera: Cerambycidae) in northern British Columbia

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ABSTRACT

The location, behavior, and sex were recorded for 329 whitespotted sawyers, *Monochamus scutellatus* (Say), on horizontal host logs in a logyard in Ft. Nelson BC. Over 65% of all males and females observed, and 58% of oviposition, occurred on the sides of horizontal host logs. This behavior would minimize the costs of desiccation and slow development of progeny on the upper and lower sections of logs, respectively. The sex ratio was male-biased throughout the season, rising to 4.1 males per female on 5 August 2000. Copulation and oviposition peaked on 9 and 21 July, respectively. By 5 August copulation was no longer observed. A late-season increase in the proportion of mobile males may represent a change in male reproductive strategy from selecting a preferred oviposition site and waiting for female arrival, to active pursuit of increasingly scarce females.

INTRODUCTION

Wood-boring beetles in the genus *Monochamus* Megerle (Coleoptera: Cerambycidae) reproduce in stressed, dying or dead coniferous trees throughout North America (Rose 1957). The larvae feed under the bark, in the sapwood and sometimes deep into the heartwood (Linsley 1961), often boring long tunnels which weaken and degrade the wood and provide infection courts for wood-rotting fungi (Vallentgoed 1991). Five North American *Monochamus* spp. are also known vectors of the pinewood nematode, *Bursaphelenchus xylophilus* (Steiner et Buhrer) Nickle (Table 1). Of the eight *Monochamus* spp. found in Canada, the whitespotted sawyer, *M. scutellatus* (Say), is the most common and has the largest range (Table 1) (Linsley and Chemsak 1984; Gosling and Gosling 1976).

Female *M. scutellatus*, deposit eggs singly in niches chewed in the bark; the eggs hatch in 12 days on average (Rose 1957; Raske 1972; Cerezke 1975). The larvae feed in the phloem and continue to feed there even after they have bored into the wood, where they also overwinter. The following spring they continue feeding and mining. Under favorable conditions *M. scutellatus* is univoltine. Mature larvae construct a pupal cell close to the wood surface, pupate and emerge from June through August. If conditions are not favorable, immature larvae continue to feed and mine throughout the summer and pupate the following spring, completing their life cycle in two years, although 3-5 year life cycles have been observed (Raske 1972). Newly-emerged adults engage in a 3-10 day period of maturation feeding on conifer foliage and shoots before reproducing (Rose 1957; Raske 1972), and return to feed on foliage and shoots throughout their life (Raske 1972).

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Table 1
Species of *Monochamus* found in Canada, their distribution and host plants. Compiled from Linsley and Chemsak (1984) and Gosling and Gosling (1976).

Species	Distribution	Host Genera
**M. carolinensis* *(Olivier)*	Eastern United States and Canada to Texas and Minnesota	*Pinus*
**M. titillator* (F.)	Eastern United States and Canada to Texas and North Dakota	*Pinus, Abies, Picea*
**M. scutellatus* (Say)	Newfoundland to Alaska, south to California and east to North Carolina	*Pinus, Abies, Larix, Picea*
M. obtusus Casey	Washington, British Columbia and Idaho to California	*Pinus, Pseudotsuga, Abies*
M. marmator Kirby	Southeastern Canada to North Carolina and the Great Lakes	*Abies, Picea*
**M. mutator* LeConte	Lake Superior region of Michigan, Minnesota, Ontario and Quebec	*Pinus, Picea, Abies, Larix*
**M. clamator* (LeConte)	California to British Columbia, Rocky Mountains and Great Basin to Southern Arizona and Honduras	*Pinus, Abies, Pseudotsuga*
M. notatus (Drury)	Eastern North America to South Carolina west to Montana and British Columbia	*Pinus, Picea, Pseudotsuga, Abies*

*Known vector of the pinewood nematode, *Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickle (Linit 1988; Vallentgoed 1991).

Differential ability of male whitespotted sawyers to defend territory at the breeding site (host logs) may cause a high degree of variation in male mating success (Hughes 1979, 1981). Hughes and Hughes (1987) found that large-diameter trees are more attractive than small-diameter trees and that females preferred the large-circumference portions of the bole. They hypothesized that large host logs would produce high quality brood in high numbers and consequently were preferred ovipositon sites. The sides of fallen logs are preferred oviposition sites (Rose 1957; Raske 1972; Cerezke 1975), with *M. scutellatus* laying eggs in the ratio of 10:3:1 on the sides, top and bottom of horizontal host logs respectively (Raske 1972).

In 1999, peak adult flight activity for *M. scutellatus*, in the Okanagan Valley of British Columbia occured between 17-31 August (McIntosh *et al.* 2001). In *M. clamator* (LeConte)[2] males emerged first and peak male emergence preceded peak female emergence (Ross 1966). Similarly male *M. alternatus* Hope emerged earlier than females (Togashi and Magira 1981). This protandry, the emergence and reproductive maturation of males in advance of females (Wiklund and Fagerström 1977), is apparently an adaptive trait (Thornhill and Alcock 1983) that allows early-emerging males to find and defend preferred oviposition sites (Hughes 1979, 1981), where they await the arrival of females.

We report the results of observations in Ft. Nelson, British Columbia, on *M. scutellatus*, demonstrating: 1) male and female preference for resting and ovipositing on the sides of horizontal host logs; 2) differential mobility and reproductive behavior over time; and 3) change in the sex ratio over time. We propose some testable hypotheses to explain our observations.

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[2] Linsley and Chemsak (1984) note that the species designated as *Monochamus maculosus* (Haldeman) by Ross (1966) is now considered to be *M. clamator* (LeConte).

MATERIALS AND METHODS

Observations were made on 30 June, 9, 21 and 30 July and 5 August 2000 between 1200–1600 h in the logyard of Slocan Forest Products Ltd. Tackama Division, in Ft. Nelson, British Columbia. The logs inspected were predominately decked white spruce, *Picea glauca* (Moench) Voss, black spruce, *P. mariana* (Mill) B.S.P., subalpine fir, *Abies lasiocarpa* (Hook.) Nutt., and lodgepole pine, *Pinus contorta* var. *latifolia* Engelmann. Whenever possible the entire surface of a log was inspected. This was accomplished by selecting logs that protruded from the end of the log deck. All observed beetles were identified and sexed in the logyard using elytral and antennal characters (Linsley and Chemsak 1984). Sample logs were randomly chosen, but inaccessible logs from the bottom and centre of log decks were excluded. During each visit logs were sampled until at least 50 beetles were observed (>10 logs sampled/visit). After sampling a log, the investigator then moved to a log in another location (minimum 2-3 m distant) to reduce the possibility of observing the same beetle more than once.

Logs were divided so that the sides, top and bottom were each equally represented by 1/3 of the available surface area (i.e. each side equaled 1/6 of the available surface). Behavior was categorized as stationary, mobile or copulating. For females, an additional category, oviposition, was characterized as chewing an oviposition niche, or ovipositing in one. Rose (1957) observed that eggs are not deposited in all oviposition niches; however we did not discriminate between chewing an oviposition niche and ovipositing. Stationary beetles were immobile and solitary. Mobile beetles were walking or running on the bark; their location when first observed was recorded. Copulating beetles were either stationary or mobile, and were defined as any pair in which the female was mounted by a male, unless the female was chewing an oviposition niche. In these cases the female was recorded as ovipositing and the male as copulating.

The Chi-square goodness of fit test was used to test the null hypotheses that male and female beetles and oviposition niches were randomly distributed on host logs. Chi-square contingency table analysis was used to test the hypotheses that male and female behavior and sex ratio were independent of date of observation. In all cases, $\alpha=0.05$.

RESULTS AND DISCUSSION

Sixty-six and 65 percent of male and female *M. scutellatus*, respectively, were found on the sides of logs (Fig. 1), and 58 percent of oviposition also occurred on the sides of logs (Fig. 1). These results support observations of preferential oviposition on the sides of horizontal logs by *M. scutellatus* (Rose 1957; Raske 1972; Cerezke 1975) and indicate that all types of activity occur mostly on the sides of the logs. Oviposition on the sides of horizontal host logs may represent a trade-off, which minimizes mortality of eggs and young larvae from desiccation on the top of logs (Rose 1957), and slow development that would occur in the cool lower portion of logs (Raske 1972). Ross (1966) allowed *M. clamator* to oviposit on ponderosa pine bolts in May and then stored the logs in the shade or in full sunlight until October of the same year. Of 67 larvae found under the bark of the shaded bolts, only one had bored into the wood, whereas 22 of the 47 larvae found under the bark of the bolts in full sunlight had bored into the wood; this developmental state would enhance their chance of surviving the winter (Raske 1972). Although we did not record the direction of exposed sides of logs, Post and Werner (1988) observed preferential oviposition by *M. scutellatus* on the south facing sides of decked white spruce logs in

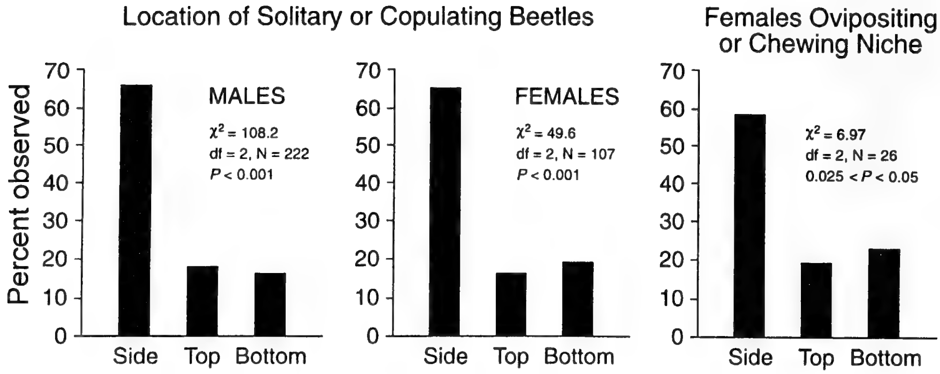

Figure 1. Locations of male and female *Monochamus scutellatus* observed on horizontal host logs and female *M. scutellatus* observed chewing oviposition niches or ovipositing on horizontal host logs in the Slocan Forest Products, Tackama Division logyard, Ft. Nelson, British Columbia. Side, top and bottom each equal 1/3 of the available surface area.

Alaska, a behavior that would maximize exposure of larvae to solar-heat in the short northern summer.

The observed sex ratio of *M. scutellatus* on host logs was always male-biased, but changed significantly over time to favor males four-fold over females by 5 August (Table 2). These observations do not agree with Hughes (1979) who found mostly female *M. scutellatus* on host logs. In *M. clamator* the sex ratio of 164 emergent beetles from fire-killed ponderosa pine was 1.1 males per female (Ross 1966). One possible explanation for our observations is that because of the high metabolic cost of oviposition, females spend a significant portion of their time feeding in the crowns of trees, and thus are found less frequently on logs than males, which remain to guard their territory (Hughes 1979, 1981). Although female *M. scutellatus* live approximately 40 days and males 30 days in the laboratory (Raske 1972), the costs of oviposition may cause females to die sooner than males in the field, resulting in the sharp rise in male to female sex ratio in August (Table 2). In northern Ontario males were observed earlier in the afternoon than females (S. Peddle, 2001, 256 Yorkshire St. N., Guelph, Ontario, N1H 5C4, personal communication). Conversely, Hughes (1979) reports that few beetles were seen before 1400 h and most of these were females. It is possible that our observed bias in male sex ratio is confounded by sampling time.

Table 2

Sex ratio of *Monochamus scutellatus* observed on host logs in the Slocan Forest Products, Tackama Division logyard in Ft. Nelson, British Columbia. Significant change in sex ratio with time, χ^2=12.7, d.f.=4, 0.025<P<0.01.

Date	N	Sex ratio males/female
30 June 2000	50	2.6
9 July 2000	80	1.4
21 July 2000	73	2.5
30 July 2000	75	1.3
5 August 2000	51	4.1
All dates	329	1.9

The observed proportions of beetles engaged in various behaviors changed significantly with time for both sexes (Fig. 2). The proportions of beetles copulating peaked on 9-July and then decreased to zero one month later. Peak oviposition by females was observed 12 days after the peak in copulation; oviposition persisted at the final observation on 5 August. It has been demonstrated that some cerambycids prefer specific host plants (i.e. tall and conspicuous host plants, see Hanks (1999) and references therein). The high proportion of stationary males early in the summer, except for the peak copulation period in early July, is consistent with the hypothesis that males secure territories in preferred oviposition sites and wait for females. When a female landed and approached within 2-3 cm, a male would dash toward and rapidly mount her. We observed copulation at all times between 1200–1600 h, whereas Hughes (1979) did not observe copulation before 1400 h. We hypothesize that the increase in male mobility on 5 August represents a change in reproductive strategy in late summer, when females have become scarce and therefore are less likely to enter a given male's territory. Switching from a territorial to roaming reproductive strategy could increase the likelihood of contacting and copulating with a female.

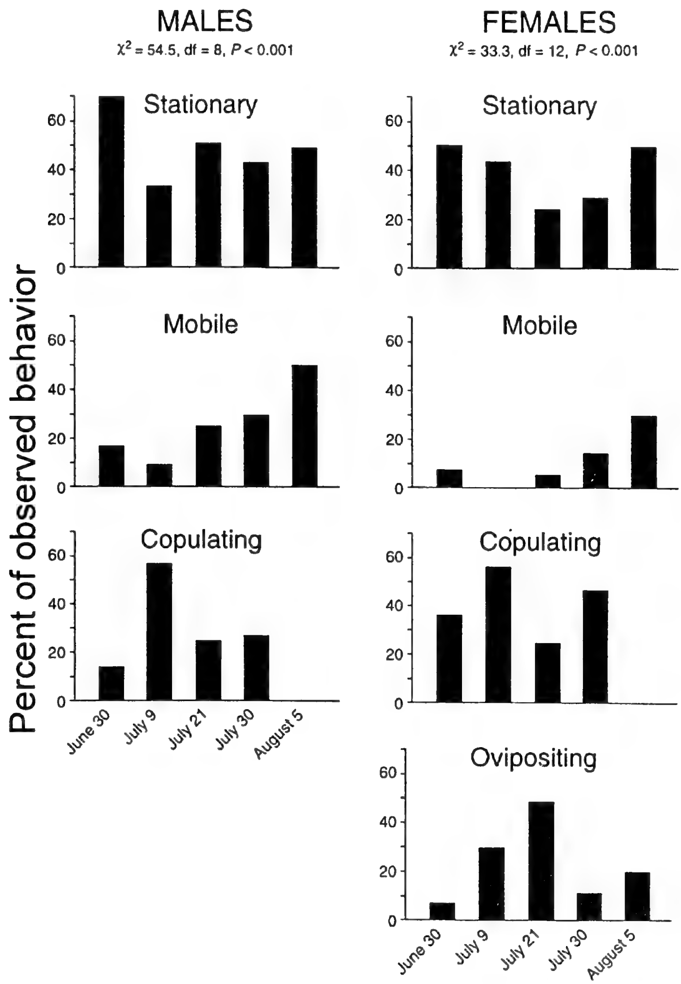

Figure 2. Proportions of observed behavior of male and female *Monochamus scutellatus* on horizontal host logs from 30 June – 5 August, 2000, Slocan Forest Products, Tackama Division logyard, Ft. Nelson, British Columbia.

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The cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Coleoptera: Curculionidae) - a review

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ABSTRACT

The cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham), which has recently become established in southern Alberta, is a serious pest of oilseed rape (*Brassica napus* L.) in Europe and the USA and poses a major threat to the economic sustainability of canola production in western Canada. This paper reviews the biology and control of this pest and identifies future research needs. Control strategies in Europe and the USA have so far relied on insecticides because no cultural or biological control methods have been successful. Research on plant resistance is in progress at several research centres and could provide the long term solution. Several parasitoid species are known to suppress populations of the weevil in Europe and are candidates for biocontrol programs in North America. Current research priorities in western Canada are to quantify the effects of weevil densities on canola seed yield, to establish economic thresholds and to design control strategies that integrate chemical, cultural and biological controls. Research programs should be established to screen a wide range of *Brassica* germplasm to identify sources of resistance for use in developing resistant cultivars for western Canada. Research on the overwintering ecology and seasonal activity of this weevil is needed to model how its range is likely to expand to other canola growing regions of Canada and to enable forecasting of outbreaks.

Key words: *Brassica*, oilseed rape, Ceutorhynchinae, *Ceutorhynchus assimilis*, *Ceutorhynchus obstrictus,* canola insect pests

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INTRODUCTION

The cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham) (Coleoptera: Curculionidae) was first detected in southern Alberta in 1995 (Butts and Byers 1996). By 2000, the weevil had become a major pest of canola[2] throughout southern Alberta (Dosdall *et al.* 2001) and had spread eastward into adjacent areas of Saskatchewan (Fig.1). *Ceutorhynchus obstrictus* poses a serious threat to the canola industry in western Canada and has prompted provincial and federal entomologists to initiate research programs to develop effective management strategies. This paper reviews the history and biology of the cabbage seedpod weevil, its damage, and strategies for its control. We also propose research priorities that will enable more effective and sustainable management of this pest.

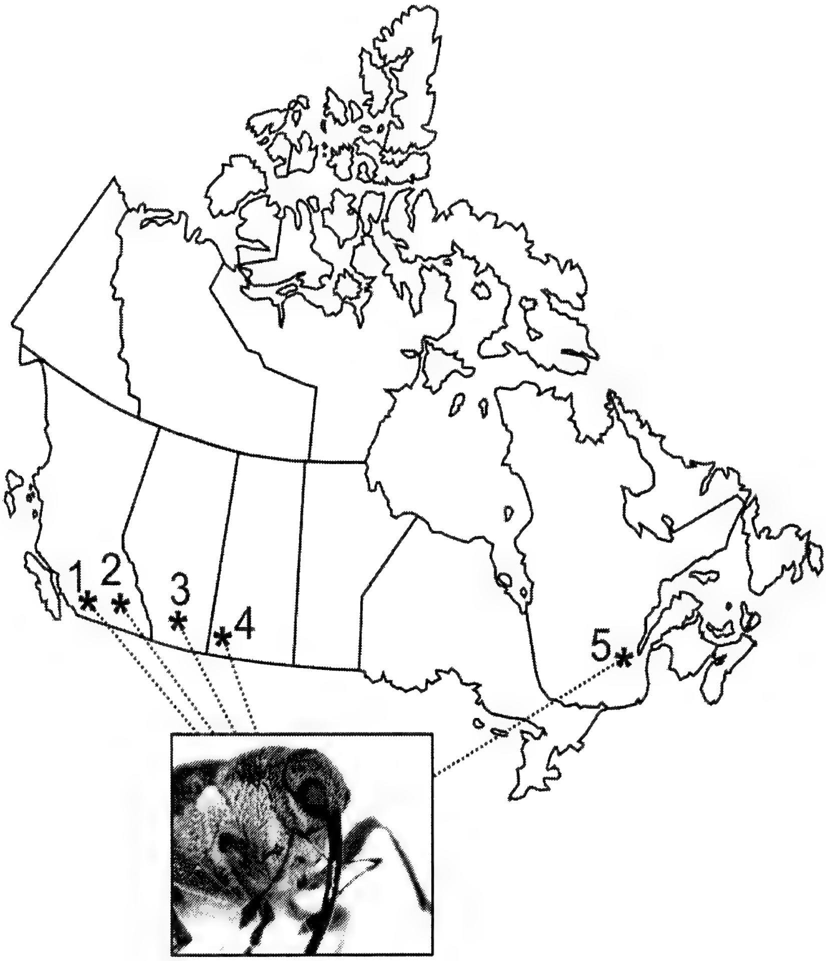

Figure 1. Distribution of the cabbage seedpod weevil in Canada as of 2000.
References: 1) McLeod 1953; 2) Philips 2000; 3) Dosdall *et al.* 2001; 4) Olfert unpublished data; 5) Brodeur *et al.* 2001. Photo by Eric Kokko, AAFC, Lethbridge, AB

[2] Canola is the term used for cultivars of oilseed rape (*Brassica napus* L. and *B. rapa* L.) that are low in erucic acid and glucosinolate; attributes desirable for the production of food grade vegetable oil and livestock meal.

HISTORY

As recommended by Colonnelli (1990, 1993) the name *C. obstrictus* Marsham will be used in this paper instead of the synonym, *C. assimilis* Paykull, used in most previous publications on this species. The cabbage seedpod weevil (CSW), also known as the turnip seed weevil or seed weevil in Europe, has been recognized as a pest of crucifers from the Mediterranean to Scandinavia since the beginning of the 19th century (Bonnemaison 1957). In North America, it was first recorded near Vancouver, British Columbia in 1931 (Baker 1936; McLeod 1953) and is now well established in the interior in both the Okanagan and Creston valleys (Philips 2000). By 1946 it had spread throughout the Pacific North-West and California (Hagen 1946, Crowell 1952). It is well established in Georgia (Buntin 1990) and Tennessee (Boyd and Lentz 1994) and probably now occurs throughout most of the USA. In 2000 it was found in Quebec (Brodeur *et al.* 2001).

BIOLOGY

Ceutorhynchus obstrictus is univoltine with the adults overwintering under leaf litter in treed areas, shelterbelts and field margins (Dmoch 1965a). A chill period of about 16 weeks at 4°C is required to break diapause (Ni *et al.* 1990). The adults, which are strong fliers, disperse from the overwintering habitats in spring when air temperatures reach 15°C (Ankersmit and Nieukerken 1954; Dmoch 1965a). They feed on the buds and flowers of various crucifers for several weeks before they start to oviposit (Doucette 1947; Dmoch 1965a; Ni *et al.* 1990). In southern Alberta they are abundant on early flowering cruciferous weeds, especially flixweed (*Descurania sophia* L. Webb) and hoary cress (*Cardaria draba* L. Desv.), until canola begins to bloom. Little ovarian development occurs below 10°C or above 25°C (Ni *et al.* 1990). Weevil numbers peak when the host crop begins flowering (Dmoch 1965b; McCaffrey *et al.* 1986). The most common host crops are cultivated crucifers, including canola, other oilseed rape, cole crops (e.g. *B. oleracea* L.) and brown mustard (*B. juncea* L). Yellow (or white) mustard, *Sinapis alba* L. is not attacked (Doucette 1947). Females lay eggs singly into young pods through feeding punctures and usually only one egg is laid per pod unless weevil densities are high. After oviposition the females brush the pod with the tip of their abdomen, apparently to apply an oviposition deterrent pheromone (Kozlowski *et al.* 1983). The larvae undergo three instars and consume three to six seeds each. When mature they chew an exit hole in the wall of the pod, drop to the ground and pupate in the soil. The new generation adults emerge from 9-30 days after exit from the pods depending on temperature (Hanson *et al.* 1948; Bonnemaison 1955, 1957; Dmoch 1965a). In southern Alberta we (L.D.) have found that this sometimes takes only 7-10 days. The entire development from egg to adult usually takes 4-6 weeks (Bonnemaison 1957). The new adults can disperse several km or more in search of food, especially late maturing crucifers, to accumulate fat reserves before finding overwintering habitats in early fall (Doucette 1947).

DAMAGE, ECONOMIC THRESHOLDS AND SAMPLING

Cabbage seedpod weevils can significantly reduce the seed yield of canola in several ways. Feeding by the overwintered adults on buds and flowers in the spring and early summer causes blossom blasting and pod abortion which may reduce the yield by up to 14% (Coutin *et al.* 1974). However, under good growing conditions canola plants can compensate for up to 60% loss of buds and flowers (Williams and Free, 1978, 1979; Free *et al.* 1983). Reduced yield can also occur as a result of interaction between the feeding or oviposition activity of the CSW adults and other insect pests. In Europe, CSW feeding punctures are used for oviposition by the pod midge, *Dasyneura brassicae* Winn. (Free *et al.* 1983). Seed losses are considerably higher when both pests occur together and as a consequence, the economic threshold for CSW adults in England is only one per plant (Free *et al.* 1983). The feeding punctures can also be used by other small insects, such as thrips, to gain access to the seeds; without the weevils, thrips feed only on the surface of the pods and cause little damage (K.M. Fry, 2000, Alberta Research Council, personal communication). This interaction might potentially be a problem in those regions where thrips are sometimes abundant in canola during flowering. Under moist conditions a reduction in seed yield and quality can also result from fungal pathogens that gain entry through the feeding punctures or larval exit holes.

The principal damage caused by CSW occurs during the larval stages (McCaffrey *et al.* 1986; Buntin 1999). Depending on seed size, three to six seeds are consumed by each larva (Dmoch 1965a) or about 20 to 30% of the seeds in each pod. With high weevil densities two to three larvae may infest a pod and consume most of the seeds. Additional losses occur at harvest because infested pods ripen prematurely and tend to shatter prior to or during harvest.

Late seeded or late maturing canola can be seriously damaged in late summer or early fall by new generation adults feeding through the pod wall on the immature seeds. Buntin *et al.* (1995) found that in Georgia and Idaho feeding by adults reduced the weight of punctured seeds by about 16% and the oil content by about 2%. The incidence of damaged seed ranged from 8 to 17% in untreated fields in Georgia and 5 to 10% in fields treated with insecticide in Idaho. Although the overall yield loss was less than 2%, a 40% decrease in germination of the damaged seed and a high incidence of abnormal seedlings, would be of concern for certified seed producers.

The relationship between weevil densities and yield loss has been little studied although this relationship is necessary for establishing economic thresholds. Studies in Scandinavia showed a clear negative relationship between weevil densities and yield (Tulisalo *et al.* 1976; Sylven and Svenson 1975). In Tulisalo's cage study, two weevils per plant reduced yield by 50% and they estimated that one weevil per four plants warranted the use of an insecticide. They found that at high weevil densities the plants attempted to compensate by producing more pods, but this was more than offset by a reduction in the average seed weight.

The presence of other pests can also affect the economic threshold for CSW. Free *et al.* (1983) determined that, in England, densities below one weevil per plant caused pod infestation rates of less than 26% and on their own did not warrant control. However, in the presence of the pod midge, *Dasyneura brassicae*, losses were much higher and control at lower weevil densities was warranted. Other studies in France (Lerin 1984) and the USA (Buntin 1999) have also found that, because of plant compensation, there is little yield loss at pod infestation levels below about 25%. Although the CSW has been a serious pest of winter canola in the US Pacific Northwest, no economic threshold has been established. However, preliminary studies from Idaho indicate that three to six weevils per 180° sweep with a standard 38 cm diameter sweep net warrants control because at these population levels yields in unsprayed plots were 15 to 35% lower than in sprayed plots (McCaffrey *et al.* 1986). A similar threshold of three to four weevils per sweep is being used in southern Alberta (Dosdall *et al.* 2001) until results from current cage and plot studies are available.

Sampling methods vary with the objective of the investigation. For population monitoring, a sweep net is normally used. Dmoch (1965a,b) determined that 4 samples of 25 sweeps each estimated weevil populations with adequate accuracy. In plot insecticide trials, the sweep net is also the usual sampling method and the number of sweeps per plot can be as low as six to eight in small plots (Buntin 1999). When the crop is fully podded and sweeping becomes difficult other methods such as dislodging the weevils into buckets or pans have been used (Brown *et al.* 1999). Yellow pan traps have been used to study the seasonal pattern of activity of seasonal activity and to monitor weevil arrival in fields (Bonnemaison 1957). Flight intercept traps have also been used to provide information about CSW spatial distribution and phenology

(Ferguson *et al.* 2000). As suggested by Dolinski (1979) we have found that pitfall traps are useful for studying the arrival of adults at, and departure from, overwintering habitats. No studies relating the results of the various trapping or sweeping methods to actual weevil densities per plant have been published. Because the weevils are concentrated on the buds and flowers in the uppermost part of the crop canopy, ongoing studies (H.A.C.) are finding the efficiency of sweep net sampling to be about twice the 10% reported for lygus bugs (Wise and Lamb 1998).

CONTROL STRATEGIES

Biological control. In Europe, and those parts of North America where it has been established for some time, the CSW is host to a number of parasitoids. Surveys in Washington (Hanson *et al.* 1948; Doucette 1948), Oregon (Doucette 1948), California (Carlson *et al.* 1951), and British Columbia (McLeod 1953) found 11 parasitoid species associated with this weevil. The pteromalid wasps, *Trichomalus perfectus* (Walker) [syn. *T. fasciatus* (Thomson)] and *Mesopolobus morys* L. (syn. *Xenocrepis pura* Mayr) were the most abundant parasitoids. *Trichomalus perfectus* and *M. morys* were also important parasitoids in northern Idaho, although the eulophid, *Necremnus duplicatus* Gahan was present in substantial numbers (Doucette 1948; Walz 1957). Recently Harmon and McCaffrey (1997) found that the introduced European braconid, *Microctonus melanopus* Ruthe, reduced survival of overwintering adult weevils in Idaho and Washington, with parasitism levels as high as 70%. In Europe, many parasitoids are known to attack the CSW (Dolinski 1979; Herting 1973; Kuhlmann and Mason 1999) with the most common being the braconids *M. melanopus* and *Diospilus oleraceus* Haliday, and the pteromalids *M. morys* and *T. perfectus* (Kuhlmann and Mason 1999, Kuhlmann *et al.* 2001).

Chemical control. Several insecticides control CSW effectively, although none are currently registered in Canada (Dosdall *et al.* 2001). Pyrethroids such as deltamethrin and alphacypermethrin are used in Europe for control of adults when the crop is at the early flowering stage (Alford *et al.* 1996). Parathion applied at the end of flowering was reported to control the larval stage of CSW in the Pacific NW of the USA and was recommended over endosulfan which was more expensive and less effective against adults (McCaffrey *et al.* 1986). In Georgia, Buntin (1999) found that the pyrethroids, bifenthrin, esfenvalerate, permethrin, and zetacypermethrin controlled CSW on winter oilseed rape more effectively than the other insecticides, including methyl parathion and endosulfan, currently registered in the USA. However, only treatment with esfenvalerate increased yield relative to untreated plots and two applications were required (Buntin 1999). However, preliminary results (H.A.C. & L.D) indicate that in most fields only one application of insecticide will be needed for control of CSW on spring canola in Canada.

Insecticide applications should, ideally, be timed to spare parasitoids and minimize disruption of biological control. Research in the UK has shown that *T. perfectus*, an ectoparasite of CSW larva, arrives in rape fields towards the end of flowering about two weeks after the weevil (Alford *et al.* 1996). Therefore, insecticide applications applied at early flowering should largely spare the parasitoid (Murchie *et al.* 1997). Buntin (1998) found that the use of esfenvalerate during bloom indirectly reduced *T. perfectus* numbers because of a reduction in the number of available hosts, but a greater proportion of the remaining host larvae were attacked. Another recent UK study (Ferguson *et al.* 2000) found that CSW tend to be spatially aggregated within fields and it might be possible to spot-spray such areas, thereby reducing mortality of beneficials. Earlier studies had shown that at low populations the weevils are aggregated along field edges (Free and Williams 1978). As part of an integrated pest management program developed in France in the 1970's, it was found that spraying only the field borders usually gave adequate control of CSW and enhanced parasitism in the rest of the field (Jourdheuil *et al.* 1974).

Cultural control. Cultural control methods for CSW have received little attention. There are no published studies on effects of rotation, intercropping, planting date or seeding rate. Because the adults disperse widely (Kjaer-Pedersen 1992), crop rotation is unlikely to reduce damage. Intercropping should be investigated because it has been shown that interplanting of canola with barley provides some protection against crucifer specialists such as flea beetles (Butts *et al.* 1999). Mixed planting with non-host crops might interfere with the chemical host finding cues used by CSW (Evans and Allen-Williams 1992). Late planted fields and experimental plots have been observed to largely escape weevil damage in southern Alberta, however, too late a seeding date exposes the crop to damage by new generation adults. Although an increase in seeding rate of canola can counteract damage by root maggots, *Delia* spp., (Dosdall *et al.* 1998) the effect of seeding rate on CSW is unknown.

Buntin (1998) investigated trap cropping as a method of managing CSW in winter oilseed rape. He used 0.35 ha plots with the peripheral 4.9 m planted with a spring cultivar (trap crop) and the rest planted with a conventional winter cultivar (main crop). Both were planted at the same time in the autumn and as a consequence the spring cultivar flowered several weeks earlier the following spring. Although weevils were more numerous in the trap crop, their control with esfenvalerate did not prevent damage and loss of yield in the unsprayed main crop. However, he speculated that trap cropping might work better at the field scale. Buechi (1990) also failed to reduce losses in oilseed rape (*B. napa)* by using turnip rape (*B. rapa*) as the trap crop. However, he did not spray the trap crop to kill the CSW adults which apparently preferred to oviposit in the oilseed rape. Ongoing studies in Alberta (Cárcamo *et al.* 2001) using an earlier flowering Polish cultivar (*B. rapa*) as the trap crop and a later flowering Argentine cultivar (*B. napa*) planted at the same time or staggered planting of the same cultivar, with the trap crop border being planted 1 to 2 weeks earlier, show that invading CSW adults are highly concentrated in the trap strips. Growers may be able to prevent damage to the main crop if the trap strip is sprayed before the CSW disperse into the later flowering main crop. Trap cropping has the potential to substantially reduce insecticide use, thereby lowering production costs and sparing nontarget species, especially pollinators and natural enemies.

Host plant resistance. The development of cultivars of canola with genetic resistance to the CSW would provide the ultimate solution. In a laboratory assay, Harmon and McCaffrey (1997) observed reduced feeding and oviposition on excised pods of a *B. rapa* line compared to two *B. napus* lines in choice tests. However, the differences were less pronounced in no-choice tests and might not be meaningful in the field.

Because yellow mustard (*S. alba)* is immune to CSW attack (Doucette 1947), hybrids of *S. alba* and *B. napus* have been produced with the expectation that these might be resistant to CSW (Brown *et al.* 1997). Although the hybrids were attacked by CSW, fewer larvae completed development in the hybrids than in the *B. napus* parent (McCaffrey *et al.* 1999). The authors attributed the effect to high concentrations of *p*-hydroxybenzyl glucosinolate inherited from the *S. alba* parent. An alternative to developing such hybrids for control of CSW is to develop cultivars of *S. alba* that produce canola quality oil. Research currently well underway at the Saskatoon Research Centre (Agriculture and Agri-Food Canada) has made good progress to developing canola quality *S. alba* lines that are better adapted than canola to the brown soil zone of Alberta and Saskatchewan and hopefully have retained the resistance to CSW.

RESEARCH PRIORITIES

Several basic and applied questions about the ability of the CSW to adapt to the Canadian prairies need answers to aid the development of sustainable management strategies. In an earlier review (Dolinski 1979) it was speculated that CSW had limited potential to become a pest of canola in western Canada because of the cold climate and apparent lack of suitable overwintering habitats. However, now that we know that it can survive here, at least in some areas, research is needed on its overwintering ecology to determine its likely range extension. Systematic surveys need to be conducted to track its spread and identify those areas where populations are increasing most rapidly. The phenology of CSW also needs to be studied in more detail to determine if it is, or can readily become, synchronized with that of canola in the more traditional production areas in the parkland ecoregions in the three prairie provinces and the Peace River region of Alberta and BC.

Of more immediate concern is the development of economic thresholds specific to the southern prairies that will enable canola growers to avoid unnecessary spraying. Detailed cage and plot experiments are required to objectively relate CSW density to seed yield and quality. Implementation of the established economic thresholds will depend on the adoption of a standardized sampling protocol. Sweep net sampling is the simplest and, although imperfect, by far the most practical method. However, conversion factors appropriate for each crop stage will be needed to relate the sweep net catches to actual CSW densities.

Interactions with other insect pests that may occur at the same time, such as lygus bugs, thrips, bertha armyworm and diamondback moth need to be investigated so that rational economic thresholds and IPM strategies for management of the insect pest complex of canola can be recommended. Insecticides known to be effective, such as pyrethroids, need to be registered, but registration should take into consideration the impact on pollinators and natural enemies. This is important because to control CSW the insecticide will probably have to be applied during flowering.

Studies should also be undertaken to further assess cultural control methods such as planting date (e.g. fall-planted spring canola), intercropping and trap cropping. Integration of appropriate cultural practices with longer-term strategies such as biological control and resistant cultivars should ensure the environmental and economic sustainability of the canola industry in Canada.

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Rearing the cranberry girdler *Chrysoteuchia topiaria* (Lepidoptera: Pyralidae) on reed canary grass *Phalaris arundinacea* (Festucoideae: Panicoideae)

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ABSTRACT

We report a method of rearing cranberry girdler *Chrysoteuchia topiaria* (Zeller), a pyralid that is a serious pest of cranberry *Vaccinium macrocarpon* Aiton. Fertile eggs from field-caught females were scattered on reed canary grass *Phalaris arundinacea* L. planted in greenhouse flats (50 eggs/flat) kept under fluorescent lights at 16L:8D and temperatures of 22-30°C (day): 19-24°C (night). Under these conditions, survival from egg to adult was 28%. Progeny of these adults entered diapause after exposure to low light (ca. 0.5 lux) as larvae. Diapause was broken by placing insects in the dark at 4.5-5.5°C for ca. 3 months, but survival was very poor (8% from egg to adult).

Key words: laboratory colony, laboratory rearing, turfgrass, *Vaccinium macrocarpon* Aiton, integrated pest management, subterranean webworm, sod webworm, diapause

INTRODUCTION

Cranberry girdler *Chrysoteuchia topiaria* (Zeller) is a serious pest of cranberries, *Vaccinium macrocarpon* Aiton in North America (Smith 1903). It is also recognized as a pest of grasses (Ainslie 1916) and coniferous seedlings (Kamm *et al.* 1983). Cranberry girdler belongs to the group of grass-infesting crambids (Pyralidae) commonly called sod webworms, and is also known as the subterranean webworm (Tashiro 1987). This pest overwinters as diapausing prepupae in the soil, and moths emerge from late May through early August (Kamm *et al.* 1990). Mated females deposit several hundred eggs (Scammell 1917, Kamm 1973b) singly or in groups at the soil surface. Neonate larvae are fragile, remaining near the surface where they feed on succulent tissue. Older larvae feed on crowns and roots, often severing them. Cranberry girdler is usually reported to be univoltine (e.g., Kamm *et al.* 1990), although moths observed flying in late August or September may represent a second generation (Smith 1903, Fitzpatrick unpublished).

Most studies of biology, chemical ecology and integrated pest management of cranberry girdler (summarized in Kamm *et al.* 1990) have been done in the field or have used insects gathered directly from the field (e.g., McDonough and Kamm 1979), because cranberry girdler is notoriously difficult to rear in the laboratory. The only report of successful rearing from egg to adult comes from Roberts and Mahr (1986), who obtained at best 17% survival from egg to adult on pinto bean diet at 16L:8D and 21°C.

Scammell (1917) complained that "some species of Crambinae defy all attempts to rear the larvae", noting that cranberry girdler was one of these. Our initial attempts to rear this insect

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(Fitzpatrick unpublished) almost led us to conclude that he was right. Under our conditions, girdler larvae did not survive on southwestern corn borer diet (Bioserve #F9763B; Bioserve, Frenchtown, NJ), sod webworm diet (Bioserve #F954B) or on pinto bean diet (modified from Shorey and Hale 1965) made in our laboratory. Only one of 200 larvae survived to the adult stage on general insect diet (Bioserve #F9004). We also tried five species of grass reported to be attractive to girdler larvae (Roland 1990): reed canary grass *Phalaris arundinacea* L., meadow foxtail *Alopecurus pratensis* L., red top *Agrostis alba* L., hard fescue *Festuca ovina* var. Duriuscula (L.) Koch., and creeping red fescue *Festuca rubra* L. Of these species, only reed canary grass sustained enough larvae for a colony. Here we report our method of rearing cranberry girdler on reed canary grass.

MATERIALS AND METHODS

Source of insects. A modified handheld vacuum (Bioquip, Gardena, CA) was used to collect mated female moths from commercial cranberry farms in Richmond and Pitt Meadows, British Columbia, in June and July 2000. Female moths were placed in plexiglass cages (0.3 x 0.3 x 0.3 m) in the laboratory at 16L:8D with temperatures ranging from 22-30°C (day): 19-24°C (night). Eggs, which are simply released from the ovipositor and dropped, were collected on sheets of wax paper or aluminum foil. If fertile, eggs changed colour from yellow to orange within 5-8 days of oviposition.

Rearing Conditions. Reed canary grass *Phalaris arundinacea* L. was seeded into a 50:50 mixture of potting soil and vermiculite in greenhouse flats (53 cm x 27.5 cm x 6.5 cm deep). The grass was watered, fertilized with 15-30-15 (N-P-K) as required, and maintained under fluorescent lights at 16L:8D in the laboratory or in the greenhouse, depending on which site was available. (At the time of this study, we had limited facilities.) In the laboratory, temperatures ranged from 22-30°C (day): 19-24°C (night). In the greenhouse, temperatures ranged from a high of 23°C during the day to a low of 15°C at night. All temperatures were recorded by Hobo® dataloggers (Onset Computer Corp., Bourne, MA). The reed canary grass grew for 10-60 days before fertile eggs were scattered onto the flats, and was kept trimmed to ca. 5-7 cm tall. Patches of grass killed by girdler larvae were reseeded. Girdler prepupae in cocoons were usually left in flats, which were placed in cages of various dimensions to contain emerging moths. Cages were made from screen (0.5 mm mesh) and PVC irrigation pipe, or plexiglass with screened openings. Flats from one rearing were placed in small controlled-environment chambers at 16L:8D with temperatures ranging from 21.5-24.5°C (day): 15-16.5°C (night). Light intensity, measured with a Hobo® datalogger, was 28-60 lux in the controlled-environment chambers. Light intensity in the laboratory and greenhouse was not measured.

We maintained some mature larvae and prepupae individually to produce unmated moths for fecundity studies (reported elsewhere). Mature larvae and prepupae in cocoons were removed from flats of reed canary grass and placed individually in 30-ml clear plastic cups containing a small amount of the moistened soil:vermiculite mixture and, if larvae were still feeding, a plug of reed canary grass. Insects in plastic cups were placed in small controlled-environment chambers under the conditions described above.

Statistics. Some moths were weighed on the day of emergence using a Sartorius microbalance (Sartorius Canada Inc., Mississauga, ON). To compare weights of adults, t-tests were performed on raw data (Systat 8.0 1998). Weights are given as mean ± standard error.

RESULTS

In mid-July 2000, a subset of 1550 fertile eggs from 131 field-collected females were scattered on 31 flats (50 eggs/flat) of reed canary grass in the laboratory. About 3 weeks later, small patches of dead grass could be lifted to reveal larvae feeding on the crowns and roots. As feeding and larval development progressed, some larvae crawled out of flats containing only dead grass. Most of these larvae were collected by hand and placed in flats containing live grass. Most larvae finished feeding by the third week of August. From 21-30 August, an uncounted number of girdler cocoons were removed from the flats and placed individually in 30-ml clear plastic cups containing the soil:vermiculite mixture. Cocoons recovered from the flats were left unopened to promote survival of the prepupa or pupa within. Cups containing cocoons were placed in the small controlled-environment chambers. Because we could not be sure that we had recovered all cocoons from the flats of grass, the flats were saved and maintained in the laboratory.

From 1 September to 27 October 2000, 268 males and 192 females emerged from the cups and flats. These individuals completed development without diapause. A subset of 60 unmated males and 60 unmated females was weighed. Males weighed 12.0±0.3 mg; females weighed 21.6±0.6 mg (t=13.72, df=118, P<0.001). From 8 September through 8 November 2000, a subset of 1900 fertile eggs from females used in fecundity studies was scattered on 19 flats of reed canary grass (100 eggs/flat) kept in the greenhouse. After 8-12 weeks, all larvae that could be found in the flats (570 larvae) were placed individually in 30-ml clear plastic cups with a plug of reed canary grass rooted in soil. All cups were placed in empty flats stacked (because space was very limited) in small chambers and repositioned every few days. In the previous rearing, cups were not tightly stacked because there were fewer cups and more space. The flats containing soil, dead grass and unrecovered cocoons were saved and also maintained in small chambers.

By early January 2001, only 32 adults had emerged. Several cocoons were opened to reveal diapausing prepupae. The measured light intensity reaching larvae inside cups in stacked flats was ca. 0.5 lux, which was so low that larvae probably did not experience the 16-h photoperiod as daylight. The light intensity experienced by larvae in cups at the top of the stack would have been close to the measured light intensity in the small chambers: 28-60 lux. We speculated that some larvae received enough light to continue their development without diapausing, but the majority did not. To break diapause, we exposed the cups containing cocoons and flats containing the remaining soil to simulated winter conditions of 4.5-5.5°C and total darkness in the small chambers from 5 January until 16 April 2001. On 17 April, photoperiod was set to 16L:8D and cups were arranged so that each received adequate light. Over the next 10 days, temperatures were gradually stepped up to 22:16°C. The flats containing the remaining soil were brought into the laboratory on April 17 (because there was insufficient space in the small chambers) and exposed to 16L:8D and approximately 22:16°C. From 4 May to 11 June 2001, 70 males and 61 females emerged from the flats of soil. No moths emerged from the cups. Males weighed less than those of the previous generation (9.7±0.2 mg; t=5.47, df=128, P<0.001), as did females (18.1±0.7 mg; t=3.88, df=119, P<0.001). At least 90% of these moths were unmated at the time of weighing. Of the individuals that never emerged from cups, 60 were pupae, 140 were prepupae, and the rest died as larvae.

DISCUSSION

When reared on reed canary grass *P. arundinacea* in greenhouse flats under fluorescent lights at a photoperiod of 16L:8D and temperatures of 22-30°C (day): 19-24°C (night), girdlers developed from egg to adult without diapause in 6-10 weeks. Roberts and Mahr (1986) reported developmental times of 10.4 weeks at 21°C and 7.6 weeks at 24°C for cranberry girdler reared through one generation without diapause on pinto bean diet.

Earlier observations in 1999 showed that this insect can be reared on reed canary grass under the above conditions through two generations without diapause (Fitzpatrick, unpublished). However, in late 2000, most of the progeny of non-diapausing girdlers entered diapause after larvae were reared at 15-23°C for the first 8-12 weeks, then exposed to low light intensity (ca. 0.5 lux) at 16L:8D and 15-24.5°C. Roberts and Mahr (1986) reared larvae at 16°C and at 21°C without triggering diapause. Our results suggest that diapause is triggered by photophase experienced by larvae, and is facultative. The only other report on photoperiod in relation to diapause in cranberry girdler comes from Kamm (1973a), who found that diapausing prepupae developed more slowly under a 12-h than a 16-h photophase.

In our study, 28% of non-diapausing cranberry girdlers survived from egg to adult. We did not quantify stage-specific mortality but we observed that late instars often crawled out of flats that had been overwatered or were very dry or were full of dying grass. These mobile larvae sometimes drowned under flats or escaped to corners of the laboratory and died. In the field, late instars may be a dispersing stage.

The survival of diapausing girdlers was very low, only about 8% from egg to adult. We suspect that the main reason for the additional mortality of diapausing girdlers was inadequate moisture in the soil, particularly in the 30-ml cups, during the 3-month simulated winter. It is also possible that larvae did not receive adequate food during development.

In both diapausing and non-diapausing groups, the average weight of newly emerged females was at least 80% greater than that of males. Adults that emerged after ca. 3 months in diapause weighed on average 17-20% less than adults of the previous, non-diapausing generation. This difference in weight may represent a physiological cost of diapause or may have resulted from insufficient food during larval development or dessication due to inadequate moisture in the soil during diapause.

In conclusion, cranberry girdler can be reared without diapause in greenhouse flats planted with reed canary grass (50 eggs/flat) and maintained under fluorescent lights at 16L:8D and temperatures of 22-30°C (day): 19-24°C (night). Late instars and prepupae in cocoons can be removed from soil in the flats and maintained individually until adult emergence.

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Monitoring the seasonal population density of *Pandemis pyrusana* (Lepidoptera: Tortricidae) within a diverse fruit crop production area in the Yakima Valley, WA

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ABSTRACT

The population dynamics of *Pandemis pyrusana* (Kearfott) were studied in 60 contiguous orchard blocks (154 hectares) of mixed fruit production situated in the Yakima Valley, Washington. Grids of sex-pheromone-baited and liquid-food-baited traps were placed at a rate of one trap of each type per 2 hectares. Trees within 50 m of each trapping location were sampled for overwintering and summer generation larvae, and fruit injury prior to harvest. Larvae from both generations were found in a low proportion of apple (*Malus domestica* Borkh.), pear (*Pyrus communis* L.), and cherry (*Prunus avium* L.) orchards, but not in the peach/nectarine (*Prunus persica* (L.)), apricot (*Prunus armeniaca* L.), or prune (*Prunus domestica* L.) orchards. Larval densities between generations increased 5-fold in apple and 10-fold in cherry and non-bearing apple. Parasitism of field-collected larvae by tachinid parasitoids averaged 37% and 23% for each generation, respectively. Low levels of fruit injury (< 0.5%) by *P. pyrusana* were detected in only five apple and pear orchards. Cumulative moth catch was 10-fold higher in sex-pheromone than food-baited traps. Moth catch in both types of traps varied significantly among crops. In general, moth catches were highest in apple and cherry. Cumulative moth catch in both trap types in apple and pear during the first flight was weakly correlated with levels of fruit injury. In contrast, moth catch during the second flight was not correlated with fruit injury. The observed low predictive ability of traps was likely due to trap saturation and contamination with non-target moths and a general dispersal of moths among orchards throughout the region. The capture of female moths versus the total of both sexes caught in food bait traps did not improve the prediction of fruit injury in apple or pear.

Key words: *Pandemis,* leafrollers, sex pheromone traps, food bait traps, fruit crops

INTRODUCTION

Pandemis spp. (Lepidoptera: Tortricidae) leafrollers are important direct pests of apple, *Malus domestica* (Borkh.), from British Columbia to California (Newcomber and Carlson 1952; Madsen *et al.* 1984; Zalom and Pickel 1988). Two species of *Pandemis* overlap geographically, within this range with *P. limitata* Robinson predominating in northcentral Washington and British Columbia and *P. pyrusana* (Kearfott) in the Yakima Valley, Washington, Oregon, and California. Levels of fruit injury caused by *P. pyrusana* have increased following the adoption of sex-pheromone-based mating disruption of codling moth, *Cydia pomonella* L., and the concurrent decreased use of the broad-spectrum organophosphate insecticides in these programs in Washington (Knight 1995) and California (Walker and Welter 2001). Management of *P. pyrusana* has relied on either the use of organophosphate insecticides, endotoxins of *Bacillus thuringiensis* Berliner, (Knight *et al.* 1998) or the use of sex pheromones for mating disruption (Knight and Turner 1999).

Management decisions for *P. pyrusana* in apple involve larval sampling in the spring prior to bloom (Beers *et al.* 1993). However, this method is labor intensive and ineffective in detecting low-density populations. The use of sex pheromone-baited traps to monitor *P. pyrusana* populations has been hampered by a poor relationship between moth catch and the within-orchard pest density, lack of knowledge of the drawing range of these lures, and limited understanding of the population dynamics and dispersal patterns of *P. pyrusana* (Brunner 1999). The adoption of low-load sex pheromone lures (Brunner 1999) and food baits that can catch both male and female moths may improve the predictive ability of traps (Landolt 2000).

Pandemis leafrollers have a broad host range that includes both cultivated and uncultivated plant species (Brunner 1983; Vakenti *et al.* 2001). Fruit injury has been reported in a range of tree fruits in Washington including apple, pear (*Pyrus communis* L.), cherry (*Prunus avium* L.), apricot (*Prunus armeniaca* L.), prune (*Prunus domestica* L.), and peach/nectarine (*Prunus persica* (L.)) (Newcomer and Carlson 1952; Brunner 1983). Reduced insecticide sprays in cherry after harvest and within blocks of non-bearing apples can allow the establishment of refugia for *P. pyrusana* populations within a region (Brunner and Beers 1990). Development of an effective area-wide management scheme for tortricid leafrollers such as *P. pyrusana* may require the application of season-long control tactics in these crops.

Grids of monitoring traps along with intensive larval sampling have been used successfully to study the area-wide population dynamics of other tortricids among various crop and non-crop hosts (Knight and Croft 1987; Knight and Hull 1988). These studies have demonstrated the patchwork pattern of overwintering pest populations and have clarified patterns of seasonal adult dispersal across crop types. A similar protocol was used in this study. The objectives of this study, conducted in 1999, were to measure the population density of *P. pyrusana* overwintering and developing during the summer within a variety of tree fruit crops within a contiguous region in the Yakima Valley, Washington, and to compare the usefulness of either a low-load sex-pheromone-baited or liquid-food-baited trap to monitor populations and predict larval densities and fruit injury levels in apple and pear orchards.

MATERIALS AND METHODS

This study was conducted in a 3 km^2 contiguous area of tree fruit production (Parker Heights) situated in the Yakima Valley of Washington (46° 29'N, -120° 24'W). *Pandemis pyrusana* had been reported to be an important pest for several apple and pear growers in this area during 1998. We identified 60 orchard blocks comprising 154 ha of apple, pear, cherry, peach, apricot, peach/nectarine, and prune production (Table 1). Apple orchards were planted with four cultivars (% of area): 'Gala' (46%), 'Golden Delicious' (19%), 'Red Delicious' (19%), and 'Fuji' (18%). All orchards received typical seasonal spray programs during the season (Olsen 2001).

Blocks were sampled for first generation larvae twice, in late May and early June, and again in August for second generation larvae. Five shoots from 10 trees within 50 m of each trap site were inspected on each date. Pole pruners were used to sample shoots randomly from the upper canopy. Rolled leaves were partially opened to determine if larvae were present. Infested shoots were placed in small paper bags, and returned to the laboratory. Recovered larvae were placed on artificial pinto bean diet (Shorey and Hale 1965) and reared under constant light at 24°C until adult eclosion to determine species and parasitism rate. Parasitoids were identified by Robert Pfannenstiel (USDA, ARS, Weslaco, TX). Apple and pear blocks were sampled for fruit injury just prior to harvest. Thirty fruit selected randomly on 20 trees within 50 m of each trap site were visually examined.

Two types of traps placed in a regular array (100 – 200 m spacing) were used to monitor adult *P. pyrusana*. Low-load (10% of the proprietary standard load) sex-pheromone-impregnated red septa (Trécé Inc., Salinas, CA) were used in delta traps (Pherocon 6, Trécé Inc., Salinas, CA). Food bait traps consisted of plastic dome traps (Scenturion Inc., Clinton, WA) loaded with 150 ml of 1.0% glacial acetic acid and brown food coloring. All traps were placed in the field the last week.

Table 1

Composition and density of tree fruit orchards within the Parker Heights study site and the number of sampling sites associated with sex-pheromone and food-bait traps.

Crop	No. orchard blocks	No. hectares	No. trapping sites
Apple	19	66.0	68
Pear	18	36.4	48
Cherry	14	22.0	28
Peach	4	17.4	20
Non-bearing apple	2	5.4	6
Apricots	3	5.2	6
Prune	1	1.2	2
Total	61	153.6	178

of May. Each trap type was placed in orchard blocks at a rate of one trap per 2 hectares for a total of 178 trap sites. Traps were placed about 2-m high in the canopy. Traps were checked weekly from early June to early August (first flight) and late August to early October (second flight). Moths caught in bait traps were returned to the laboratory for identification and *P. pyrusana* moths were sexed under a dissecting microscope. Sex-pheromone septa were replaced every 4 weeks. Sticky trap liners used in delta traps and the liquid bait solution in the dome traps were replaced as necessary.

Data Analysis. All moth count data were transformed to stabilize variances [square root $(x \pm 0.01)$] prior to analysis of variance (Analytical Software 2000). Moth catches in the single trap of each type placed in the prune orchard were not included in these analyses. Means were separated with Fisher's LSD test where significant differences occurred ($P < 0.05$). Linear correlation coefficients were computed among the cumulative mean moth counts per trap during each flight period, larval densities, and percent fruit injury. A chi-square contingency test was used to compare the proportion of parasitized larvae among crops during each generation.

RESULTS

Larval Sampling. Overwintering larvae were found in only 10 blocks within the study site: apple (4), non-bearing apple (2), pear (2), and cherry (2); and were not found in any blocks of peach/nectarine, apricot, or prune. While non-bearing apples had the highest mean percentage of infested shoots (Table 2), the percentage of infested shoots ranged up to 5% in pear and 6% in apple. Parasitism of overwintering larvae by the tachinids, *Nemorilla pyste* Walker and *Nilea erecta* Coquillett, totaled 37% and varied significantly among crops ($\chi^2 = 11.47$, df = 3, $P < 0.01$): 12.5% in cherry, 37.8% in apple, 50.0% in pear, and 85.7% in non-bearing apple.

Larval population density within the study site was roughly 3-fold larger during the summer than the overwintering generation, but densities increased nearly 5-fold in apple and 10-fold in both non-bearing apple and cherry blocks (Table 2). Summer generation larvae were sampled in three blocks of apple, three blocks of non-bearing apple, and two blocks of cherry. These included four blocks in which an overwintering population was not previously detected. In addition, in five blocks, overwintering larval populations were detected but no second generation larvae were found. The highest mean percentage of infested shoots occurred in non-bearing apple (Table 2). There were no infested shoots found in pear orchards during the summer. Apple orchards with the highest densities of summer generation larvae were situated near two areas containing cherry and non-bearing apple. Tachinids parasitized 23% of the

Table 2

Correlations among the overwintering and summer larval densities and fruit injury for *P. pyrusana* within tree fruit crops in the Parker Heights study site.

	% (± SE) infested shoots			Correlation coefficients[a]		
Crop	Overwintering larvae (OL)	Summer larvae (SL)	% (± SE) fruit injury (FI)	OL-SL	OL-FI	SL-FI
Non-bearing apple	0.50±0.27	5.88±2.10	-	0.83**	-	-
Apple	0.45±0.18	2.07±0.68	0.06±0.02	0.38	0.18	0.83**
Pear	0.25±0.16	0.00±0.00	0.03±0.02	0.00	0.21	0.00
Cherry	0.28±0.14	2.64±1.28	-	0.15	-	-
Peach	0.0	0.0	0.0	-	-	-
Apricot	0.0	0.0	0.0	-	-	-
Prune	0.0	0.0	0.0	-	-	-

[a] Correlation coefficients followed by ** were significant at $P < 0.01$.

field-collected summer generation larvae and no difference was found among crops ($\chi^2 = 3.45$, df = 2, $P = 0.18$).

Moth Flight. Moth catch in sex-pheromone-baited traps varied among crops during the first moth flight ($F = 3.55$; df = 5,82, $P < 0.01$) and was higher in apple, pear and cherry than in peach (Table 3). During the first flight, moth catch in non-bearing apple and apricot did not differ from the other crops. Cumulative moth catch in sex-pheromone traps increased about 400% between generations but did not vary among crops during the second flight ($F = 0.76$; df = 5, 82; $P = 0.58$).

Moth catch in the food-bait traps was much lower than in sex-pheromone traps during both flights (Table 3). The male:female sex ratio was 0.60 and 2.26 during the two moth flights, respectively. Cumulative male catch varied significantly among crops during both the first ($F = 2.65$; df = 5, 82; $P < 0.05$) and second moth flight ($F = 3.00$; df = 5, 82; $P < 0.05$). Male moth catch was lowest in apricot during both flights. Male moth catch in cherry during the second flight was significantly higher than in all other crops except apple (Table 3). Cumulative female catch varied among crops during the first flight, ($F = 3.02$; df = 5, 82; $P < 0.01$) and counts were higher in apple and cherry than in peach and non-bearing apple (Table 3). Moth catch in food-bait traps increased about 250% between the two flights. Cumulative total moth catch in the bait traps varied among crops during both flights (first flight: $F = 2.81$; df = 5, 82; $P < 0.05$ and second flight: $F = 2.46$; df = 5,82; $P < 0.05$). Cumulative moth catch in bait traps during the first flight in apple and cherry were significantly higher than peach, apricot and non-bearing apple (Table 3). Cumulative catch in bait traps during the second flight in cherry were greater than those in apricot and pear.

Fruit Injury. Fruit injury by *P. pyrusana* was detected in only one pear and four apple blocks within the study site and ranged from 0.1 to 0.5%. Surprisingly, no overwintering or summer generation larvae were detected in samples collected from three of these five blocks. All orchards with fruit injury were adjacent to or near blocks of cherry and non-bearing apple.

Correlations Among Population Measures. The overwintering density of larvae in both apple and pear orchards was not correlated with levels of fruit injury ($P = 0.79$ and $P = 0.77$, respectively) (Table 2). However, summer larval densities in apple were well correlated with fruit injury ($P < 0.001$). The percentage of shoots infested by overwintering larvae was not significantly correlated with percentage of shoots infested with summer larvae in apple ($P = 0.27$) or cherry ($P = 0.90$). However, larval densities in non-bearing apple blocks were significantly correlated ($P < 0.01$) (Table 2).

The correlations of cumulative moth catch per trap during each flight period with other

Table 3

Cumulative *P. pyrusana* moth catch (± SE) in sex-pheromone-baited and liquid-food-baited traps for the first (May – June) and second (July – August) moth flight within tree fruit crops in the Parker Heights study site.

	Sex-pheromone traps		Liquid-bait traps					
			Male		Female		Male + female	
Crop	1st flight	2nd flight	1st flight	2nd flight	1st flight	2nd flight	1st flight	2nd flight
Apple	68.5±15.0b	207.1±23.0a	5.7±1.5c	13.4±4.3bc	8.2±2.1b	8.0±2.3a	13.9±3.4b	21.4±6.6ab
Pear	81.0±16.3b	210.5±26.8a	4.3±1.3bc	3.4±0.8a	5.4±1.3ab	4.2±1.6a	9.8±2.5ab	7.7±2.3a
Cherry	53.3±12.5b	226.1±31.5a	3.8±1.4abc	27.4±14c	8.9±3.5b	18.1±7.3a	12.7±4.8b	45.2±21.4b
Peach	9.8 ±3.7a	177.4±21.2a	0.7±0.3ab	3.6±2.2a	1.1±0.3a	5.2±3.5a	1.8±0.4a	8.8±4.6ab
Non-bearing apple	39.3±10.2ab	182.7±32.4a	1.0±0.7ab	10.3±3.8ab	0.9±0.3a	5.4±4.0a	1.9±1.0a	15.7±5.4ab
Apricot	18.0±3.8ab	92.7±17.4a	0.0±0.0a	1.0±0.7a	1.5±0.5ab	4.5±1.5a	1.5±0.6a	5.5±1.5a
Prune	16.0	78.0	0.0	0.0	0.0	1.0	0.0	1.0

Column means followed by a different letter are significantly different at $P < 0.05$, Fishers LSD. Moth catch from the single prune orchard was not used in these statistical analyses.

measures of population density varied for each trap type in apple and pear (Table 4). Cumulative moth catch from both trap types during the first flight was significantly correlated with fruit injury in apples and pears but this relationship was weak (r's < 0.50; Table 4). Restricting the cumulative moth counts to the first 3 or 4 weeks of the season did not improve these correlations (r's < 0.45). In comparison, moth catches during the second flight were not correlated with fruit injury (Table 4). Cumulative moth catch per trap during the first and second flight were correlated for each type of trap. However, moth catch in sex-pheromone-baited traps during both flight periods was not correlated with either overwintering or summer larval densities. In comparison moth catch in the food-bait traps during the first flight period was correlated with overwintering larval density and summer larval density; and moth catch during the second flight was correlated with summer larval density (Table 4). Correlations of cumulative moths and cumulative female moths for each flight with larval densities and fruit injury were similar (Table 4).

Table 4

Correlations of cumulative moth catch during the 1st and 2nd moth flight of *P. pyrusana* in traps baited with either low-load sex-pheromone lures or a liquid-food bait with selected population measures across all apple and pear blocks within the Parker Heights study site.

Trap type	Flight period	Population measure	Correlation coefficient[a]
Low-load Sex-pheromone	1st flight	Overwintering larval density	0.04
		Summer larval density	0.25
		2nd moth flight	0.41**
		% fruit injury	0.45**
	2nd flight	Overwintering larval density	0.02
		Summer larval density	0.21
		% fruit injury	0.18
Liquid-food bait[b]	1st flight	Overwintering larval density	0.40* (0.44**)
		Summer larval density	0.60** (0.61**)
		2nd moth flight	0.32* (0.36**)
		% fruit injury	0.46** (0.37**)
	2nd flight	Overwintering larval density	0.17 (0.11)
		Summer larval density	0.40** (0.35**)
		% fruit injury	0.07 (0.07)

[a] Correlation coefficients followed by * were significant at $P < 0.05$; coefficients followed by ** were significant at $P < 0.01$.

[b] Correlation coefficients in brackets are for cumulative female moth catch only.

DISCUSSION

Establishing action thresholds based on the capture of male moths in sex-pheromone-baited traps has been difficult for many tortricid pests that occur in high densities within orchards (Madsen and Peters 1976; Minks *et al.* 1995; Walker and Welter 1999). Success has been achieved by reducing the effects of trap saturation by either using only early-season catches (Knight and Hull 1989) or by reducing the attractiveness of the lure (Faccioli *et al.* 1993). However, these approaches have not always improved the performance of sex-pheromone traps. A significant correlation of peak moth catch and larval density could not be established for the apple pest, *Argyrotaenia citrana* (Fernald) with traps baited with lures across a 1,000-fold range in their sex-pheromone load (Walker and Welter 1999).

The utility of sex-pheromone traps to accurately predict the population density of *P. pyrusana* may be limited. Walker and Welter (2001) found a significant but moderate relationship ($r^2 = 0.59$, $P = 0.04$) between peak weekly moth catch of *P. pyrusana* during the first moth flight and summer larval density in California apple orchards. While Brunner (1999) suggested that the use of low-load (5%) sex-pheromone lures improved the accuracy of traps in predicting larval populations and fruit injury, these data have not been published. Results reported herein found that low-load (10%) sex-pheromone lures were, at best, weak predictors of local population densities estimated by either larval sampling or levels of fruit injury.

Many factors affect the performance of lure-baited traps and the correlation of moth catch with local larval population density. Moth capture within traps is influenced by operational factors including the lure's emission characteristics and the attractant's chemical stability, and the size, geometry, placement, and maintenance of the trap (McNeil 1991). Saturation of the trap's catch surface with moths and non-target species can also reduce the effectiveness of traps to reflect relatively high population densities (Brown 1984). An accurate estimate of low-density leafroller larval populations is difficult to achieve without extensive host sampling. Furthermore, *P. pyrusana* larvae were typically found feeding on shoot terminals in the upper canopy of trees, and the variability in tree height among orchards and crops may have created a sampling bias in the estimate of larval density. In general, a greater number of larvae were detected in apple orchards with smaller canopies - non-bearing apple and younger blocks of Fuji. The relationship between moth catch and fruit injury is further impacted by a large number of horticultural and biological factors including cultivar and crop load, tree size and pruning, and spray practices. Orchards within our study site varied widely for many of these factors.

Moth catch of *P. pyrusana* in both types of traps during first flight was a better predictor of larval populations and fruit injury than moth catch during second flight. This result is similar to data previously reported for tufted apple bud moth *Platynota idaeusalis* (Walker) (Knight and Hull 1988) and *A. citrana* (Knight and Croft 1987). Both of these studies used grids of sex pheromone-baited traps within a diverse agricultural setting. Both leafroller pests overwintered primarily within managed agricultural sites and early-season male moth catches reflected this local distribution. However, the adults of both species are highly mobile and male moth catches of the summer generation flight were more homogeneous within the region. Similarly, counts of male *P. pyrusana* during second flight were uniformly high among 56 of the 60 orchards in Parker Heights.

While, moth catches during first flight in food bait traps were more closely associated with spring and summer larval densities than moth catches in sex-pheromone-baited traps, both trap types were similar in predicting fruit injury. Interestingly, the counts of female moths in the food bait traps did not improve the prediction of local population density. Liquid-food-bait traps had a greater number of problems associated with their use than the sex-pheromone traps. First, the acetic acid mixture evaporated rapidly during the warmer weather in August and required frequent servicing. The food-bait traps were not selective and caught a large number of non-target moths (Lepidoptera: Noctuidae) that saturated the traps. Identification and sexing of *P. pyrusana* individuals from a large decomposing mixture of insects was time consuming. The decomposition and fermentation of the mixture was also highly attractive to muscid flies and may have released volatile chemicals that may have reduced the attractiveness of the bait to *P. pyrusana*. Development of dry food baits placed in either sticky or insecticide-treated traps will likely reduce these problems (Landolt and Alfaro 2001).

Establishing effective management of a polyphagous pest such as *P. pyrusana* requires a concerted area-wide program across all potential hosts. Interestingly, populations of *P. pyrusana* in Parker Heights were not detected in the eight commercial orchards of peach/nectarine, apricot, and prune despite these crops' apparent host suitability (Brunner 1983). Its absence in these crops may have been due to the use of broad-spectrum insecticides for other key pests in these crops. For example, early-season and summer sprays for green peach aphid, *Myzus persicae* (Sulzer), peach twig borer, *Anarsia lineatella* (Zeller), oriental fruit moth, *Grapholitha molesta* (Busck), and western flower thrips, *Frankliniella occidentalis* (Pergande), are widely used in these stone fruits (Olsen 2001). In contrast, *P. pyrusana* larvae were found in over a third of the cherry orchards. Cherry is sprayed early in the season for phytophagous mites and the black cherry aphid, *Myzus cerasi* (Fabricus), and receives a series of cover sprays through June for the western cherry fruit fly, *Rhagoletis indifferens* (Curran). However, Washington growers typically do not apply any insecticides to cherry after June. The role of cherry orchards in serving as refugia for leafrollers was also reported for *P. idaeusalis* in a typical mixed-fruit production area in Pennsylvania (Knight and Hull 1988).

Leafroller management in apple and pear tends to ignore the potential role of these extra-orchard habitats and this allows populations of *P. pyrusana* to remain established at high levels within a given region. Even leafroller populations in non-bearing apple blocks are generally not treated. Instead, leafrollers are managed by individual growers within-season in their respective orchards with one or more well-timed applications of efficacious sprays. Implementation of an effective leafroller management strategy, however, is often hampered by poor spring weather, poor spray timing, the survival of larvae feeding within protected leaf shelters, and insecticide resistance.

Conversely, the idea of growers working together to implement an effective area-wide pest management program that suppresses a pest population across all host habitats would seem to be more effective and has recently been demonstrated for codling moth, *Cydia pomonella* L. (Calkins 1998). Similarly, the obliquebanded leafroller, *Choristoneura rosaceana* Harris was effectively managed by 13 growers using sex-pheromone-based mating disruption and *B. thuringiensis* sprays (Knight *et al.* 2001). The effectiveness of the area-wide approach requires that the pest population density be reduced to low levels through an integration of selective tactics. The success of the codling moth project was predicated on the clean-up of all problem sites that harbored high pest populations (Knight 1999). Similarly, effective area-wide management of *P. pyrusana* will require that populations in the surrounding cherry and non-bearing apple blocks be managed successfully.

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Fleas (Siphonaptera) from sciurid and murid rodents on the eastern slope of the Cascade Range, Kittitas County, Washington

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ABSTRACT

Eight species of rodent fleas [Ctenophthalmidae: *Megarthroglossus procus* Jordan & Rothschild; Leptopsyllidae: *Peromyscopsylla selenis* (Rothschild); Ceratophyllidae: *Ceratophyllus ciliatus protinus* Jordan, *Eumolpianus eumolpi eumolpi* (Rothschild), *Malaraeus telchinus* (Rothschild), *Opisodasys vesperalis* (Jordan), *Orchopeas agilis* (Rothschild) and *Oropsylla idahoensis* (Baker)] were collected in 1993 and 1995 from seven species of rodents [*Neotamias amoenus* (J.A. Allen), *N. townsendii* (Bachman), *Spermophilus saturatus* (Rhoads), *Glaucomys sabrinus* (Shaw), *Neotoma cinerea* (Ord), *Clethrionomys gapperi* (Vigors) and *Microtus longicaudus* (Merriam)] live and snap trapped. There were four new county records for *M. procus*, *P. selenis*, *O. vesperalis* and *O. idahoensis*, and there were five new host records for the state with *M. procus* and *C. ciliatus protinus ex G. sabrinus*, *P. selenis* and *M. telchinus ex C. gapperi* and *P. selenis ex M. longicaudus*. Distribution patterns and host preferences in the Pacific Northwest are discussed.

Key words: fleas, Siphonaptera, rodents, Washington State

INTRODUCTION

The flea fauna of Washington is less well known than its neighbors British Columbia and Oregon, with only 80 species of fleas recorded while British Columbia has 98 species and Oregon has 110 (Holland 1985; Lewis *et al.* 1988). The number of publications concerning fleas is smaller for Washington than for Oregon (Lewis *et al.* 1988). The number of locality/county symbols on distribution maps is fewest for Washington (Haddow *et al.* 1983; Holland 1985; Lewis *et al.* 1988). Washington ranks last, at least in part, because of its comparatively small land area (172,266 km^2). Oregon is 76,858 km^2 larger, and British Columbia (948,600 km^2) is 2.25 times larger than Oregon and Washington combined. Danks (1995) considered range of habitats as well as comparative land areas and found the same lower ranking for Washington in his tabulations from

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published species records in the order Dictyoptera and according to selected families and genera in the orders Hemiptera, Coleoptera, Diptera, Lepidoptera and Hymenoptera.

As Lewis *et al.* (1988) concluded from their review of literature, the flea faunas of the states contiguous with Oregon "… are in much need of additional study." In the present study, we contribute new data for eight rodent fleas in Kittitas County, central Washington, with five new flea-host associations for the state.

MATERIALS AND METHODS

All flea specimens were received from the University of Alaska (Fairbanks) Museum mammalogy section, preserved in alcohol. All were collected by one of us (MKM) in Wenatchee National Forest, Kittitas County, Washington during 1993 and 1995. Hosts were collected with snap traps (woodrats) and Havahart® and Sherman® live traps and snap traps (flying squirrels, chipmunks and voles). Host specimen number (AF number) for the University of Alaska mammal collection is designated in brackets. Fleas were permanently mounted on microscope slides by standard techniques (Lewis *et al.* 1988). All flea specimens were deposited in the US National Museum insect collection. The western chipmunk genus *Neotamias*, as proposed by Jameson (1999), is adopted here.

SPECIES ACCOUNTS

Ctenophthalmidae

Megarthroglossus procus Jordan & Rothschild, 1915

South Fork Taneum Creek, 1.6 km west of South Fork Meadows, 47°5'49.08"N, 121°0'37.68"W (1150m), 23 Aug 1995 [AF 13631], 1♀ *ex Glaucomys sabrinus* (Shaw) (northern flying squirrel) .

The specimen is identified as *M. procus*, although "… a definite identification is possible only if male specimens are available" (Tipton *et al.* 1979). Characters such as the spermathecal form and the lack of a noticeable sinus on the posterior margin of sternum VII, plus the known host associations, are consistent with this identification. The morphologically similar *M. jamesoni* Smit occurs in California and Nevada (Lewis *et al.* 1988). *Megarthroglossus procus* is known from Skagit, Whatcom and Yakima Counties (Tipton *et al.* 1979). Our specimen adds Kittitas County and a new host for the state.

Megarthroglossus procus is widely distributed in western North America, from the Pacific Northwest and as far east as western Nebraska. There is an apparent void east of the Cascades in Washington and Oregon (Mendez 1956; Tipton *et al.* 1979). *Megarthroglossus divisus* (Baker) is known to replace *M. procus* in nests of *G. sabrinus* in northeastern Oregon (Wilson and Bull 1977; Whitaker *et al.* 1983).

Records from British Columbia, Oregon and California convinced Holland (1949b, 1985) that the true host of *M. procus* is *Tamiasciurus douglasii* (Bachman) (Douglas' squirrel). From the wide variety of recorded hosts, Lewis *et al.* (1988) were inclined to name *T. hudsonicus* (Erxleben) (red squirrel) as a preferred host. More collecting from *G. sabrinus* and especially its nests will probably establish it as another preferred host of *M. procus*.

Leptopsyllidae

Peromyscopsylla selenis (Rothschild, 1906)

South Cle Elum Ridge, along US Forest Service road 3350, 47°8'20.10"N, 120°58'12.24"W (1172m), 21 Sep 1995 [AF 5504], 1♀ *ex Microtus longicaudus* (Merriam) (long-tailed vole). South Fork Taneum Creek, 1.6 km west of South Fork Meadows, 47°5'49.08"N, 121°0'37.68"W (1150m), 17 Aug 1995 [AF 5499], 1♀ *ex*

Clethrionomys gapperi (Vigors) (southern red-backed vole). Same locality but 25 Aug 1995 [AF 13640], 1♀ *ex C. gapperi*.

Peromyscopsylla selenis is a common flea found on arvicoline rodents and accidentally on other hosts in many areas of the western United States and Canada (Johnson and Traub 1954) but sparsely recorded in Washington State. The earliest collections in the state were in 1935 from *Microtus richardsoni* (DeKay) (water vole) in Skamania County and in 1938 from *M. townsendii* (Bachman) (Townsend's vole) in Skagit County (Hopkins and Rothschild 1971). Hubbard (1943, 1947) recorded a 1943 collection from *M. richardsoni* in Klickitat County. Johnson and Traub (1954) added a record from a *Microtus* sp. in Spokane County. The distribution map of Lewis *et al.* (1988) has marks for three of these counties plus Whitman County. Our two hosts, *C. gapperi* and *M. longicaudus*, are new for the state in a county not previously known for *P. selenis*.

Ceratophyllidae

Ceratophyllus ciliatus protinus Jordan, 1929

South Fork Taneum Creek, 1.6 km west of South Fork Meadows, 47°5'49.08"N, 121°0'37.68"W (1150m), 17 Aug 1995 [AF 13575], 1♂, 3♀♀ *ex Neotamias townsendii* (Bachman) (Townsend's chipmunk). Same date and locality [AF13574], 2♂♂ *ex N. townsendii*. Same date and locality [AF 13573], 1♂, 3♀♀ *ex N. townsendii*. Same date and locality [AF 13626], 1♂, 1♀ *ex N. townsendii*. Same locality but 18 Aug 1995 [AF 13599], 1♂ *ex G. sabrinus*. Same date and locality as previous [AF 13601], 1♀ *ex N. townsendii*. South Fork Taneum Creek, 0.8 km west of South Fork Meadows, 47°5'51.96"N, 121°0'6.00"W (1152m), 16 Aug 1995 [AF 5474], 1♂, 2♀♀ *ex N. townsendii*. Same date and locality as previous [AF 5481], 1♂ *ex N. townsendii*. Same locality but 24 Aug 1995 [AF 14912], 1♀ *ex N. townsendii*.

This taxon is well known from tree squirrels, chipmunks and some associated small mammals in western Washington, Oregon and British Columbia (Hubbard 1947; Johnson 1961; Haddow *et al.* 1983; Holland 1985). The earliest record for Washington is from Carson, Skamania County, 1939 (Hubbard 1940), and since then King, Kittitas, Pierce and Yakima Counties were added (Lewis *et al.* 1988). Lewis and Maser (1981) and Lewis *et al.* (1988) reported large numbers of *C. ciliatus protinus* on Townsend's chipmunk in Oregon. All but one of our 19 specimens came from this host. The exception came from *G. sabrinus*, a host record that is new for the state.

Eumolpianus eumolpi eumolpi (Rothschild, 1905)

South Cle Elum Ridge, 1.6 km southwest of Peoh Point along USFS road 3350, 47°8'31.74"N, 120°57'42.54"W (1411m), 21 Sep 1995 [AF 14925], 2♀♀ *ex Neotamias amoenus* (J.A. Allen) (yellow-pine chipmunk).

The genus *Eumolpianus* was erected by Smit (1983) to include the distinctive chipmunk fleas of the "*eumolpi* group," genus *Monopsyllus*, of Traub and Johnson (1952) (see also Johnson 1961). The range of the genus *Eumolpianus* is roughly that of its preferred hosts, chipmunks of the genus *Neotamias* in Canada, the western and northern United States and Mexico (Johnson 1961; Haddow *et al.* 1983; Holland 1985). Of the two nominal subspecies, *E. e. eumolpi* occurs in the Pacific Northwest and is one of the most common fleas of Washington east of the Cascade crest. Since the early collection of 1920 in Adams County (Jellison and Senger 1976), it has been reported from the following 11 counties: Asotin, Chelan, Ferry, Grant, Kittitas, Klickitat, Lincoln, Spokane, Stevens, Whitman and Yakima (Hubbard 1943; Miller and Drake 1954; Johnson 1961; Jellison and Senger 1976; Lewis *et al.* 1988). Nonetheless, distribution maps continue to show no records in the moister areas west of the Cascades (Johnson 1961; Haddow *et al.* 1983; Lewis *et al.* 1988).

Malaraeus telchinus (Rothschild, 1905)

South Fork Taneum Creek, 1.6 km west of South Fork Meadows, 47°5'49.08"N, 121°0'37.68"W (1150m), 24 Aug 1995 [AF 13616], 1♂ *ex C. gapperi*. South Cle Elum Ridge, 1.2 km east of USFS road 214 along USFS road 3350, 47°8'20.10"N, 120°58'12.24"W (1172m), 21 Sep 1995 [AF 5504], 1♀ *ex M. longicaudus*.

This is the more commonly collected species of *Malaraeus* in the Pacific Northwest; *M. sinomus* is unknown in Washington. *Malaraeus telchinus* is recorded from Clark, Grant, Klickitat, Lincoln, Skamania, Whitman and Yakima Counties (Hubbard 1947; Jellison and Senger 1976; Lewis *et al.* 1988). *Malaraeus telchinus* is found on a variety of mice and voles in mesic habitats; however, there are no published records from *Clethrionomys* in the State of Washington.

Opisodasys vesperalis (Jordan, 1929)

All *ex G. sabrinus*. South Fork Taneum Creek, 0.8 km west of South Fork Meadows, 47°5'51.96"N, 121°0'6.00"W (1152m), 10 Aug 1995 [AF 5466], 1♀. Same locality but 18 Aug 1995 [AF 13588], 1♀. Same locality but 23 Aug 1995 [AF 35114], 2♀♀. South Fork Taneum Creek, 1.6 km west of South Fork Meadows, 47°5'49.08"N, 121°0'37.68"W (1150m), 23 Aug 1995 [AF 13622], 2♀♀. Same date and locality [AF 13631], 4♂♂, 2♀♀.

Glaucomys sabrinus is the preferred host of this flea in the Pacific Northwest. *Opisodasys vesperalis* is also found on *G. volans* (L.) (southern flying squirrel) in other areas of North America. Sparse collection records in British Columbia (Holland 1985) and Washington (Lewis *et al.*1988) probably reflect the need to examine more *G. sabrinus* and their nests for fleas. It was previously unknown from Kittitas County, being known in the state only from Clallam, Cowlitz and Lincoln Counties (Jellison and Senger 1976; Lewis *et al.* 1988). The presence of *Opisodasys pseudarctomys* (Baker), another true *Glaucomys* flea that is unknown from the state (Haddow *et al.* 1983), may also be established by further collections from *G. sabrinus* or especially their nests.

Orchopeas agilis (Rothschild, 1905)

All *ex Neotoma cinerea* (Ord) (bushy-tailed woodrat). S Fork Taneum Creek, USFS road 135, in abandoned cabin, 47°6'11"N, 120°57'1"W (900m), 25 Sep 1993 [AF 5405], 1♂, 6♀♀. 12 Oct 1993 [AF 5427], 1♂. [AF 5428], 2♂♂, 4♀♀. [AF 5429], 1♂, 1♀.

This parasite of *Neotoma* spp. was originally described as *Ceratophyllus agilis* by Rothschild (1905) from a type series collected from *N. cinerea* in Banff, Alberta and other mammals from other localities in Alberta and British Columbia (Holland 1985). Jordan (1929) reduced this taxon to a subspecies of *C. sexdentatus* (Baker). Jordan (1933) published the genus name *Orchopeas* to replace the preoccupied genus name *Bakerella* Wagner. In his review of the fleas of British Columbia, Wagner (1936) listed this flea as *Orchopeas sexdentatus agilis*.

Recently, Lewis (1998, 2000) reviewed the genus *Orchopeas* Jordan and elevated to species each of the six taxa that had been subspecies of *O. sexdentatus*. Lewis (2000) also noted that *O. agilis* is the member of the *O. sexdentatus* group with the widest distribution, ranging from the Yukon Territory through British Columbia and western Alberta, eastern Washington, Oregon and California, the Basin and Mountain states south into the Mojave Desert in Nevada, Utah and Arizona, and into the Rio Grande watershed of New Mexico (Haddow *et al.* 1983; Holland 1985; Lewis *et al.* 1988).

Orchopeas agilis is known from several *Neotoma* spp., but *N. cinerea* is the only species in Washington and Canada (Cowan and Guiguet 1965; Ingles 1965; Banfield 1974). Locality records of *O. agilis* are especially numerous in southern British Columbia (Holland 1985). In Washington there are records of collections of either *O. sexdentatus* or *O. s. agilis* (both = *O. agilis*) in eight counties: Benton, Douglas, Franklin, Grant, Klickitat, Lincoln, Spokane and Yakima (Hubbard 1940, 1943, 1947; Bacon 1953; O'Farrell 1975; Jellison and Senger 1976; Lewis *et al.* 1988). Our new records of *O. agilis* confirmed Kittitas County.

In a survey of wild animal diseases in five counties in the Columbia Basin, Miller and Drake (1954) found *O. agilis* only on *Peromyscus maniculatus* (Wagner) (deer mouse). Only a small, unspecified number of specimens were collected in one or more unnamed counties. The counties surveyed were Adams, Franklin, Grant, Kittitas and Lincoln.

The nine contiguous counties with records occupy much of the state east of the Cascades. *Orchopeas cascadensis* Jordan, the other member of the *O. sexdentatus* group in Washington, is known only from west of the Cascades in Clark County (Hubbard 1947; Lewis *et al.* 1988; Lewis 2000).

Oropsylla idahoensis (Baker, 1904)

South Fork Taneum Creek, 1.6 km west of South Fork Meadows, 47°5'49.08"N, 121°0'37.68"W (1150m), 16 Aug 1995 [AF 5484], 1♂, 2♀♀ *ex Spermophilus saturatus* (Rhoads) (Cascade golden-mantled ground squirrel).

This is the only flea known to parasitize *S. saturatus*. Early records from this host for Washington are in three counties: Skamania (1935), Yakima (1938) and Klickitat (1939, 1943) (Hubbard 1940, 1943, 1947). Hubbard (1947) also mentioned locality records in Skamania and Yakima Counties without giving collection dates and numbers of specimens. Holland (1949a) recorded early collections from *S. saturatus* in British Columbia: Princeton (1939) and Manning Provincial Park (1945). Holland (1985) gave two additional records for Manning Provincial Park (1953 and 1955). Our new record is in a county that lies on the same longitude (121°) that runs through contiguous Yakima County to the south and Manning Provincial Park to the north.

The wider-ranging Pacific Northwest *Spermophilus* spp. are hosts to other species of fleas in addition to *O. idahoensis* (see Wagner 1936; Jellison 1945; Holland 1985; Lewis *et al.* 1988). The apparent absence of these fleas on *S. saturatus* could be a reflection of less collecting effort, as this ground squirrel has been classified by some authors as a subspecies of *S. lateralis* (Say), a common, wide-ranging western North American ground squirrel. *Spermophilus saturatus* is nowhere sympatric with *S. lateralis*, being restricted to a small range on the eastern slopes of the Cascades in Washington and British Columbia (Cowan and Guiguet 1965; Ingles 1965; Banfield 1974; Tomich 1982; Trombulak 1988).

CONCLUSION

Although no fleas were added to the Washington list, the five new host records suggest that future surveys should include rodents known to host fleas on the lists for British Columbia and Oregon. With only one species of flea known for the rodent *Spermophilus saturatus*, a thorough survey in this mammal's small Washington to British Columbia range is desirable. Mammals other than rodents, such as opossums, shrews, moles, bats, pikas and carnivores deserve more attention as do domestic mammals and birds, wild and domestic. Above all, nests of mammals and birds need to be examined for adult fleas and their poorly known larval stages.

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Use of Japanese-beetle traps to monitor flight of the Pacific coast wireworm, *Limonius canus* (Coleoptera: Elateridae), and effects of trap height and color

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ABSTRACT

Japanese-beetle traps were used to monitor flight of the Pacific coast wireworm, *Limonius canus* LeConte, in an agricultural field in northern Oregon. Overwintered beetles first appeared in traps in mid-March 2000 and 2001, and were collected until mid- to late-May both years. Most (93%) of the females collected at the beginning of the flight period had been inseminated, which may indicate that mating takes place very soon after beetles emerge from the soil. Sex ratios favored males at the beginning of the flight period and favored females at the end of the flight period. Lower temperatures in April 2001 compared to those in 2000 may have caused a delay in timing of the peak catch (relative to timing in 2000) by almost 3 weeks. A count of over eight beetles per trap per 7-day sampling interval was obtained during the week of peak catch in April 2000. Traps were hung at three heights:1.5, 0.9, and 0.3 m above ground. Catch decreased with increasing trap height. Traps that had been painted yellow collected more beetles than traps painted white, which in turn collected more beetles than traps painted red, green, dark blue, or black. Two other elaterids, *Ctenicera pruinina* (Horn) and *Cardiophorus montanus* Bland, were also trapped during the study.

Key words: *Limonius canus*, click beetles, monitoring, flight, trap

INTRODUCTION

The Pacific coast wireworm, *Limonius canus* LeConte (Coleoptera: Elateridae), inhabits irrigated soils of western North America, where it is a pest of grain and vegetable crops (Gibson 1939; Lane and Stone 1960). Like other wireworm species (Stone 1941; Lane and Stone 1960), *L. canus* requires several years to complete its life cycle (Landis and Onsager 1966). The insect overwinters in the soil primarily in the larval stage as a mix of ages. Final-instar larvae pupate in summer, and the pupae eclose into the adult stage in fall and winter. Adults remain in the soil during the winter, emerging the following spring apparently in response to increasing soil temperatures. Life span of the overwintered (post-emergence) adult appears to be no longer than 2 months (Toba 1986).

There is a critical need for research on this and other wireworm pests that could lead to advances in managing these insects (Jansson and Seal 1994). Research into new ways of sampling populations is needed, to allow studies of population biology and to assist growers in making management decisions (Jansson and Seal 1994). Much of the previous research done on sampling these insects has concentrated on the larval stage (e.g., Onsager 1975; Toba and Turner 1983; Williams *et al.* 1992). Considerably less study has focused on the adult click beetle, despite the fact that the adult stage is responsible for spreading wireworm infestations (Boiteau *et al.* 2000).

This study tests whether traps that were developed to monitor Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabaeidae), might be used to sample adult *L. canus*.

Japanese-beetle traps have several advantages over other traps used to sample click beetles (including sticky traps, window interception traps, and water pan traps), in that they are simple to set out in the field, are easily monitored, and require no adhesive materials such as tanglefoot to trap the insect. We used these traps to document the flight period of male and female *L. canus* in an agricultural field located in north-central Oregon, and determined if seasonal trends in trap catch were associated with air temperature. Second, traps were placed at different heights to learn if catch depended upon height of the traps above ground, as shown for other Elateridae (Boiteau *et al.* 2000). Third, we compared traps of different colors to monitor their effectiveness. Finally, we dissected female beetles trapped on one date at the beginning of the female flight period to determine if they were mated. Other wireworm species mate very soon after emergence from the soil in spring (Stone 1941; Zacharuk 1962), but it is not known whether *L. canus* exhibits similar behavior.

MATERIALS AND METHODS

All studies were conducted between March and May, 2000 and 2001 at the Agricultural Research and Extension Center, Oregon State University, Hermiston, Oregon. Yellow, four-vaned Japanese-beetle traps (Trécé, Salinas, CA) were hung on metal poles in a fallow field adjacent to a circle of irrigated wheat. The same location was used both years of the study. Ten poles were set out in a line at spacings of approximately 20 m. Three traps at different heights were hung on each pole: 1.5 m, 0.9 m, and 0.3 m above ground. Vegetation in the surrounding field and immediately beneath the traps was cut by a mower or by hand to prevent plants from obscuring the lowest traps. Clear glass jars were used as the collecting reservoirs beneath the traps. Jars were emptied every 7 d between March and May. Click beetles were counted, identified, and categorized to sex. Air temperature data were obtained from a weather station located at the study site and maintained by Experiment Station personnel.

Trap catch data were compared among trap heights using analysis of variance, with each pole being considered a block. To determine if trap catch increased or decreased as a linear or curvilinear function of height, linear and quadratic contrasts were extracted in each analysis.

A second study was done to determine the effects of trap color on catch. The visible surfaces of yellow Japanese-beetle traps were painted with one of six colors (Krylon High Gloss paints, Sherwin-Williams, Cleveland, OH): Sun Yellow Gloss, Glossy White, Emerald Green, Banner Red, Gloss Black, and True Blue Gloss. Traps were hung at 0.3 m above ground on fence lines at the Hermiston Experiment Station during the same time interval as the height tests. In 2000, traps were placed at the northern edge of the station adjacent to plots of wheat and potatoes. Catch of *L. canus* was small here, so in 2001 the traps were moved 200-500 m to the south, where they were hung 0.3 m above ground on fence lines adjacent to an irrigated circle of wheat. Six traps of each color were set out in a randomized complete-block design with six replicates. Adjacent traps within a block were approximately 5 m apart. Adjacent blocks were separated by at least 20 m. Traps were emptied weekly, and click beetles were counted, identified, and sexed. Data were analyzed using analysis of variance followed by an LSD-test to separate treatments (trap colors).

To determine whether the first female *L. canus* collected in traps in 2001 had been inseminated, we dissected beetles that had been collected on 1 May during the height test. On 24 April, 2001, water was added to each collecting jar on each trap to prevent beetles from mating while in the jar. Water was used rather than a preservative to avoid the possibility that odors from the preservative might affect trap catch. The collecting jars received water from rainfall at irregular intervals over the course of the studies, so the presence of water in the jars was not something unusual. Jars were collected 1 week later and samples were taken to the laboratory. Female *L. canus* were dissected in alcohol to remove the internal reproductive organs, using the drawings of Becker (1958) and Zacharuk (1958) as visual reference. The spermatophoral receptacle (Zacharuk 1958) was then examined under a dissecting microscope to determine whether a spermatophore was present. If no spermatophore was found, the internal organs were teased apart with dissecting needles, crushed on the microscope slide, and examined for sperm using a compound microscope at 100-400x (in other Elateridae absence of a spermatophore does not indicate lack of mating, as the spermatophore is slowly broken down in the female; Zacharuk 1958). Decomposed beetles were not dissected.

Voucher specimens have been deposited with the M.T. James Entomology Museum, Washington State University, Pullman.

RESULTS

The largest weekly catch of *L. canus* in the height test was about three-fold higher in 2000 than 2001 (Fig. 1). Beetles began showing up in traps in mid- to late-March apparently in response to warming temperatures (Fig. 1). We captured beetles well into May both years. The peak in captures occurred almost 3 weeks later in 2001 (1 May sample) than in 2000 (12 April sample). Moreover, the peak catch contained a much larger percentage of females in 2001 than 2000 (see below). Lower temperatures in late March and early April 2001 relative to conditions in 2000 may have caused reduced levels of flight activity in 2001 compared to levels over the same time interval in 2000 (Fig. 1).

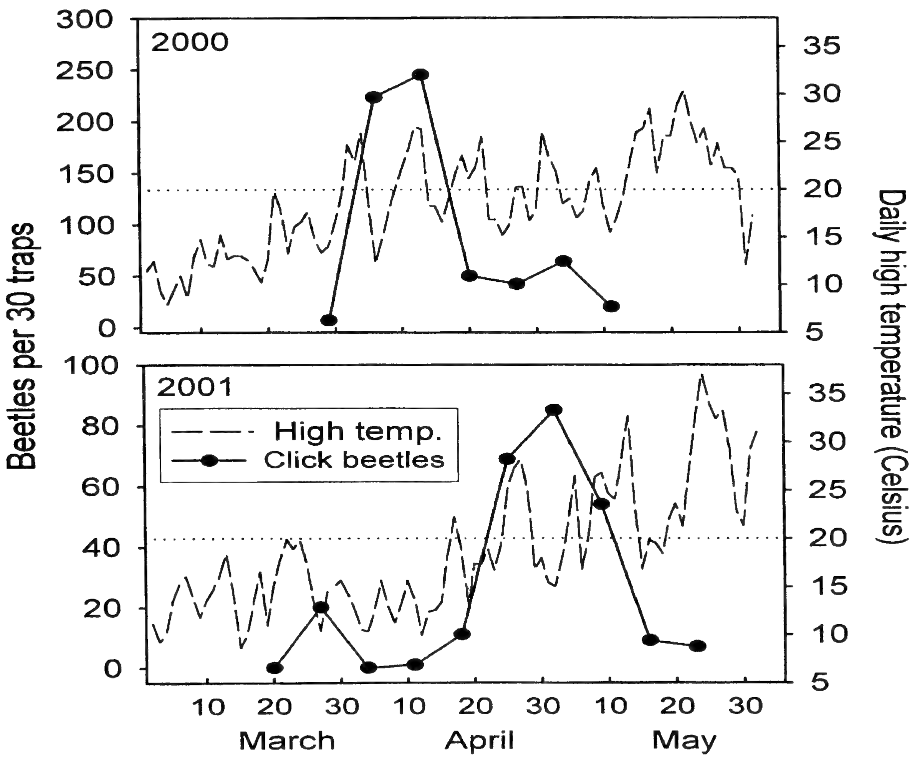

Figure 1. Numbers of *L. canus* collected in 30 traps (10 poles x 3 traps per pole) per week (solid lines) and daily high air temperatures (dashed lines); Hermiston Agricultural Research and Extension Center, Hermiston, Oregon. Horizontal dotted line at 20° C included in each panel to provide perspective.

Males predominated in the March and April samples, whereas females were more abundant than males in samples obtained in May (Figs. 2-3). Samples obtained during peak flight had a much higher proportion of males in 2000 (88.6% male [217/245 beetles]; 12 April sample) than in 2001 (50.6% male [43/85 beetles]; 1 May sample). Total numbers of male beetles collected over the sampling period was larger in 2000 than in 2001 ($\bar{x} = 50.4$ beetles per three traps in 2000 vs 15.6 beetles per three traps in 2001; $F = 131.5$, df= 1,18, $P < 0.001$; numbers pooled for the three traps on the same pole and summed across dates). Totals for females were similar between years ($\bar{x} = 14.7$ beetles per three traps in 2000 vs 10.1 beetles per three traps in 2001; $F = 3.2$, df= 1,18, $P = 0.09$). In both years, numbers decreased with increasing height of the trap (Figs. 2-3).

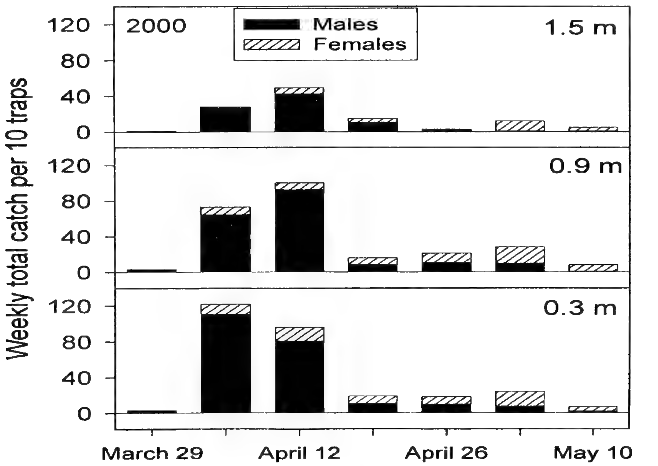

Figure 2. Weekly total catch of *L. canus* per 10 traps at each of three heights; 2000 data. Mean number of beetles per trap (sexes combined; summed over 7-week sampling period): 28.9 (0.3 meters), 24.9 (0.9 meters), and 11.3 (1.5 meters); $F = 29.2$; df = 2,18; $P < 0.001$ (contrasts: linear effects of height, $P < 0.001$; quadratic effects of height, $P = 0.03$).

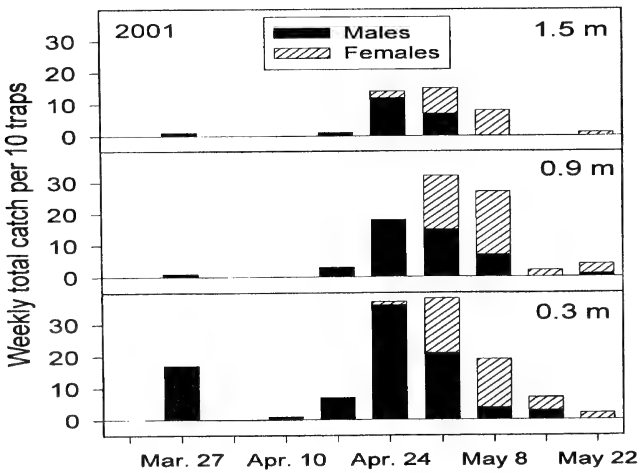

Figure 3. Weekly total catch of *L. canus* per 10 traps at each of three heights; 2001 data. Mean number of beetles per trap (sexes combined; summed over 10-week sampling period): 13.0 (0.3 meters), 8.7 (0.9 meters), and 4.0 (1.5 meters); $F = 16.6$; df = 2,18; $P < 0.001$ (contrasts: linear effects of height, $P < 0.001$; quadratic effects of height, $P = 0.88$).

Click beetles other than *L. canus* collected in the traps included *Ctenicera pruinina* (Horn), *Cardiophorus montanus* Bland, and unidentified *Dalopius* and *Melanotus* (Table 1). Of these, *C. pruinina* (Great Basin Wireworm) is a known pest of vegetable and grain crops in the Pacific northwest. Most of the beetles were collected in the lower and middle traps, as with *L. canus*. Sex ratios were male-biased (Table 1).

Few *L. canus* were collected in the 7-week test of trap color done in 2000 (Table 2). The traps were moved to a different area of the station in 2001 with better results. In 2001 (10 weeks), traps that had been painted yellow caught significantly more *L. canus* than white traps (Table 2), and either color caught more beetles than the blue, green, red, or black traps. Samples had male-biased sex ratios in all trap colors (Table 2). Other species collected included *C. pruinina* and *C. montanus*.

Thirty-nine female *L. canus* were dissected from the 1 May, 2001 samples in the height test. Of these females, 14 contained a spermatophore, 22 contained sperm but no spermatophore, and in 3 females we failed to find either a spermatophore or sperm.

Table 1

Click beetles other than *L. canus* collected in Japanese-beetle traps during height test (summed over sampling dates); M - males, F - females.

	1.5 meters		0.9 meters		0.3 meters	
	M	F	M	F	M	F
29 March - 10 May 2000						
Ctenicera pruinina (Horn)	1	0	1	0	5	0
Cardiophorus montanus Bland	0	1	7	2	7	3
Dalopius sp.	1	0	1	0	3	1
27 March - 22 May 2001						
Ctenicera pruinina	1	0	6	0	2	0
Cardiophorus montanus	1	0	5	0	10	4
Melanotus sp.	0	0	0	1	0	0

Table 2

Click beetles collected in Japanese-beetle traps of different colors. Numbers are totals for the 7-week (2000) or 10-week (2001) sampling periods. M - males, F - females. Six traps per color. Analysis of variance for the 2001 *L. canus* data (summing data for sexes) showed significant differences among colors ($F = 13.9$; df = 5,25; $P < 0.001$). An LSD-test showed significantly ($P < 0.05$) higher catches in yellow traps than in white traps, which in turn had significantly more beetles than green, black, blue, or red traps.

	Yellow		White		Green		Black		Blue		Red	
	M	F	M	F	M	F	M	F	M	F	M	F
29 March - 10 May 2000												
Limonius canus	5	1	4	0	3	0	2	0	1	0	1	0
Ctenicera pruinina	0	0	0	0	1	0	0	0	3	0	0	0
Cardiophorus montanus	5	1	2	1	2	1	4	1	5	1	0	0
27 March - 22 May 2001												
Limonius canus	43	12	24	11	14	3	13	4	11	5	9	5
Ctenicera pruinina	0	0	0	0	4	0	1	0	0	0	1	0
Cardiophorus montanus	1	0	0	0	1	0	0	1	0	1	0	0

DISCUSSION

There is a need for both basic and applied research on the Elateridae to improve our understanding of these insects but also to provide the knowledge necessary to develop more effective management programs for the pest species (Jansson and Seal 1994). In many pest Elateridae, the larval stage has received considerably more study than the adult stage (Boiteau *et al.* 2000). This bias may reflect the difference in longevity between larvae and adults, and also the fact that adult click beetles do little damage. Thus, for many pest Elateridae, we still lack basic information about the biology of adults, including details about phenology, mating behavior and sex pheromones, fecundity, egglaying, feeding habits, and dispersal.

Several of these research topics, particularly phenology and dispersal, require having tools that can be used in the field to monitor movements by the adult beetle. A variety of techniques have been used to monitor flying click beetles, such as sweep nets (Shirck 1942), water pan traps (Iwanaga and Kawamura 2000), window interception traps (Boiteau *et al.* 2000), sticky traps (Furlan 1996), and funnel-vane traps (Iwanaga and Kawamura 2000). For species that spend most or all of their adult lives on or near the ground, adult beetles have been trapped using mats of cut vegetation (Gough and Evans 1942; Roebuck *et al.* 1947) and pitfall traps (Doane 1963). These different sampling methods have been used to determine direction of flight (Lafrance 1963), dispersal distances (Doane 1963), phenology (Lafrance 1963), reproductive status of females (Shirck 1939), and response to chemical attractants (Iwanaga and Kawamura 2000).

We tested whether traps that were designed to monitor Japanese beetles could be used to monitor flight of *L. canus* and other Elateridae. Japanese-beetle traps are commonly used to monitor flight activity of Coleoptera other than the Japanese beetle, particularly other Scarabaeidae (Crocker *et al.* 1999). Metzger and Sim (1933) listed species and numbers of Elateridae that were caught in Japanese-beetle traps placed in an area of New Jersey, and showed that large numbers of a species of *Melanotus* were collected in the traps. The Elateridae that we collected were composed mostly of *L. canus*, but we also collected small numbers of other species. The low numbers of these other species were probably due to low densities in the study area rather than to trap inefficiency. That is, larval collections made at the station over the last several years have been mostly *L. canus* (unpubl.).

Limonius canus adults were active between mid-March and mid- to late-May (Fig. 1). Emergence of the adults in March was probably in response to warming soil temperatures, as suggested for other Elateridae (Lafrance 1963). Flight appears also to have been affected by temperature, because trap catch dropped substantially in late March and early April 2001 coinciding with 2 weeks of maximum air temperatures below 20° C (Fig. 1). Shirck (1939) stated that cool conditions prevented flight by a closely related species, the sugarbeet wireworm (*Limonius californicus* (Mannerheim)), and Doane (1961) showed that numbers of *Ctenicera destructor* (Brown) captured in funnel traps dropped in cool weather. Because of the cooler temperatures in 2001, the peak catch of *L. canus* occurred almost 3 weeks later in 2001 than 2000 (Fig. 1). Also, total trap catch over the duration of the study was lower in 2001 than 2000, largely because of the reduced flight activity of male *L. canus* during April 2001. The sex ratios (Figs. 2-3) show either that males emerged earlier in spring than females, or that males were more likely than females to engage in flight during March and early April. Others have shown that male Elateridae emerge in spring before females (Stone 1941; Shirck 1942; Zacharuk 1962). Male *Limonius agonus* (Say) emerge 1 to 3 days earlier than females (Begg 1962). Seasonal totals of beetles in the height test were composed of relatively more males in 2000 (77.4% of beetles) than in 2001 (60.8%), probably due to the reduced catch of males in April 2001 associated with cooler temperatures.

Efficient use of Japanese beetle traps to monitor *L. canus* requires information about the roles of trap color and placement in affecting catch. Although based upon relatively small numbers of beetles, traps that had been painted yellow collected significantly more *L. canus* than traps painted white, which in turn collected significantly more beetles than traps painted green, red, dark blue, or black. These results are similar to those of Furlan (1996), who showed that yellow or white sticky traps collected more click beetles (*Agriotes ustulatus* Schäller) than red, black, or green traps. Other phytophagous Coleoptera show a preference for yellow over other colors (Fleming *et al.* 1940; Cross *et al.* 1976). We also showed that more *L. canus* were collected in traps set at 0.3 m and 0.9 m than at 1.5 m above ground (Figs. 2-3). Boiteau *et al.* (2000) used interception traps to collect over 40 species of Elateridae, and noted that trap catch decreased with increasing height of the traps. The exact relationship between trap height and trap catch varied with species. Furlan (1996) showed that sticky traps placed just above the tops of vegetation collected more *A. ustulatus* than traps at higher elevations.

Lastly, almost all of the females collected at the beginning of their flight period had been mated (at least 36 of the 39 females that were dissected contained sperm or a spermatophore). *Limonius canus* evidently mates soon after emergence in spring, as noted for the congeneric *L. californicus* (Stone 1935, 1941). Click beetles in other genera also mate soon after emergence from the soil (Cohen 1942; Zacharuk 1962). In *C. destructor*, the female may be mated while still below the soil surface (Zacharuk 1962). However, because we do not know the age of the females that were trapped in this study (i.e., we have no data on emergence), and because we do not know the amount of time between the day that a female was mated and the day that she was trapped, we cannot say when, following emergence from the soil, mating occurred. Begg (1962) showed that female *Limonius agonus* was most dispersive relatively late in the oviposition period, and it may be that *L. canus* has a similar life history. If so, the female beetles that we collected may have been mated long before being trapped.

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Qualitative analyses of larval oral exudate from eastern and western spruce budworms (Lepidoptera: Tortricidae)

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ABSTRACT

A two-choice feeding bioassay was used to investigate the effects of dilution, centrifugation, storage and autoclaving on the repellency of the oral exudate of eastern and western spruce budworms, *Choristoneura fumiferana* (Clem.) and *C. occidentalis* Free., to their respective conspecifics. The exudate from insects reared on either artificial diet or foliage was active at a volume equal to the amount emitted by one larva when disturbed with a pipet in the laboratory, but repellency was lost at lower doses. Centrifugation did not partition the exudate into active and inactive fractions. Exudate from both diet- and foliage-reared insects was active for at least 48 h at room temperature. However, after being frozen for one month, exudate from diet-reared insects was still active, while that from foliage-reared insects was not.

Key words: *Choristoneura fumiferana*, *Choristoneura occidentalis*, spruce budworm, oral exudate, regurgitant, epideictic pheromone

INTRODUCTION

Many insects release oral secretions when they are disturbed or handled (Davies and McCauley 1970, Corbet 1971, Eisner *et al.* 1974). While these secretions may serve to protect the emitters from predators and parasitoids (Eisner *et al.* 1974), they may also be used as epideictic pheromones (Prokopy 1981), to repel competing individuals from potentially overcrowded resources (Corbet 1971). Larvae of the spruce budworm and the western spruce budworm, *Choristoneura fumiferana* (Clem.) and *C. occidentalis* Free., respectively, have been shown to produce an oral exudate that repels conspecifics (Poirier and Borden 1995). In two-choice feeding bioassays, larvae of both species avoided feeding stations that had been treated with conspecific exudate (Poirier and Borden 1996). Larvae of both species responded to con- and heterospecific oral exudate in the same manner, as did laboratory-reared and wild-caught larvae. Larvae reared on artificial diet responded to exudate from both diet- and foliage-reared larvae, whereas foliage-reared larvae responded only to exudate from other foliage-reared larvae (Poirier and Borden 2000).

When the bioactive components are known, it may prove possible to exploit the activity of the oral exudate in the management of spruce budworms. Isolation and identification of the active components (Brand *et al.* 1979) can be facilitated by an understanding of the properties of the exudate. We investigated the threshold concentration for repellency, whether or not the active components are carried in the exudate in suspension or solution, the thermostability of the repellent, its persistence under bioassay conditions, and the duration the exudate may be stored without losing its bioactivity.

METHODS

Insects. Laboratory-reared insects of both species were obtained as eggs or diapausing second instars from the Canadian Forest Service, Sault Ste. Marie, Ontario, from colonies maintained under laboratory conditions for many years at high population densities. Wild *C. occidentalis* larvae were collected in June 1994 near Kamloops, BC by L.M.P.

All insects were reared in the laboratory at approximately 24°C, 60% RH, and a photoperiodic regime of 16L:8D. Diet-fed larvae of both species were reared on an agar-based artificial spruce budworm diet (Bio-Serv Inc., Frenchtown, New Jersey) in 30 ml disposable vials. Two larvae were kept in each vial. Foliage-fed *C. occidentalis* larvae were reared on potted 3-year-old Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco.

Bioassay. Each experiment (Exp.) employed a two-choice, diet-station bioassay, modified from Poirier and Borden (1996) to preclude any interaction between organic solvents and the diet stations, if such solvents were to be used during chemical procedures. Circular glass cover slips (18 mm diam.) were attached to the ceiling of the petri dish bioassay chambers using chloroform, so that diet stations on the cover slips had their centers 3 cm apart. Exudate or water treatments (2 μl) were applied to the glass in a ring around the outer edge of one cover slip; third- to fifth- instar larvae produce an average of 2 μl of oral exudate when disturbed with a pipet in the laboratory (Poirier and Borden 1996). The other cover slip was left untreated. A drop of molten artificial diet was then applied to the center of each cover slip within, but not contacting, the exudate treatment ring. Separate dishes, with one station treated with 2 μl of distilled water, served as controls. A conspecific third- to fifth-instar larva, randomized with respect to age, was then placed in the center of the bottom of each petri dish chamber, and left undisturbed for 24 h under the above rearing conditions. These test larvae were taken from the same food source as the larvae that provided the exudate. At the end of 24 h, the stations were checked for signs of feeding or establishment, such as feeding cavities or silk feeding tunnels. Larvae that did not establish on a feeding station were included in the sample, unless they had molted or pupated over the 24 h test period. Earlier studies by Poirier and Borden (1996, 2000) showed that non-feeding larvae provide important information about the degree of repellency of various treatments. Larvae were thus categorized as not feeding, feeding on the untreated station, or feeding on the treated station.

For each experiment, the numbers of larvae in the three categories were compared between experimental and control dishes using Fisher's Exact Test for a 2 X 3 contingency table, $\alpha = 0.05$ (Steel and Torrie 1980, Mehta and Patel 1983; Schlotzhauer and Littell 1987). Possible variation due to larval age was not taken into account.

Threshold for Bioactivity. Exp. 1 used third- to fifth-instar diet-reared *C. fumiferana*. Exp. 2 used third- to fifth-instar wild-collected *C. occidentalis*, reared on foliage. Exudate was collected by drawing it into a 5 μl micropipet after touching a larva with the pipet. The exudate from several larvae was pooled in a glass vial kept on ice. The exudate was then diluted 10-, 100- and 1000-fold by serial dilution in distilled water. One station in each bioassay dish was treated with 2 μl of distilled water (control dishes), 2 μl of undiluted exudate or 2 μl of one of the three exudate dilutions. Twenty dishes were prepared for each of the five treatments. An uninduced test larva, *i.e.* a larva that had not been induced to produce exudate, was placed in each dish, and left undisturbed for 24 h.

Solubility. Exp. 3 used third- to fifth-instar diet-reared *C. occidentalis* larvae, from the laboratory colony. Exp. 4 used third- to fifth-instar wild-collected *C. occidentalis*, reared on foliage. For both experiments, exudate was collected from larvae using a 5 µl micropipet, and pooled in three Eppendorf tubes kept on ice. Two tubes were centrifuged at 13,000 rpm for 5 min in a Micro-Centaur benchtop Eppendorf centrifuge. The supernatant was drawn off one tube with an Eppendorf Pipetman automatic pipet and retained, and distilled water was added to the pellet fraction to bring it back to the pre-centrifugation volume. In the second tube, the pellet was resuspended in the supernatant with an automatic pipet. The third tube was left untreated. One station in each bioassay dish was treated with 2 µl of either distilled water (control dishes), whole exudate, supernatant, pellet suspension, or centrifuged and then reconstituted exudate. Forty dishes (replicates) were prepared for each of the five treatments. An uninduced test larva was placed in each dish, and left undisturbed for 24 h.

Storage Duration. Exp. 5 used third- to fifth-instar diet-reared *C. fumiferana.* Exp. 6 used third- to fifth-instar wild-collected *C. occidentalis* larvae, reared on foliage. On three consecutive days, exudate was collected from larvae using a 5 µl micropipet, and pooled in a glass vial kept on ice until the exudate was applied to the feeding stations. One feeding station in each dish was treated with 2 µl of either distilled water or exudate. Test larvae were introduced to the exudate-treated dishes. Exudate was added to the exudate-treated dishes 0, 24 or 48 h prior to the introduction of test larvae. The water-treated control dishes were tested immediately (0 h delay). The treatments were staggered so that larvae were added to all dishes on the same day. The dishes for 24 and 48 h delayed testing were held under the above rearing conditions until larvae were added. Twenty dishes (replicates) were prepared for each of the four treatments in each experiment. An uninduced test larva was placed in each dish, and left undisturbed for 24 h.

In Exp. 7, third- to fifth-instar, diet-reared *C. fumiferana* larvae were used. Exudate was collected from larvae using a 5 µl micropipet, and pooled in glass vials kept on ice. One vial was used immediately. The other vials were stored at approximately -4°C for one week or one month. One feeding station in each dish was treated with 2 µl of either distilled water (control dishes), fresh exudate, week-old exudate, or month-old exudate. Twenty dishes were prepared for each of the four treatments. An uninduced test larva was placed in each dish, and left undisturbed for 24 h.

Thermal Stability. All insects used in Exp. 8 were third- to fifth-instar diet-reared *C. occidentalis* larvae from the laboratory colony. Oral exudate was collected from larvae using a 5 µl micropipet, and pooled. Half the exudate was autoclaved for 15 min at 15 kPa and 122°C. One feeding station in each dish was treated with 2 µl of distilled water (control dishes), 2 µl of fresh exudate, or 2 µl of autoclaved exudate. Twenty dishes (replicates) were prepared for each of the three treatments. An uninduced test larva was placed in each dish, and left undisturbed for 24 h.

RESULTS

The results of all eight experiments are given in Table 1.

Threshold for Bioactivity. When the exudate was diluted by any of the three dilution rates, the numbers of larvae in the three response categories were not significantly different between experimental and control dishes in either experiment (Exp. 1, 2). Only larvae in dishes treated with undiluted exudate were significantly deterred from feeding on the treated station, with most larvae establishing on the untreated feeding station. Results were similar for *C. fumiferana* reared on artificial diet (Exp. 1) and *C. occidentalis* reared on foliage (Exp. 2).

Solubility. In Exp. 3, diet-fed larvae were significantly deterred from feeding only on diet stations treated with whole or reconstituted exudate. There was no difference between

Table 1

Feeding responses by *Choristoneura fumiferana* or *C. occidentalis* larvae to treated or untreated diet stations in eight experiments testing the potency, solubility, longevity and stability of larval oral exudate.

Experiment and Treatments	n	Number of larvae			*P* value (Fisher's Exact Test)
		Not feeding	Feeding on untreated station	Feeding on treated station	
Experiment 1,*C. fumiferana*, threshold for bioactivity, test larvae diet-reared					
Control: distilled water *vs.* untreated	19	2	9	8	
Diet-reared exudate *vs.* untreated	17	3	11	3	0.043
Diet-reared exudate, 0.1X *vs.* untreated	20	2	11	7	0.897
Diet-reared exudate, 0.01X *vs.* untreated	18	0	8	10	0.513
Diet-reared exudate, 0.001X *vs.* untreated	18	1	10	7	1.00
Experiment 2, *C. occidentalis*, threshold for bioactivity, test larvae foliage-reared					
Control: distilled water *vs* untreated	20	2	8	10	
Diet-reared exudate *vs.* untreated	20	1	16	3	0.032
Diet-reared exudate, 0.1X *vs.* untreated	19	2	8	9	1.00
Diet-reared exudate, 0.01X *vs.* untreated	20	1	10	9	0.805
Experiment 3, *C. occidentalis*, solubility, test larvae diet-reared					
Control: distilled water *vs.* untreated	19	0	9	10	
Diet-reared exudate *vs.* untreated	33	2	24	7	0.043
Diet-reared exudate supernatant *vs.* untreated	34	5	14	15	0.280
Diet-reared exudate pellet *vs.* untreated	35	4	20	11	0.183
Reconstituted diet-reared exudate *vs.* untreated	33	2	24	7	0.043

Experiment and Treatments	n	Number of larvae			*P* value (Fisher's Exact Test)
		Not feeding	Feeding on untreated station	Feeding on treated station	
Experiment 4, *C. occidentalis*, solubility, test larvae foliage-reared					
Control: distilled water *vs.* untreated	24	1	12	11	
Foliage-reared exudate *vs.* untreated	36	0	30	6	0.011
Foliage-reared exudate supernatant *vs.* untreated	40	0	32	8	0.017
Foliage-reared exudate pellet *vs.* untreated	33	0	27	6	0.026
Reconstituted foliage-reared exudate *vs.* untreated	23	1	19	3	0.030
Experiment 5, *C. fumiferana*, storage duration, test larvae diet-reared					
Control: distilled water *vs.* untreated	19	1	10	8	
Diet-reared exudate, 0 h old *vs.* untreated	18	1	12	5	0.019
Diet-reared exudate, 24 h old *vs.* untreated	20	1	15	4	0.036
Diet-reared exudate, 48 h old *vs.* untreated	19	1	15	3	0.019
Experiment 6, *C. occidentalis*, storage duration, test larvae foliage-reared					
Control: distilled water *vs.* untreated	17	0	8	9	
Foliage-reared exudate, 0 h old *vs.* untreated	18	3	13	2	0.010
Foliage-reared exudate, 24 h old *vs.* untreated	19	1	13	5	0.033
Foliage-reared exudate, 48 h old *vs.* untreated	17	3	6	8	0.284

Experiment and Treatments	n	Number of larvae			*P* value (Fisher's Exact Test)
		Not feeding	Feeding on untreated station	Feeding on treated station	
Experiment 7, *C. fumiferana*, storage duration, test larvae diet-reared					
Control: distilled water *vs.* untreated	19	2	9	8	
Fresh diet-reared exudate *vs.* untreated	19	1	15	3	0.011
1 week old diet-reared exudate *vs.* untreated	17	3	11	3	0.043
1 month old diet-reared exudate *vs.* untreated	18	2	9	7	1.00
Experiment 8, *C. occidentalis*, thermal stability, test larvae: diet-reared					
Control: distilled water *vs.* untreated	20	1	10	9	
Fresh diet-reared exudate *vs.* untreated	19	5	12	2	0.035
Autoclaved diet-reared exudate *vs.* untreated	20	3	10	7	0.604

control dishes and dishes treated with supernatant or the pellet resuspension. However, in Exp. 4, the numbers of foliage-fed larvae in the three response categories were significantly different from the control dishes in all treatments.

Storage Duration. In Exp. 5, more diet-reared larvae fed on the untreated than exudate-treated station for all delay times, demonstrating persistent bioactivity of exudate from diet-reared larvae for at least 48 h under laboratory conditions. However, in Exp. 6, the bioactivity of exudate from foliage-reared larvae persisted for >24 h, but <48 h. When the exudate from diet-reared larvae was frozen at -4°C, bioactivity persisted for at least a week, but less than one month (Exp. 7).

Thermal Stability. The numbers of larvae in the three response categories were significantly different from the control dishes in the fresh exudate treatment only (Exp. 8), indicating that autoclaving for 15 min destroyed all deterrent activity.

DISCUSSION

Poirier and Borden (1995) showed that each larva of *C. fumiferana* and *C. occidentalis* produced about 2 µl of oral exudate per induction. The results of Exp. 1 and 2 show clearly that application of one larval equivalent of exudate is necessary to elicit a response from test larvae in the laboratory bioassay. Because this biologically realistic dose is necessary for bioassays, it is probable that large amounts of starting material will be needed for chemical fractionation, bioassay and analysis (Brand *et al.* 1979), if the active constituents in the exudate are to be identified.

The results from Exp. 3 and 4 were not conclusive. Centrifugation did not destroy the bioactivity of exudate from either diet- or foliage-reared larvae, since reconstituted exudate was as deterrent as whole exudate. Exudate from diet-reared insects may have had some of the repellent components carried as a suspension, but the particulate matter alone was not repellent. Exudate from foliage-reared insects appeared to have the repellent components equally distributed between the pellet and the supernatant, with both fractions being as repellent as whole exudate. It is possible that the centrifugation used was not sufficient to separate the materials in the exudate, and that better results might have been achieved by using higher centrifugation speeds or a longer duration. However, since the exudate apparently consists of a partially digested substrate (Poirier 1995), it is also possible that a portion of the repellent component is still associated with the particulate matter suspended in the exudate, while the remainder is free in solution. Diet-reared larvae may produce lower concentrations of repellent than foliage-reared insects or may lack an independently repellent component that is present in the regurgitate of foliage-reared larvae (Poirier and Borden 2000). In either case, for diet-reared larvae, dividing the exudate between two fractions could reduce the concentration in one or both fractions below the response threshold.

Exp. 5, 6 and 7 indicate that exudate from both diet- and foliage-reared larvae deteriorates over time, although the breakdown appears to be faster in the latter case. While this deterioration may be mediated by microbial activity, it seems likely that the repellent components will also be subject to the action of larval enzymes contained in the regurgitant. The retention of residual foliar enzymes in the regurgitant could account for the shorter longevity of repellency in the regurgitant of foliage-reared larvae than in that of diet-reared larvae. It is possible to store the exudate at -4°C for at least a week, but storage at a lower temperature may increase longevity by halting further enzymatic activity.

Autoclaving appears to destroy the bioactivity of the exudate from diet-reared larvae (Exp. 8). Because a number of materials may be significantly altered by high temperatures, this result does little to indicate the type of compound involved in the repellency. However, the bioactive material may prove to be unstable in certain laboratory procedures, *e.g.* gas chromatography, that involve heat.

These experiments provide considerable insight into the nature of the bioactive constituent(s) in the larval oral exudate of these two *Choristoneura* spp. It persists for up to 48 h at room temperature, and survives storage when frozen at -4°C for at least one week. However, it is thermally unstable under pressure at 122°C. When centrifuged, the bioactive component(s) from foliage-reared larvae does not partition completely, suggesting that some fraction remains associated with the particulate matter in the exudate, while some is in solution. Lastly, below a biologically realistic concentration of one larval equivalent, bioactivity is lost. Because diet can influence bioactivity (Poirier and Borden 2000), and because the components of the artificial diet are known, modification of this diet could potentially provide further insight into the nature of the bioactive component(s).

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Verbenone interrupts the response to aggregation pheromone in the northern spruce engraver, *Ips perturbatus* (Coleoptera: Scolytidae), in south-central and interior Alaska

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ABSTRACT

Field tests of verbenone, a potential antiaggregation pheromone of the northern spruce engraver, *Ips perturbatus* (Eichhoff), were conducted in south-central and interior Alaska in stands of Lutz spruce, *Picea* x*lutzii* (Little), and white spruce, *P. glauca* (Moench) Voss, respectively. Addition of 84%-(–)-verbenone at a high release rate to the three-component aggregation pheromone of *I. perturbatus* (racemic ipsenol, racemic ipsdienol, and 83%-(-)-*cis*-verbenol), significantly reduced trap catches. The results of this study, combined with previous results on the presence of verbenone in extracts of volatiles collected from feeding *I. perturbatus* and GC-EAD data, are consistent with antiaggregant behavioral activity of verbenone for *I. perturbatus*.

Key words: Bark beetles, *Ips perturbatus*, semiochemicals, pheromones, antiaggregation pheromones, verbenone, white spruce, *Picea glauca*, Lutz spruce, *Picea* x*lutzii*, Alaska

INTRODUCTION

The northern spruce engraver, *Ips perturbatus* (Eichhoff) (Coleoptera: Scolytidae), is distributed transcontinentally in the boreal region of North America, generally following the distribution of white spruce, *Picea glauca* (Moench) Voss (Bright 1976; Wood 1982; Robertson 2000). In Alaska it colonizes standing white spruce and Lutz spruce, *Picea* x*lutzii* Little, that are stressed by natural disturbances such as drought, flooding, wind, ice, and snow damage. Human activities such as logging and right-of-way clearance also provide significant amounts of potential host material (Holsten and Werner 1987; Holsten 1996, 1997, 1998). Normally, endemic populations may infest individual standing spruce trees, but during warm, dry summers following mild winters, engraver beetle populations can increase significantly and kill groups of standing spruce trees. Historically, only limited tree mortality has been caused by this beetle in Lutz spruce forests in south-central Alaska. However, damage caused by *I. perturbatus* and other *Ips* spp. may assume greater economic importance as more habitat is provided through climate change and human activities (Robertson 2000). For example, in 1996 more than 47% of the residual spruce in a thinned area near Granite Creek in south-central Alaska became infested with *I. perturbatus* and *I. tridens* (Mannerheim). Spring drought conditions as well as the recent overall "warming" of the Kenai Peninsula apparently led to this rapid increase in *Ips* activity in 1996 (Anon. 1999; Holsten 1996, 1997, 1998).

Increased tree mortality in Alaska caused by *Ips* spp. has stimulated research on new management tactics utilizing semiochemicals. From 1977 through 1992, field tests of the efficacy of various bark beetle semiochemicals showed that ipsdienol (2-methyl-6-methylene-2,7-octadien-4-ol) and 2-methyl-3-buten-2-ol were generally attractive to *I. perturbatus*. Ipsenol (2-methyl-6-methylene-7-octen-4-ol), 3-methylcyclohex-2-enone, and verbenone (4,6,6-trimethylbicyclo[3.1.1]hept-3-en-2-one) were found to be generally inhibitory (Werner 1993). Seybold and co-workers found that *I. perturbatus* produce >99%-(-)-ipsenol, ~90%-(+)-ipsdienol, and *cis*-verbenol (unpublished data), while Holsten *et al.* (2000) found that a combination of racemic ipsenol, racemic ipsdienol, and 83%-(–)-*cis*-verbenol[1] was attractive to *I. perturbatus* in field assays.

The presence of verbenone in an extract of volatiles trapped from the headspace above male and female *I. perturbatus* feeding on *P. xlutzii*, and verbenone's activity in coupled gas chromatographic-electroantennographic detection (GC-EAD) assays suggest that verbenone may be behaviorally active for *I. perturbatus*. Verbenone collected from the volatile headspace above feeding male and female *I. perturbatus* may be synthesized by the insects, by microbes, or through autooxidation of host α-pinene (Seybold *et al.* 2000). Verbenone has been shown to interrupt aggregation in other *Ips* spp. and in a variety of other scolytids (Borden 1997). For example, laboratory bioassays with *I. paraconfusus* Lanier (McPheron *et al.* 1997) showed that increasing concentrations of verbenone resulted in slower responses by beetles reaching an attractant source of naturally produced male pheromone volatiles. In limited field studies of verbenone's effect on aggregation of *I. perturbatus*, Werner (1993) showed a 19% reduction in trap catch when verbenone was added to ipsdienol.

Building on semiochemical studies by Holsten *et al.* (2000) and Werner (1988, 1993) and in response to increased *Ips* activity in south-central Alaska in 1996, efforts to apply *Ips* attractants and antiaggregants for population manipulation (Shea 1994; Salom and Hobson 1995) have been renewed in south-central and interior Alaska.We tested the efficacy of one enantiomeric blend of verbenone as an antiaggregant for *I. perturbatus* at two locations in Alaska.

MATERIALS AND METHODS

Study area characteristics. In the south-central Alaska site (Kenai Peninsula, 150 km south of Anchorage), characterized by a transitional climate, traps were placed among Lutz spruce trees located at 250 m elevation in the Granite Creek campground area. This stand contained trees that were about 90 years old with a mean diameter at 1.3 m height of 7.5 cm, a mean height of 10 m, and a stand density of about 600 per ha. Shrub cover was sparse, consisting mostly of blue-joint reedgrass, *Calamagrostis canadensis* (Michx.) Beauv., and *Salix* spp.

In the interior site, characterized by a continental climate, traps were placed among white spruce trees located at 500 m elevation near Tok. This stand contained trees that

[1] The enantiomeric composition of *cis*-verbenol in Holsten et al. (2000) was incorrectly reported as 83%-(+). It was 83%-(–).

originated from a fire about 80 years ago and had recently been thinned to about 1400 stems per ha, including 20 stems per ha of quaking aspen, *Populus tremuloides* Michx.. White spruce trees had a mean diameter at 1.3 m height of 9.5 cm and a mean height of 10 m. Shrub cover was sparse with only green alder, *Alnus crispa* (Ait.) Pursh, crowberry, *Empetrum nigrum* L., Labrador tea, *Ledum groenlandicum* L., mountain cranberry, *Vaccinium vitis-idaea* L., and highbush cranberry, *Viburnam edule* (Michx.) Raf., occupying the site.

Trap Placement and Semiochemicals. Twelve-unit, multiple funnel traps (Lindgren 1983) were hung from branches of non-host or dead spruce trees, or on nylon rope suspended between host trees. Traps at both sites were hung at least 10 m apart (Bakke *et al.* 1983) with collection containers 0.3 m aboveground. Traps were baited with semiochemicals (Table 1) dispensed from polyethylene bubble cap release devices (PheroTech, Inc., Delta, BC, Canada[2]). To reduce cost, racemic semiochemicals were used where available. The three-component attractant of ipsenol, ipsdienol, and *cis*-verbenol was used because it is more attractive than ipsdienol alone (Holsten *et al.* 2000). Each component of the attractant and verbenone were released from separate bubble caps. Beetles were collected from traps weekly from late May through July. Trapped insects were placed in labeled plastic bags and frozen for later identification and counting.

Table 1

Release rates of synthetic semiochemicals used in *Ips perturbatus* trapping studies, Alaska, 2000[1].

Semiochemical	Enantiomeric composition	Bubble cap load (mg)	Bubble cap release rate (mg/day)[2]
Ipsdienol	Racemic	40	0.2
Ipsenol	Racemic	20	0.2
cis-verbenol	83%-(−)	75	0.6
Verbenone	84%-(−)	790	3.5

[1]All semiochemicals have chemical purity >98 percent.
[2] Release rates determined at 22^{0}C.

Experimental Design and Statistical Analyses. Treatments were completely randomized in each field test and were initially replicated at least ten times at each location. However, in some instances trap catches were discarded from the experiment because neighboring trees became infested with *I. perturbatus* and these natural aggregations influenced trap catches. Thus, the number of replicates varied from 9 to 10 (Granite Creek) or 7 to 10 (Tok) (Table 2). Treatments were: 1) Attractant (ipsenol + ipsdienol + *cis*-verbenol), 2) Attractant + high dosage (two bubble caps) of verbenone[3], 3) Attractant + low dosage (one bubble cap) of verbenone, 4) Verbenone alone (low and high dosages used at Granite Creek; low dosage used at Tok), and 5) Unbaited traps as controls. Statistical analyses

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

[3] As the enantiomeric composition of verbenone associated with feeding *I. perturbatus* has not yet been determined, we used “standard” verbenone bubble caps (PheroTech Inc.) typically applied for mountain pine beetle, *Dendroctonus ponderosae*.

were completed using "Statistix 7" software[4]. Numbers of *I. perturbatus* caught by each treatment were first examined by the Shapiro-Wilk Test to determine whether data conformed to a normal distribution. Since they did not, data were transformed using the natural log + 1 before being subjected to ANOVA followed by Tukey's (1953) comparison of means test ($\alpha = 0.05$). Untransformed means are reported in the results.

Table 2

Effect of 84%-(–)-verbenone on the response of *Ips perturbatus* to an attractant composed of racemic ipsdienol, racemic ipsenol , and 83%-(–)-*cis*-verbenol in multiple funnel traps, Granite Creek and Tok, Alaska, 2000[1].

	No. of beetles caught (mean ± SE)[2]	
Treatment	Granite Creek (n[3])	Tok (n)
Attractant	288.8 ± 66.7^{a} (10)	731.5 ± 101.8^{a} (7)
Attractant + Low Verbenone	112.0 ± 16.9^{a} (10)	194.6 ± 47.0^{b} (7)
Attractant + High Verbenone	46.5 ± 8.7^{b} (9)	136.2 ± 23.5^{b} (8)
High Verbenone	1.2 ± 0.4^{c} (9)	
Low Verbenone	0.4 ± 0.1^{c} (10)	3.0 ± 0.9^{c} (9)
Unbaited trap	1.6 ± 0.8^{c} (10)	5.9 ± 3.3^{c} (10)

[1] Granite Creek trapping study had one additional treatment; high release rate of verbenone alone (two release devices).
[2] Mean and standard error values followed by same letter within each column are not significantly different, P< 0.05, Tukey's comparison of means test.
[3] Number of replications

RESULTS

The overall effect of treatment was significant at both locations (Granite Creek, F = 98.2, df = 5,52, $P < 0.001$; Tok, F = 64.6, df = 4,36, $P < 0.001$). The ternary blend of racemic ipsdienol, racemic ipsenol, and 83%-(-)-*cis*-verbenol was significantly more attractive to *I. perturbatus* than the unbaited trap (Table 2). Because sexes of *I. perturbatus* cannot be differentiated by external morphology, the sex ratio of the captured beetles was not determined. Verbenone released at a high rate reduced mean trap catches at both Tok and Granite Creek by a factor of five relative to the attractant (Table 2). Addition of verbenone at a low release rate also significantly reduced trap catches of *I. perturbatus* at Tok (Table 2). There was no significant difference at either location between the responses to verbenone alone and to the unbaited control (Table 2).

DISCUSSION

The dose-dependent effect of verbenone on the response of *I. perturbatus* to its attractant (noted at Granite Creek) has also been demonstrated for other species of *Ips* (Miller *et al.*1995, McPheron *et al.*1997). With *I. perturbatus*, Werner (1993) showed a 19% reduction in trap catch when verbenone [87%-(–) and 5 mg/day] was added to racemic ipsdienol (0.2 mg/day). However, we have demonstrated higher reductions (62% to 84%) in trap catches when verbenone [84%-(–) and 3.5 or 7 mg/day] was added to the three-component attractant. The enantiomeric blends and release rates of verbenone used by us and by Werner (1993) were similar, while the ipsdienol used in each study was

[4] "Statistix 7", 2000, Analytical Software, PO Box 12185, Tallahassee FL 32317-2185.

identical in chemical composition and release. Differences in the effect of verbenone on trap catches between our study and that of Werner (1993) could have been due to variation in *I. perturbatus* populations, to differences in trapping technique, or particularly to differences in attractant used as the positive control for interruption. In as much as Werner (1993) only used one of the three components we used in our attractant, it is possible that his 19% reduction might have been higher if all three pheromone components had been used.

We now have identified an antiaggregânt for *I. perturbatus* (verbenone) that is associated with feeding *I. perturbatus* adults (unpublished data). Although we do not know the exact enantiomeric composition of verbenone associated with *I. perturbatus* or the timing of its release during host colonization, we have achieved a significant reduction in trap catches using the commercially available, and relatively inexpensive verbenone bubble cap containing 84%-(–)-verbenone. If verbenone is released late in the colonization process, it may function naturally as an antiaggregation pheromone to minimize further attacks on host material. As has been demonstrated for *Ips pini* (Say) in lodgepole pine, *Pinus contorta latifolia* (Engelmann) Critchfield (Borden *et al.* 1992; Devlin *et al.* 1994), treatment of white and Lutz spruce logging debris with commercially available verbenone may reduce the level of colonization of host material and population increase by this forest pest.

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Geographic and temporal distribution of *Agriotes obscurus* and *A. lineatus* (Coleoptera: Elateridae) in British Columbia and Washington as determined by pheromone trap surveys

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ABSTRACT

Initial and peak catch of male Agriotes obscurus (L.) in pheromone traps in the lower Fraser Valley of BC occurred 15.6 and 18.7 days, respectively, before A. lineatus (L.). Both A. obscurus and A. lineatus were taken in pheromone traps from each of 77 fields monitored throughout the lower Fraser Valley during 2000 and 2001, expanding the known ranges of both species. No specimens of either species were taken in pheromone traps set at 56 sites distributed throughout the Okanagan, Similkameen and Nichola Valleys in 2000, but one specimen of A. lineatus was found in a private collection that had been captured near Merritt BC. This is the first record of A. lineatus in BC outside of the lower Fraser Valley. Of nine counties surveyed in Washington State in 2000, A. obscurus was taken in traps at several sites in Whatcom county, especially along the Canada/US border, and A. lineatus was taken at several sites in Whatcom, Snohomish and Pierce counties.

Key words: wireworms, Elateridae, *Agriotes lineatus*, *Agriotes obscurus*, pheromone traps

INTRODUCTION

In 1952, a proceedings of the Entomological Society of British Columbia was published to commemorate the fiftieth anniversary of the society. In that issue, an article entitled, 'List of the Elateridae of British Columbia', was published by M.C. Lane, an entomologist from the Bureau of Entomology and Plant Quarantine in Walla Walla, Washington. Among the 150 species known to be in BC at that time, Lane listed the dusky click beetle, *Agriotes obscurus* (L.) (Coleoptera: Elateridae), and the lined click beetle, *A. lineatus* (L.), as being present on Vancouver Island but not on the mainland (Lane 1952). These species had just been discovered in 1949 by King (1950) at Cobble Hill, near Victoria, and shortly thereafter, *A. obscurus* was found on the mainland at the eastern end of the lower Fraser Valley near Agassiz (King *et al.* 1952). By 1980, *A. obscurus* larvae and related damage had been reported from several farms in Surrey, about 70 km west of Agassiz, and *A. lineatus* had spread from Vancouver Island to Vancouver on the mainland (Wilkinson 1980). In a recent survey conducted in the lower Fraser Valley in 1996 and 1997, *A. obscurus* was taken in pitfall traps from several locations between Delta and Agassiz (Vernon and Päts 1997). The easternmost record of *A. obscurus* was in Laidlaw, between Hope and Agassiz. The survey also showed that *A. lineatus* was now established in Delta, which was the only region where the two species overlapped in pitfall traps in the lower Fraser Valley. A single specimen of *A. obscurus* caught in a pitfall trap in a field of raspberries in Lynden, WA in 1997 was the first recorded occurrence of this species in Washington State (Vernon and Päts 1997). Other than the Lynden capture, neither species has been reported outside of the lower Fraser Valley in BC, or elsewhere in Washington.

The initial discoveries of *A. obscurus* and *A. lineatus* in BC (King 1950; King *et al.* 1952) were of particular importance at that time, since both were introductions from Europe, and both were considered among Europe's most destructive insects (Eidt 1953). It is believed that both species were introduced to BC from Europe around 1900 (Wilkinson 1963), although the actual time and means of introduction are not known for certain. It has been hypothesized that *A. obscurus* larvae may have been introduced to the Agassiz area on hops with soil brought from Europe (A.T.S. Wilkinson, personal communication). Introductions of *A. obscurus*, *A. lineatus* and *A. sputator* (L.) to the east coast of Canada in the 1800s have been attributed to the dumping of soil ballast from ships coming from Europe (Eidt 1953). Instances of ballast dumping are also recorded in areas of Puget Sound and Portland Oregon in the US (Lindroth 1957), and in Departure Bay just north of Nanaimo on Vancouver Island (Scudder 1958).

Once established in Canada, the dispersal of *A. obscurus* and *A. lineatus* was believed to have been slow due to the 4-year life cycle of these species (Wilkinson *et al.* 1976). Following its discovery in Agassiz, BC in 1952 (King *et al.* 1952), a subsequent delimitation survey showed that the area affected was confined to less than 320 ha, which was bounded by the Fraser River on the south and east and by heavily wooded terrain on the west and north. (Wilkinson 1957). In Nova Scotia, introduced *Agriotes* spp. were initially restricted to the vicinity of old ports that were also confined by water and forests (Eidt 1953). It was also believed by workers studying these species in Nova Scotia and BC that dispersal was slow because the adults had not been observed to fly (Wilkinson *et al.* 1976; Eidt 1953). With the gradual urbanization of BC and Nova Scotia, however, several new manmade avenues of dispersal appear to be accelerating the movement of wireworms into new areas. The movement of wireworm-infested soil for example, either as topsoil for landscaping purposes, or in soil associated with sod farms or ornamental plants has likely played a role in spreading both species throughout the lower Fraser Valley of BC and beyond since the early reports (R.S. Vernon, personal observation).

When organochlorine insecticides commonly used to control wireworms were withdrawn from BC and elsewhere, Wilkinson (1980) predicted that European wireworms would eventually become a serious threat to agriculture in BC. This prediction has come true, particularly within the past decade where wireworm damage has increased dramatically in small fruit, vegetable, ornamental and forage crops throughout the Fraser Valley. Wireworms have been particularly damaging to potatoes in the lower Fraser Valley, where holes and scars have reduced marketable yields on conventional farms, and where entire fields of organic potatoes have been rendered unmarketable (R. S. Vernon, personal observation). Wireworms are also a major concern to the strawberry industry, where considerable seedling mortality can occur to newly established plantings, and where wireworms in mature plantings will enter fruit in contact with the ground to become contaminants during processing. The damage is always associated with *A. obscurus* or *A. lineatus* or both (Vernon and Päts 1997), but because these species are extremely difficult to distinguish from each other using larval characteristics alone (Wilkinson 1963), it is not known what species are damaging crops in certain areas.

The recent survey of *A. obscurus* and *A. lineatus* distribution in the lower Fraser Valley and Lynden Washington by Vernon and Päts (1997), relied primarily upon historical Elaterid collections at the Pacific Agri-Food Research Centre (AAFC) at Agassiz, and pitfall traps placed in a total of 12 field sites during 1996 and 1997. In 1999, pheromone traps for *A. obscurus* and *A. lineatus* were developed that are much more convenient and effective at trapping adult male click beetles than pitfall traps (R. S. Vernon, unpublished data). In 2000, these pheromone traps were used to survey the Okanagan, Similkameen and Nichola Valleys of BC and western Washington for *A. obscurus* and *A. lineatus*. The traps were also used in strawberry and potato fields throughout the lower Fraser Valley during 2000 and 2001, and the spatial and temporal occurrence of *A. obscurus* and *A. lineatus* beetles in these three survey areas is described in this paper.

MATERIALS AND METHODS

Pheromone trapping. The traps used in these surveys were Vernon Beetle Traps (PheroTech Inc., Delta, BC) baited with bubble cap lures containing pheromone blends for *A. lineatus* and *A. obscurus* (LaGasa *et al.* 2000). The pheromone lure formulations remain proprietary information at the present time. The trap, constructed of durable polyvinyl chloride (PVC), is designed to capture and confine adult male beetles that are attracted to the internal pheromone lure and fall in after ascending shallow ramps. No killing agent or preservative was used inside the traps, which relied on regular servicing to provide specimens in good condition. Traps were placed at ground level, with entry ramps flush with or slightly covered by adjacent soil to provide unimpeded beetle entry. Sample collection involved removal of one of the ramp inserts and shaking the trap contents into a tray.

Lower Fraser Valley surveys. In the spring of 2000, pheromone traps for *A. obscurus* and *A. lineatus* were installed in 17 strawberry fields in the lower Fraser Valley from Delta to Chilliwack (Fig. 1). Trap placement, spacing and numbers were dependent on field size and shape, but generally 10 traps were installed along each of six evenly spaced rows of strawberries to achieve good field coverage. Traps were consecutively numbered (e.g. 1 to 60) with odd- numbered traps baited with *A. lineatus* lures and even-numbered traps with *A. obscurus* lures. This was done for both species throughout the growing season in the westernmost seven fields (Richmond, Delta and Surrey), whereas in the easternmost 10 fields (Aldergrove, Abbotsford and Chilliwack), *A. lineatus* traps were not installed until late May. Traps were checked on a weekly to biweekly basis from mid-April to mid-July, during which time all beetles were removed and saved for identification.

Additional pheromone traps purchased by growers were installed by private consultants in headland areas surrounding 18 potato fields in Delta in 2000. Each field had a single pair of *A. obscurus* and *A. lineatus* traps, with 10 m between the paired traps. These traps were checked weekly from 13 April to 3 July, during which time all beetles were removed and saved for identification.

In the Spring of 2001, pheromone traps for *A. obscurus* and *A. lineatus* were installed in 50 strawberry fields in the lower Fraser Valley, again from Delta to Chilliwack but also in areas north of the Fraser River that had never been surveyed (Fig. 1). Seven of the fields monitored in 2001 had also been monitored with pheromone traps during the 2000 growing season. Each field had five pairs of *A. obscurus* and *A. lineatus* traps. Trap pairs were located midway along each side of each field, about 10 m in from the field edges with about 10 m between paired traps. Another pair of traps was located in the approximate center of each field. Traps were checked on a biweekly basis from mid-March to mid-July, during which time all beetles were removed and saved for identification. A 10-ha field of pasture in Surrey, and a 1-ha fallowed field in Agassiz were also monitored in 2001 for *A. obscurus* and *A. lineatus* using the pheromone traps, with four of each trap placed at random locations inside the fields.

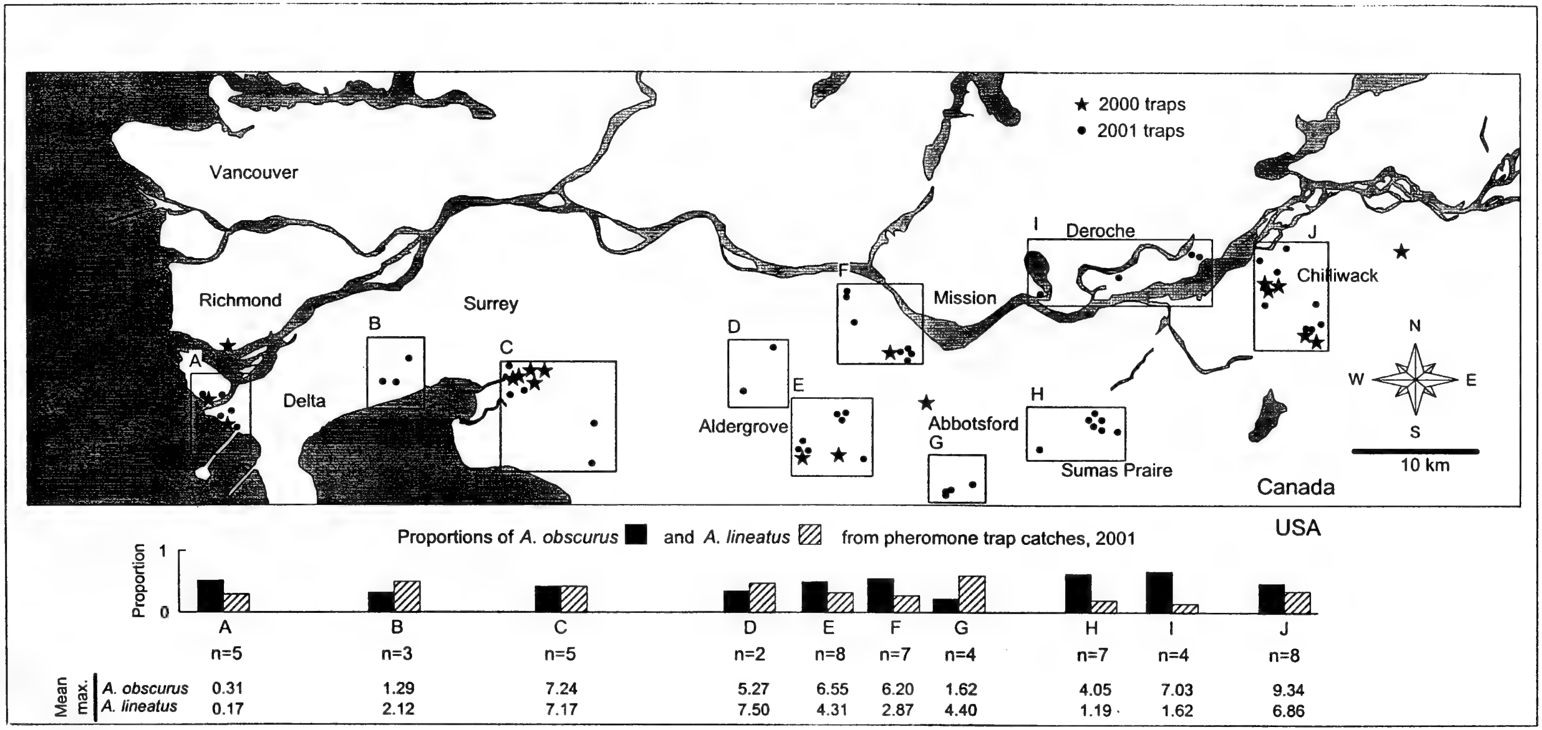

Figure 1. Locations of pheromone traps for both *A. obscurus* and *A. lineatus* in agricultural regions of the lower Fraser Valley in 2000 and 2001. Histograms represent the mean proportion of *A. obscurus* versus *A. lineatus* taken among fields in discrete areas of the Fraser Valley in 2001 (proportions were calculated using the grande mean peak catches of each species in each area, shown under each histogram, between March and July, 2001; n = number of fields). Mean maximum *A. obscurus* and *A. lineatus* cited are beetles per trap per day.

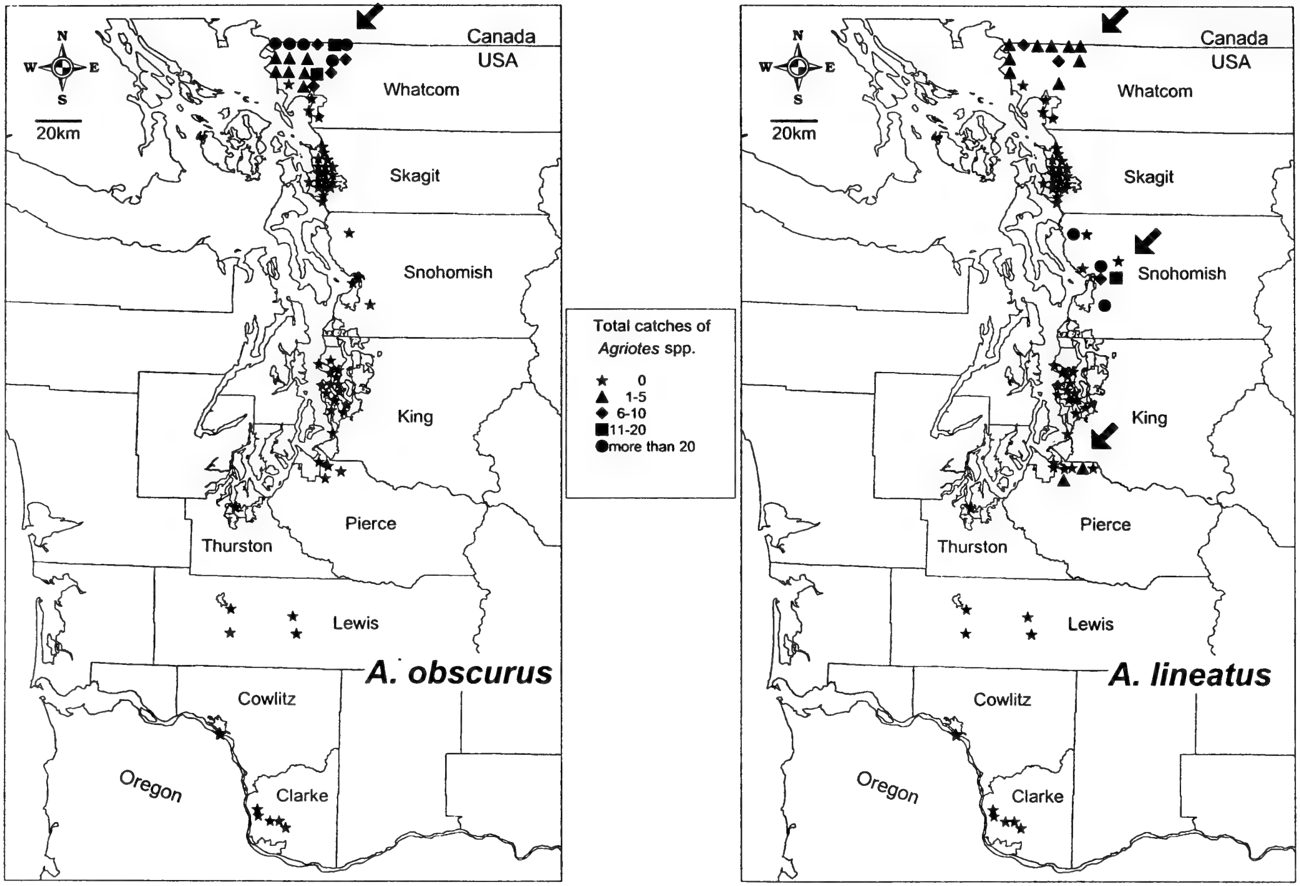

Figure 2. Locations of pheromone traps and total catch of *A. obscurus* and *A. lineatus* in nine counties in western Washington in 2000. Arrows indicate general areas where beetles were trapped.

Interior BC surveys. From 19-26 May, 2000, six pairs of *A. obscurus* and *A. lineatus* traps were established in the Similkameen Valley of BC between Keremeos and Osoyoos. From 26 May to 23 June, 29 pairs of traps were established in the Okanagan Valley between Osoyoos and Salmon Arm, and 13 pairs of traps between Salmon Arm and Kamloops from 23 June to10 July. An additional eight traps were established between Merritt and Kamloops in the Nichola Valley from 23-30 June. The traps were placed amongst grass in roadside ditches along highways and country roads. Paired traps were placed either on the same side of the road, and spaced 7-10 m apart, or placed on opposite sides of the road, and spaced 15-20 m apart.

Washington State surveys. Traps were initially installed from mid-April to early-May, 2000, and were checked as frequently as possible until removal in July or early August. Trap checking intervals varied from weekly in priority areas of Whatcom county, to a month or more in southwestern Washington counties. At sites where high levels of the target beetles were collected in the first trap checks in Whatcom County, traps were subsequently relocated to more southern locations to gather additional delimiting information. Trapping sites in the northern counties of Whatcom and Skagit were established in an approximate grid pattern, with between 3.2 and 6.4 km between traps (Fig. 2).

The physical criteria for trap sites included: proximity to areas of turf, pasture, or other grassy locations, which are considered favored wireworm habitat; and protected situations where traps would be less likely disturbed or damaged. Outside of the northern counties, traps were located near ports or nurseries where the target species may have been introduced through shipping ballast or infested nursery stock.

RESULTS

Initial and peak emergence of *A. obscurus* and *A. lineatus*.

Fields of strawberries that were monitored simultaneously for *A. obscurus* and *A. lineatus* in the Surrey region of the lower Fraser Valley in 2000 suggested that the peak activity period of adult *A. obscurus* males preceded that of *A. lineatus*. Unfortunately, numbers of *A. obscurus* taken in pheromone traps in the Surrey fields (installed 13 April) were already high when traps were first inspected on 19 April (range: 1.1-8.5 beetles per trap per day), indicating that the initial emergence period of *A. obscurus* had been missed. For *A. obscurus*, the highest recorded catches in traps occurred between 19-27 April in the Surrey fields (range: 1.6-8.5 beetles per trap per day), and between 19 April and 4 May in the Aldergrove, Abbotsford and Chilliwack fields (range: 1.3-20.8 beetles per trap per day). Numbers of *A. lineatus* in the Surrey fields were quite low in traps on 19 April (range: 0-0.11 beetles per trap per day) with peak catches occurring on 16 June (range: 0.9-1.9 beetles per trap per day). Trapping for *A. lineatus* began too late in the Aldergrove, Abbotsford and Chilliwack fields to determine the initial or peak activity periods.

Since it appeared that the initial emergence period of *A. obscurus* and *A. lineatus* was missed in 2000, sampling began between 14-22 March in the 2001 strawberry field surveys. Dates of first catch of *A. obscurus* varied considerably between the various regions monitored in the lower Fraser Valley in 2001 (Table 1). The very earliest catch of *A. obscurus* occurred on 23 March in five out of eight fields in Chilliwack at the eastern end of the lower Fraser Valley (mean of eight fields = 28 March) with mean initial catch in other regions ranging from 3-28 April. Mean peak catch of *A. obscurus* ranged from 3-19 May (Table 1). The dates of initial catch of *A. obscurus* are similar to those reported in Europe (i.e. United Kingdom, France, Switzerland and Poland), where initial captures generally occurred in the last week of March or first week of April (Cohen 1942).

The very earliest catch of *A. lineatus* in pheromone traps was again in Chilliwack in two out of six fields on 17 April (mean of six fields = 24 April) with mean initial catch in other regions ranging from 24 April to 5 May (Table 1). Mean peak catch of *A. lineatus* among regions ranged from 25 May to 2 June (Table 1). The difference in mean initial and mean peak catch between *A. obscurus* and *A. lineatus* in the lower Fraser Valley was 15.6 and 18.7 days, respectively.

Table 1

Mean number of Julian days required for initial and peak catches of *A. obscurus* and *A. lineatus* in strawberry fields monitored with pheromone traps in eight regions of the lower Fraser Valley in 2001. Regions are arranged from east to west.

Region Monitored	# Fields[1]	Julian date of initial catch *A. obscurus*	Julian date of initial catch *A. lineatus*	# Fields[1]	Julian date of peak catch *A. obscurus*	Julian date of peak catch *A. lineatus*
Chilliwack	8:6	86.5	113.7	8:8	129.3	145.0
Sumas Prairie	5:5	105.8	117.6	5:4	122.8	148.0
Deroche	4:4	104.8	119.0	4:4	132.5	150.0
Abbotsford	4:4	110.0	122.0	0:4	-	150.0
S. Aldergrove	7:7	106.0	119.1	7:7	125.0	153.3
N.Aldergrove	8:8	93.0	119.5	8:8	131.5	149.0
Surrey	5:5	107.6	119.6	5:5	131.6	149.0
Delta	6:6	117.8	125.0	7:7	139.1	147.0
Mean		103.9	119.5		130.2	148.9

[1]The number of fields in each region with mean *A. obscurus* catch ≥ 0.1 (left number) or *A. lineatus* catch ≥ 0.1(right number) beetles per trap per day, during initial or peak trap catch.

Geographic distribution of *A. obscurus* and *A. lineatus*.

Lower Fraser Valley. In the initial pheromone trap survey of 17 strawberry fields in 2000, *A. obscurus* and *A. lineatus* were both found in all fields sampled in Richmond (one field), Delta (two fields), Surrey (four fields), Aldergrove (two fields) Abbotsford (two fields) and Chilliwack (six fields) (Fig. 1). Of 18 headland areas surrounding potato fields monitored with pheromone traps in Delta in 2000, both species were found in all but one field (i.e. on Westham Island) which failed to capture any *A. obscurus.*

The 2000 survey findings were verified and expanded upon in the survey of 50 strawberry fields in 2001, where both species were taken in pheromone traps in all fields monitored in Delta (8 fields), Surrey (5 fields), Aldergrove (16 fields), Abbotsford (4 fields), Mission/Deroche (4 fields), Sumas Prairie (5 fields) and Chilliwack (8 fields) (Fig. 1). Both species were also taken in pheromone traps placed in a fallow field in Agassiz. The catches of *A. obscurus* in Richmond and Mission/Deroche, and catches of *A. lineatus* in Aldergrove, Abbotsford, Mission/Deroche, Sumas Prairie, Chilliwack and Agassiz are the first records of these species in these areas, and both species now appear to coexist throughout the lower Fraser Valley.

The mean number and relative proportions of *A. obscurus* and *A. lineatus* in traps in geographically distinct groups of fields varied somewhat throughout the lower Fraser Valley in 2001 (Fig. 1). The data show that numbers of *A. obscurus* caught in pheromone traps were generally lower relative to *A. lineatus* in the western half of the Valley, but were higher in most of the sampled areas in the eastern half of the Valley. In the field sampled in Agassiz (north east of Chilliwack) in 2001, the proportion of *A. obscurus* was very high (0.98).

Okanagan Valley, BC. No specimens of *A. obscurus* or *A. lineatus* were taken in pheromone traps at any of the 56 sites sampled in the Okanagan, Similkameen or Nichola Valleys of BC between 19 May and 10 July in 2000. However, based on the observations above which showed that *A. obscurus* emerges and peaks earlier than *A. lineatus* (Table 1), the traps that were set in the Nichola Valley from Merritt to Kamloops between 23-30 June, and those set between Kamloops and Salmon Arm between 30 June and 10 July, may have missed the *A. obscurus* and possibly the *A. lineatus* adult generations. The negative results in traps set in the Okanagan and Similkameen valleys, however, suggests that neither species has been introduced to those regions.

Merritt, BC. A single specimen of *A. lineatus* was found in the collection of Professor J.H. Borden (Simon Fraser University), which was caught between 1990-93 in a bark beetle pheromone trap at Miner Creek in an actively logged and reforested area 25 km southwest of Merritt (collector, Alejandro Camacho-Vera). This is the first record of *A. lineatus* in the interior of BC outside of the lower Fraser Valley.

Washington State. Of the eight counties monitored in 2000, *A. obscurus* was collected only in Whatcom county, where 18 out of 22 sites were positive and catches were highest near the Canadian border (Fig. 2). At these sites, between 68 and 76 adult *A. obscurus* were captured during 7-day trapping intervals in late April. *Agriotes lineatus* had a broader distribution, being captured in Whatcom (11 of 15 sites), Snohomish (5 of 8 sites) and Pierce (2 of 7 sites) counties. The highest average number of beetles per positive trap was in Snohomish county (21.2 beetles), followed by Whatcom county (2.5 beetles) and Pierce county (1 beetle).

The disparate collections of *A. lineatus* in this survey, occurring in three counties separated by counties without collections, suggest the possibility of a disjunct population of that species in parts of the Puget Sound area. The extent of collections that were recorded in this survey, occurring as far south as the Fife area in Pierce County, clearly demonstrates that *A. lineatus* is currently established in areas outside of the previously known infested areas of BC. Whether the detected populations in Snohomish and Pierce Counties represent natural spread from BC or are the result of independent introductions was not determined from this survey.

DISCUSSION

Since their hypothesized introductions to Vancouver Island (*A. obscurus* and *A. lineatus*) and Agassiz (*A. obscurus*) about a century ago (Wilkinson 1963), both species are now found throughout the lower Fraser Valley of BC, and at least *A. lineatus* is probably established near Merritt in the interior. Both species are also well established in areas of Washington state. The fact that *A. lineatus* was not found in pitfall traps at most sites east of Delta BC in the survey by Vernon and Päts (1997) shows the value of using pheromone traps as a delimiting survey tool for these species. Pheromone traps indicated that both species were present in virtually all fields monitored throughout the lower Fraser Valley, and the large numbers of beetles caught in some fields (e.g. 60 traps placed in one Chilliwack field in 2000 caught over 25,000 *A. obscurus*) indicates that both species are very well established. Because both species are polyphagous, and will feed among the roots of many crops, it is almost a certainty that they are being introduced to new areas through the movement of soil or via the transplanting of plants from infested areas. *Agriotes* spp. (either *A. lineatus* or *A. obscurus*) wireworms were found in soil surrounding cedar seedlings originating from the Chilliwack area that were awaiting planting at a Harrison Lake park (just north of Agassiz), and were also found in topsoil moved from a Chilliwack farm to a residence in Rosedale in 1996 (R.S. Vernon, personal observation). The abundance of *A. lineatus* and *A. obscurus* in the lower Fraser Valley and Washington state, and the distant movement of soil or plants with soil (i.e. ornamentals or seedlings for reforestation) will likely spread these pests rapidly to new regions of BC, Washington and beyond.

The observation that the time of emergence and peak catch of *A. obscurus* preceded that of *A. lineatus* by 15.6 and 18.7 days, respectively, will help to better streamline surveys and interpret data in the future. These observations are also important in the development of pest management strategies that target the adult stage of these species.

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