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ISSN 0071-0768

PROCEEDINGS

of the

ENTOMOLOGICAL SOCIETY OF ONTARIO

Volume

One Hundred and Eighteen

1987

Published February, 1988

ISSN 0071-0768

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CONCENTRATIONS OF METHYL BROMIDE INSIDE FLOUR MILLS AND IN THE ATMOSPHERE AROUND THE MILLS DURING AND AFTER FUMIGATION

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Abstract *Proc. ent. Soc. Ont.* 118:1-6 (1987)

The concentrations of methyl bromide established in three flour mills during fumigation varied according to the size and condition of the structures and to the weather conditions on the days of the treatments. In a 15 hour exposure the concentrations in the mills dropped by 75% or more, even when additional fumigant was added to supplement that originally applied. During aeration, a maximum concentration of 27 ppm was recorded at a distance of 25 m from one mill in the first 5 minutes and at 20 minutes the concentration had declined to 7 ppm.

Introduction

Restrictions on the use of liquid "spot" fumigants in flour mills have brought about the need for alternative procedures to control insects that infest the mills. One effective method for achieving the degree of insect control that is needed to satisfy health standards is to apply the fumigant, methyl bromide, in a general fumigation treatment to the entire mill facility. This procedure, although more costly than the spot fumigation treatments, can be effective if conducted according to recommendations.

In carrying out a general fumigation of a building, sufficient gas to kill the insects must be liberated into the free space and then maintained at the toxic level for a defined period of time. After the treatment, the residual gas remaining in the building is dispersed into the atmosphere outside the mill. The normal procedure for aeration involves either opening doors and windows to allow the gas to diffuse or the operation of exhaust fans to blow it outside the mill. Thus, the residual fumigant can be quickly diluted to low concentrations by mixing with the outside atmosphere. The rate of the dispersal and diluting process is thought to be rapid because of the great amount of space into which the gas is liberated.

However, the question of dispersing the toxic gas into the environment, where it might pose a hazard to human beings is a subject of concern. One of the main questions is whether the gas does disperse as rapidly as has been assumed or whether it flows out of the buildings in plume-like currents without appreciable dilution to create potential hazards to human beings. This concern has pointed up the need for information on the levels of fumigant that occur in the atmosphere in and around buildings during a fumigation treatment. The purpose of this investigation was to determine concentrations of the fumigant methyl bromide that occured both inside flour mills during the treatment and outside during the aeration procedure.

Methods

For this investigation three different flour mills in southern Ontario were fumigated according to standard procedures (Bond, 1984). The concentrations of methyl bromide within the buildings were measured at various locations during the fumigation so that distribution of the gas and losses through leakage and/or sorption could be determined. In addition, samples from the atmosphere outside the building were taken as the residual gas was liberated during the aeration process. Mill no. I was a rectangular, one storey building of about 8750 m^3 (309 000 ft^3) volume, constructed of steel, asbestos sheeting and with a tarred roof. Mill no. 2 was a five storey irregularly shaped building attached to a feed mill. It was constructed of brick, wood and corrugated steel sheeting in different areas and had

a volume of approximately 7080 m^3 (250 000 ft^3). Mill no. 3 was also a five storey building of brick and wood with a flat tarred roof and it had a volume of 1700 m^3 (60 000 ft^3). All visible openings in the buildings were sealed with masking tape or polyethylene sheeting fixed in place with masking tape.

Methyl bromide was released into the space of Mill no. 1 from three cylinders placed at appropriate locations and in Mills no. 2 and 3 the gas was released from cylinders placed on each floor. The quantities of fumigant released and the temperatures in the different mills are shown in Table I.

TABLE I. Quantities of methyl bromide applied to mills no. 1, 2 and 3 with inside temperatures as noted.

Mill No. 1 (35°C)	**Mill No. 2 (24°C)**	**Mill No. 3 (24°C-13°C)**
159 Kg +23 Kg at 5 h	250 Kg +23 Kg at each of 3, 4, 5 h	55 Kg +27 Kg at 5 h

Fans were placed at appropriate locations to aid in dispersal of fumigant to obtain as uniform distribution as possible and these were run for 30 min after release of the fumigant. The concentrations of methyl bromide within the buildings were measured during the fumigation at sampling points chosen, as far as possible, at sites that would give a fair indication of the distribution of gas in the free space. Lengths of 2 mm nylon ID tubing were payed out from the chosen sampling locations in the mill to a position outside the mill where gas samples could be drawn for analysis in a Photovac 10S30® gas chromatograph. The ends of the tubing were closed off by use of Swagelock® fittings containing silicone rubber septa. Thus samples could be taken by piercing the septa with the needle of the syringe and withdrawing the desired quantity of the gas sample from the tube. A 500 ml syringe was used to purge the internal volume of the tubing and then a 10 µl syringe was used to take 6µl samples from the tubing for analysis in the gas chromatograph.

Analyses were made at intervals to determine the concentrations of the gas at each position and thus to establish the degree of dispersal of the gas and the drop of the concentrations as losses occurred through leakage and/or sorption. Additional gas was added to increase the concentration levels in the mills as required (see Table I above).

During the aeration period the concentrations of the gas were measured both inside and outside the buildings. Samples from inside were taken as described above and the samples from outside were taken at chosen sites as shown in Table II. The sites for collecting these samples were determined by the patterns of air flow around the buildings. An electric smoke generator filled with kerosene was used to produce a smoke cloud that gave visual indication of the air flow pattern for the location where the fumigant was to be liberated from the building and samples for analysis were taken in the pathway of air flow at various distances from the buildings.

TABLE II. Sites for sampling methyl bromide around the mill during the aeration.

	Mill No. 1	**Mill No. 2**	**Mill No. 3**
Location where fumigant exhausted:	Doorway (2.4 x 2.4m)	Doorway (2.1 x 0.9 m)	Exhaust fan
Wind speed (KPH):	NW 5-15	NW 30-35	S 20-25
Sampling site* No. 1:	18	14	45
No. 2:	36	25	75

*Figures indicate distances (m) from point where fumigant exhausted from building to point where air samples taken.

The sampling flasks (250 ml) used for taking air from the outside atmosphere were fitted with slow release valves for drawing in the air over a predetermined period of time (5 min) and an adapter with a silicone rubber septum for taking samples, by gas syringe, for subsequent analysis by GLC. These flasks were evacuated to less than 10 mm pressure using a vacuum pump, then taken to the chosen sampling site, placed at a position about 1.5 M above the ground and the slow release valve was opened to admit the air. The samples so obtained were analysed by gas chromatography using the Photovac 10 S 30 gas chromatograph with a photoionization detector, a 3 mm diam., 1 m long column packed with Carbopak® and with a carrier flow rate of 30 cc per min. Methyl bromide has a retention time of 4.5 min in this system and it can be analysed with the instrument over a wide range of concentrations; in these tests, high concentrations up to 37 mg L^{-1} (8724 ppm) were analysed inside the mill during the treatment and low concentrations down to 0.2 ppm were anaylsed (with a precision of 4% coefficient of variation) in the outside atmosphere during aeration.

Observations made during this investigation showed a relatively rapid decline in fumigant concentrations early in the treatment to leave comparatively low levels for much of the exposure period. This fall in concentration raised the question of efficacy, particularly in the latter hours of the treatment. For example a low concentration of 1 mg L^{-1} is well below that which is the level that is believed to be effective for control and thus the question of termination of the treatment arises when concentration falls to this level. Some bioassay tests were therefore carried out with two week old adults of red flour beetle *Tribolium castaneum* (Herbst) to determine toxicity of methyl bromide at these low levels. The regimes followed in these tests are given in Table IV (below).

Results and Discussion

The concentrations of methyl bromide found in the central areas of the mills during the treatment are shown in Figure 1 and indicate great variation from one structure to another. In mill no. 1, a relatively tight-fitted one-storey structure, gas loss was slow over the 15 h period of the treatment, while in mills no. 2 and 3 the gas concentrations fell rapidly after application so that additional gas had to be added to maintain the toxic concentration for sufficient time to kill the insects. The rapid losses of fumigant in mills no. 2 and 3 were probably caused by lack of gas tightness of the structures. Also the cold weather conditions at the times of the treatments may have increased updraft effects to cause dilution and loss of fumigant. Both of these mills were treated on relatively cold, windy days when updraft conditions in such buildings were likely to be appreciable. Nevertheless the concentrations developed during the treatments were sufficient to control the insects.

Calculation of the dosages to which the insects were exposed (ie. Concentrations × Time products as determined from the areas under the curves in Fig. 1) gives approximate values as follows: Mill no. 1, 175 mg h L^{-1}; Mill no. 2, 75 mg h L^{-1}; and Mill no. 3, 112 mg h L^{-1}. These values all exceeded the C × T product of 64 mg h L^{-1}, the LD_{99} for a common flour mill insect the Confused Flour Beetle, *Tribolium confusum* Jacquelin du Val (Bond and Monro 1961) and observations on infestations in these mills, where the insects were mainly Flat-grain Beetle, *Cryptolestes pusillus* (Schoener), revealed no living insects after the treatments were completed.

The treatments were brought to a conclusion by exhausting the residual gas into the outside atmosphere. From the data collected it can be seen that even though the concentrations within the mills were low at this time further dilution occurred rapidly to reduce concentrations to even lower levels (Table III). It should be noted that at Mill No. 2 fumigant was carried a considerable distance from the site of liberation at concentrations above the threshold limit value of methyl bromide (5ppm) and at a point 25 m from the exhaust point the concentration was only a little lower than that found at 14 m distance.

With regard to the efficacy of the treatments for insect control, particularly under circumstances where rapid loss of fumigant early in the treatment lead to low concentrations for much of the exposure period, the results, shown in Table IV, give some indication of

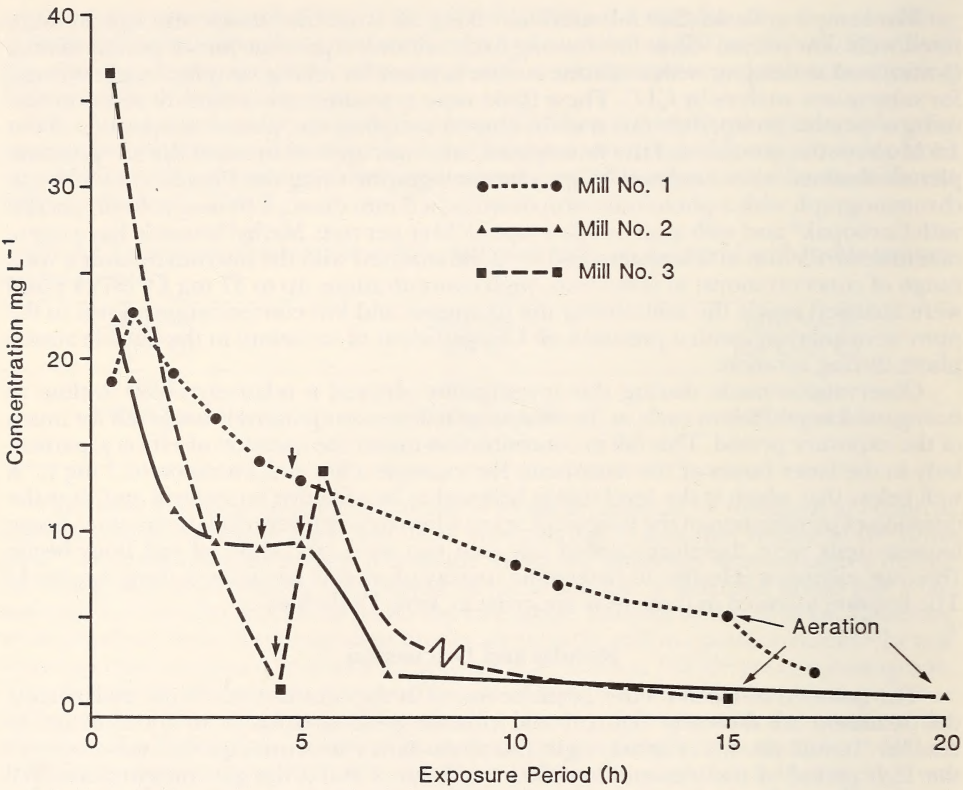

FIGURE 1. Concentrations of methyl bromide found in three flour mills during a fumigation treatment when dosages of 18 mg L^{-1} were introduced into Mill no. 1, 35 mg L^{-1} in Mill No. 2 and 32 mg L^{-1} in Mill No. 3. Additional fumigant was added at points indicated by arrows: 23 Kg at 5 h in Mill No. 1, 23 Kg at 3, 4, and 5 h in Mill No. 2 and 27 Kg at 5 h in Mill No. 3.

TABLE III. Concentrations of methyl bromide (ppm) found in the wind stream around the mills during the aeration period.

Mill No.	Time (min.) after beginning of aeration	Concentration (ppm)[1] site 1	site 2
1	5	6.7	1
	10	4	–
2	5	23	27
	20	14	7
	35	7	6
	45	7	5
	90	6	–
3	5	.05	.02
	16	.05	trace
	27	.01	.01
	37	0	0
	49	0	–

[1] For location of sampling sites see Table II.

the significance of these low concentrations. From the data obtained in the laboratory, it can be seen that continued exposure to a low concentration can increase efficacy when insects are first exposed, to higher concentrations. Mortality was greater for insects exposed to 1 mg L^{-1} (235 ppm) for 19 h after initial exposure to higher concentrations for the first 5 h than for those exposed for only 5 h. However with a reverse protocol, in which insects were first exposed to the low concentration of 1 mg L^{-1} for 19 h and then to the higher concentrations for 5 h, the increase in efficacy did not occur. These results indicate that continuing a treatment, after the concentrations fall, as they did in the field trials described here, can have some value and additional control can be achieved even at low concentrations that are normally ineffective.

Although the few observations given in this report are of a preliminary nature and are insufficient to allow any definitive conclusions they do give some indication of the great variation that may take place in different facilities under different atmospheric conditions. Furthermore, the fall in concentration that occurred during the treatment points to the possibility that large amounts of the fumigant escaped to the outside atmosphere during the treatment period. Data from all treatments clearly show that the internal concentration at the end of the exposure period was a relatively small proportion of the initial dosage applied (calculated on the basis of weight of fumigant applied). This means that because a large amount was lost through leakage and sorption during the treatment, any hazard posed by exhaust of the residual gas at the end of the treatment was correspondingly reduced.

TABLE IV. Treatment of *T. castaneum* adults with rising or falling concentrations of methyl bromide for periods of 5 h with some insects being further treated with a constant concentration of 1 mg L^{-1} for 19 h.

Dosage Range (mg L^{-1})	Exposure [1] Period (hours)	Mortality (%)[2]
13, 10, 6, 2, 1	5	25
13, 10, 6, 2, 1	5 + 19	81.2
1, 2, 6, 10, 13	5	16.7
1, 2, 6, 10, 13	19 + 5	18.5
14, 11, 7, 3, 1	5	62.9
14, 11, 7, 3, 1	5 + 19	95.8
1, 3, 7, 11, 14	5	38.7
1, 3, 7, 11, 14	19 + 5	43.0
15, 12, 8, 4, 1	5	78.5
15, 12, 8, 4, 1	5 + 19	98.8
1, 4, 8, 12, 15	5	69.0
1, 4, 8, 12, 15	19 + 5	63.0
16, 13, 9, 5, 1	5	94.8
16, 13, 9, 5, 1	5 + 19	100
1, 5, 9, 13, 16	5	93.4
1, 5, 9, 13, 16	19 + 5	89.8

[1] All insects were exposed to a rising or falling concentration of fumigant for 5 hours and some were exposed as indicated to a concentration of 1 mg L^{-1} for an additional 19 h either before or after the 5 hour treatment.

[2] Data are averages of 2 treatments except for the dosage range 1-15 mg L^{-1} when 4 repeat treatments were made.

Considerably more tests on a number of mills are needed to obtain a comprehensive picture of the concentrations of fumigant that may exist both inside and outside the buildings during and after fumigation treatments. Because of the great variety in structures, environmental conditions and other parameters of the treatment the extent of hazard to human beings living or working in the vicinity of flour mills during treatment will only be known when more data are accumulated. However, the results obtained in these three tests suggest that when a treatment is carried out using carefully controlled procedures the risk need not be very great.

Acknowledgements

We are grateful for Mr. R. Sellen of Sellen Grain Services Ltd., Thamesville, Ontario for cooperation and assistance in carrying out this work and to Photovac Inc., Thornhill, Ontario for assistance with the analytical equipment.

References

Bond, E.J. and H.A.U. Monro. 1961. The toxicity of various fumigants to the cadelle *Tenebroides mauritanicus*. Journal of Economic Entomology, 54:451-454.

Bond, E.J. 1984. Manual of fumigation for insect control. FAO Plant Production and Protection Paper 54. Food and Agriculture Organization. Rome. 432 pp.

(Received 8 September, 1986; accepted 15 February, 1987)

CONTROL OF GERMAN COCKROACHES, *BLATTELLA GERMANICA* L. (ORTHOPTERA: BLATTELLIDAE), USING HYDRAMETHYLNON BAITS IN AN ANIMAL HEALTH FACILITY

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Abstract *Proc. ent. Soc. Ont.* 118:7-12 (1987)

This study investigated the efficacy and use of hydramethylnon, an amidinohydrazone insecticide, for control of the German cockroach *(Blattella germanica* L.) under Canadian conditions. Other parameters which were studied included bait depletion and trap displacement. Three to six hydramethylnon bait stations per nine square meters provided excellent control in three of four study areas. Up to 100% control was achieved over a three month period compared with 0 to 67% control obtained in two rooms where propoxur baits or crack and crevice treatments were used. Despite reinitiation of conventional control measures, reinfestation of all but two of the treated areas occurred during the four months following the removal of the hydramethylnon.

Introduction

Of the four domiciliary species of cockroach commonly encountered in Canada, German cockroaches represent the greatest concern because of their predominance, the aesthetic problems they cause and their implication in the transmission of several pathogenic nematodes, tapeworms, bacteria and fungi (Cochran 1982). Ebling (1975) has reviewed the biology of the German cockroach.

Conventional control measures currently involve application of non-residual and residual insecticidal liquids, dusts or baits belonging to the pyrethroid, organophosphorous and carbamate classes. Sanitation and exclusion also contribute to effective control of cockroaches and, to a lesser extent, mechanical methods or "natural" agents, such as sticky traps and boric acid, are sometimes employed. These methods have occasionally proven inadequate, especially in sensitive areas such as human and animal health care facilities, schools, pet stores and near delicate machinery where their use is often restricted or prohibited.

Hydramethylnon, an amidinohydrazone, was first described by Lovell (1979) as a promising candidate for control of several species of insects, including German cockroaches. Hydramethylnon is packaged in a child-proof plastic feeding station (5 x 5 x 1 cm) containing 1.5 grams of a 1.65% bait (24.75 mg a.i.). The remaining ingredients consist of a non-insecticidal, wax-like substance containing oatmeal and lard. The active ingredient is a yellowish, odourless, non-volatile solid exhibiting little solubility in water and most organic solvents (American Cyanamid 1982). Hydramethylnon has poor contact activity and is thought to function exclusively as a slow-acting stomach poison interfering with mitochondrial energy production (Hollingshaus and Little 1984).

Our objective was to study the efficacy of a 1.65% hydramethylnon bait, under Canadian field conditions, in an animal health facility with a history of cockroach infestations.

Materials and Methods

The study was performed within the animal health unit of a major metropolitan zoological park. Because of the restrictions on the use of conventional insecticides and the abundance of food, moisture, warmth and harbourages, cockroaches had been a recurring problem within this facility. As the areas used in this study were designed to serve as quarantine units, they provided an ideal opportunity to draw comparisons between adjacent areas with a similar control history while ensuring minimal immigration/emigration of resident cockroach populations between rooms.

Cockroach populations were monitored before and during the study using sticky traps[1] placed for a 24 hour period at 0, 2, 4, 8, 12 and 30 weeks after the treatments were applied. The use of these traps to monitor populations is described by Moor and Granovsky (1984). These sticky traps were placed along areas where cockroaches were believed to travel. The number of captures provided a relative index of the severity of the infestations. Trap placements were marked on floor plans and in the rooms by using sticky labels to ensure that all placements were as nearly identical as possible at the time of each assessment. Percent control was calculated based on the difference in the number of cockroaches captured during a 24 hour period following treatment compared with the number captured at 0 weeks (baseline). In addition to the total numbers captured, sex ratios and the proportion in the various life stages were recorded to monitor any changes in the population composition.

Following the initial assessment of the cockroach infestation, hydramethylnon bait stations were placed within the designated rooms (A to D) at rates ranging from 3 to 6 stations/9 m^2. Stations were attached using double-sided adhesive disks (1 cm^2) in areas where cockroaches were evident. These trap placements were also recorded on the floor plans to facilitate recovery of the stations and monitoring of the bait depletion. Conventional control materials were removed from rooms A to D. Control in rooms E and F was continued without any disruption by a licensed pest control firm and the populations were monitored in the manner previously described.

Percent depletion of the hydramethylnon bait was monitored in rooms A and B by replacing the feeding stations at 2, 4 and 8 weeks after the commencement of the trial. The used stations were opened and the bait remaining was weighed. After twelve weeks the hydramethylnon stations were removed from all of the trial areas and their contents were weighed to determine the rate of depletion. At this time conventional control methods were reinstated by the contracted pest control firm. Four months after the removal of the hydramethylnon, six sticky traps were placed in each of the former trial areas and the populations were reassessed in the manner previously described.

Results and Discussion

The number of live cockroaches captured during a 24 hour period and the percent reduction, relative to the baseline, are summarized in Table I. The hydramethylnon bait provided up to 100% control of German cockroaches over a three month period in rooms A, B and C. Rooms A and B contained caged small animals. Room C contained animals in larger pens on either side of a central runway. Sanitation ranged from fair to good depending on the type of animals present, their numbers, and their bedding, food or water requirements. At twelve weeks after placement of the hydramethylnon baits, no live cockroaches were discovered in rooms A, B or C either on the sticky traps or upon visual inspection.

An 87% reduction in German cockroaches was obtained in room D during the first month after treatment with the hydramethylnon; however, based on the sticky trap captures, this control was subsequently lost (Table I). Upon our further investigation, two factors were observed which might explain this reinfestation. First, six of the hydramethylnon traps in the area of an open floor drain were nearly completely depleted at the conclusion of the study. Second, one of the twelve sticky traps in this room adjacent to the drain accounted for 55% and 81% of the live captures in this room at 8 and 12 weeks after treatment, respectively. Thus, we concluded that the loss of control was primarily the result of bait depletion in this critical area rather than poor efficacy. Also of interest is our observation that relatively few early instar nymphs were evident at either 8 or 12 weeks. That suggested reinfestation involved an isolated pocket and arose from only a few escaped roaches. Had the control failure been more widespread, a heterogenous mix of the life stages throughout the room,. similar to that in the pre-treatment surveillance, would have been expected.

[1]Mr. Sticky Roach Traps® distributed by Abell Waco Ltd., Rexdale, Ontario.

TABLE I. The number of cockroaches captured during a 24 hour period in several areas of an animal health facility before and after treatment with hydramethylnon or propoxur.

Room[1]	Treatment[2]	Time	Number of Live Captures/Room[3] Male[4]	Female[4]	Young Nymph[4]	Old Nymph[4]	Total	Percent Reduction
A	hydramethylnon	PRE	9 (32)	9 (32)	5 (16)	5 (16)	28	—
(8)	@ 5.1 stations	2 wks.	3 (23)	4 (31)	5 (38)	1 (8)	13	58
	per 9 m² (N = 18)	4 wks.	1 (20)	1 (20)	0	3 (60)	5	82
		8 wks.	1 (33)	1 (33)	1 (33)	0	3	89
		12 wks.	0	0	0	0	0	100
B	hydramethylnon	PRE	114 (24)	98 (21)	206 (44)	51 (11)	469	—
(9)	@ 5.1 stations	2 wks.	4 (7)	13 (24)	9 (17)	28 (52)	54	88
	per 9 m² (N = 27)	4 wks.	1 (8)	0	3 (23)	9 (69)	13	97
		8 wks.	1 (50)	1 (50)	0	0	2	99
		12 wks.	0	0	0	0	0	100
C	hydramethylnon	PRE	23 (27)	19 (22)	25 (29)	19 (35)	86	—
(10)	@ 2.7 stations	2 wks.	2 (33)	2 (33)	1 (17)	1 (17)	6	93
	per 9 m² (N = 44)	4 wks.	0	0	1 (25)	3 (75)	4	95
		8 wks.	0	2 (66)	0	1 (33)	3	97
		12 wks.	0	0	0	0	0	100
D	hydramethylnon	PRE	16 (42)	9 (24)	8 (21)	5 (13)	38	—
(12)	@ 3.4 stations	2 wks.	4 (57)	1 (14)	2 (28)	0	7	82
	per 9 m² (N = 56)	4 wks.	3 (60)	1 (20)	1 (20)	0	5	87
		8 wks.	21 (43)	12 (24)	5 (10)	11 (23)	49	0
		12 wks.	32 (36)	23 (26)	4 (5)	30 (33)	89	0
E	propoxur	PRE	0	0	0	0	0	—
(9)	0.1-1.0%	2 wks.	2 (50)	1 (25)	1 (25)	0	4	0
	residual	4 wks.	3 (50)	1 (16)	2 (33)	0	6	0
		8 wks.	3 (42)	3 (42)	1 (8)	0	7	0
		12 wks.	0	2 (18)	6 (55)	3 (27)	11	0
F	propoxur[5]	PRE	26 (19)	24 (17)	58 (42)	31 (22)	139	—
(11)	@ 1 station	2 wks.	9 (14)	13 (20)	8 (12)	35 (54)	65	53
	per 9 m² (N = 13)	4 wks.	10 (21)	7 (15)	4 (9)	26 (55)	47	66
		8 wks.	22 (48)	16 (35)	5 (11)	3 (6)	46	67
		12 wks.	16 (26)	13 (21)	15 (25)	17 (28)	61	44

[1] Numbers in parentheses indicate number of sticky traps per room.
[2] Parentheses: N = the number of bait stations per room.
[3] Young Nymphs = immatures 1-5 mm length; Old Nymphs ⩾5 mm length.
[4] Number in parentheses indicates percent of population in indicated life stage.
[5] This treatment consisted of a 1% propoxur + peanut butter bait preparation.

Hydramethylnon bait depletion is shown in Table II. Bait depletion was not substantial in either rooms A or C, where moderate populations were established and sanitation was fair. Under those conditions, control was achieved and maintained. In room B, the severity of the infestation resulted in a rapid depletion of the bait initially with a gradual decrease in feeding activity after two months. Consequently, under conditions of severe feeding pressure, it was apparent that to achieve and maintain control the hydramethylnon bait had to be replenished as it was depleted. Thus, the period of time in which control was achieved was not primarily influenced by the severity of the infestation, provided that a continued supply of fresh toxicant was available. This was demonstrated by the control achieved in room B relative to rooms A and C, both of

which had far less severe pre-treatment populations; and by the loss of control in room D as previously discussed.

The propoxur treatments in rooms E and F did not appear to provide control comparable to that which was provided by the hydramethylnon bait during the twelve week efficacy study (Table I). Room E was a small staff kitchen with relatively good sanitation. At the outset, no cockroaches were detected in this area; however, during the subsequent surveillance the number of captures increased gradually. Room F was similar to rooms C and D in design and sanitation and although some control was evident, the level of suppression did not improve with time. That suggested that the propoxur was inadequate to erradicate the infestation in the manner in which it was administered in this situation. Furthermore, because all life stages were evident in both rooms throughout the surveillance period, it appeared that a degree of stability remained in the cockroach population despite the propoxur treatment.

TABLE II. Depletion and loss of hydramethylnon bait stations from various rooms within an animal health facility.

Room	Initial Number of Stations	Mean % Depletion at (weeks)				Number of Stations Recovered[1]
		2	4	8	12	
A	18	15.6	15.8	16.2	0.8	11 (61)
B	27	45.4	24.9	20.2	9.2	27 (100)
C	44	—[2]	—[2]	—[2]	35.6	30 (68)
D	56	—[2]	—[2]	—[2]	21.5	37 (66)

[1] Numbers in parentheses indicate percent recovery at termination.
[2] Bait depletion was not determined at this time.

In addition to depletion, a third route by which hydramethylnon was lost from the control areas was by displacement. Table II shows that following the twelve week treatment period only 61 to 68% of the feeding stations were recovered from rooms A, C and D. It is assumed that the rest of the stations were either lost, removed or displaced. This is an operational difficulty which will require strict attention since reduced control might occur if losses of product were not rectified.

The rate at which the trial areas were reinfested was studied approximately four months after the removal of the hydramethylnon bait (Table III). Six sticky traps were placed in each of the rooms for a 24 hour period and assessed in the manner previously described. Control still appeared to be satisfactory in rooms A and B and, based on the generation time for German cockroaches, it seemed that the hydramethylnon had actually eliminated the cockroaches in these areas and that no new infestations were introduced. Furthermore, based on the pre-treatment population in room B following prolonged use of conventional control methods, it seems that the hydramethylnon was able to provide superior control. In contrast, control in room C was not maintained following the removal of the hydramethylnon and cockroach populations had reverted to the pre-treatment levels. This reversion was possibly the result of the introduction and establishment of new live material in contaminated feed, bedding and/or equipment. Similarly, the number of cockroaches in room D had further increased which suggested that the conventional control practices failed to provide adequate control in these areas once they were reinstated during the interim following the removal of the hydramethylnon bait stations.

TABLE III. Number of cockroaches captured during a 24 hour period four months following removal of hydramethylnon from an animal health facility.

Room	Treatment History	No. Live Captures/Room[1]				
		Male	Female	Young Nymph	Old Nymph	Total
A	hydramethylnon	4 (67)	2 (33)	0	0	6
B	hydramethylnon	1 (50)	1 (50)	0	0	2
C	hydramethylnon	34 (26)	20 (15)	58 (45)	19 (14)	130
D	hydramethylnon	98 (41)	46 (19)	40 (17)	55 (23)	239
E	propoxur-residual	0	0	0	0	0
F	propoxur-bait	67 (16)	47 (11)	224 (53)	85 (20)	423

[1] Numbers in parentheses indicate percent of population in a particular life stage based on catches from six sticky traps per room.

Cockroaches were not detected in room E. That indicated that the infestation in the area was controlled by a residual propoxur spray applied several weeks earlier. No control was evident in room F where more cockroaches were apparent than in either of the other similar rooms which had been previously treated with hydramethylnon. In this room, as well as rooms C and D, the sensitivity of the animals prohibited the use of conventional residual sprays and propoxur + peanut butter bait stations were used instead. Based on our observations, these stations were either not as efficaceous or they were not present in sufficient numbers to ensure adequate control.

In conclusion, 3 to 6 hydramethylnon stations per 9 m^2 provided up to 100% control of German cockroaches over a three month period in three study areas. This control was superior to that achieved by a professional pest control firm using propoxur bait stations. Furthermore, in the apparent absence of pest introductions from outside the treated areas, no reversion was observed in two rooms up to four months following use of the hydramethylnon and this demonstrated that pest eradication was feasible in a severe field situation. Control in a third room was lost between four and eight weeks after the study started and likely resulted from a combination of bait depletion and neglected bait maintenance in an area with inadequate sanitation. The maintenance was purposefully neglected even though the sticky trap monitoring indicated deteriorating control. This was permitted to illustrate the importance of proper bait maintenance. Control in a room where a propoxur residual was used provided adequate control although the use of propoxur bait stations in another room where residual treatments where not permitted proved inadequate. In that situation we suspect that a greater number of the propoxur stations was probably warranted. Complete reinfestation of three of the large animal units occurred during a four month period following removal of the hydramethylnon, despite the use of conventional methods. Our results have illustrated the efficacy of the hydramethylnon bait under Canadian field conditions and the importance of correct placement and product maintenance for optimum results.

Acknowledgements

The authors would like to extend their sincere appreciation to the Health Unit Staff for their interest and cooperation in this project.

References

American Cyanamid Company 1982. AC 217,300 Insecticide – Technical Information Report. American Cyanamid Company. Princeton, N.J., 20 pp.

*Cochran, D.G. 1982. Cockroaches – Biology and control. World Health Organization. WHO/VBC/82.856. 53 pp.

Ebling, W. 1975. Pests on or near food. pp. 217-244 *In:* Urban Entomology. University of California, Los Angeles.

Hollingshaus, J.G. and R.J. Little. 1984. Comparative toxicology of AC 217,300 in various species of insects. Pesticide Biochemistry and Physiology, 22: 337-345.

Lovell, J.B. 1979. Amidinohydrazones – A new class of insecticides. Proceedings of the British Crop Protection Conference – Pests and Diseases, 2: 575-582.

Moor, W. and T. Granovsky. 1984. Interpreting cockroach sticky trap catches. Pest Control Technology, 12(10): 64-72.

(Received 16 September, 1986; accepted July 2, 1987)

TRICHOPTERA FROM COLD FRESHWATER SPRINGS IN CANADA: RECORDS AND COMMENTS*

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Abstract *Proc. ent. Soc. Ont.* 118:13-23 (1987)

The "Springs Project" of the Biological Survey of Canada (Terrestrial Arthropods) is aimed at furthering knowledge of systematics, zoogeography and ecology of invertebrates from these aquatic habitats. The need for a preliminary synthesis for the Trichoptera was prompted by the existence of over 175 records from Canadian springs and they indicate several interesting trends: certain species of caddisfly appear to be restricted to springs and springbrooks even though they may have wide geographic ranges, e.g. *Chyranda centralis*; some entire genera are restricted to these cold water habitats, e.g. *Anagapetus*; many genera that occur in springs are endemic to western Canada or exhibit their greatest diversity there, e.g. *Psychoglypha, Parapsyche* and *Lepidostoma*. Larvae of species from springs seem physiologically well-suited to these habitats and grow adequately in water that is seldom warm. Species show one-and sometimes two-year life cycles, and diet, which includes both plant and animal material, varies among species. Typical assemblages of caddisflies from cold water springs contain both obligate and facultative crenophiles. To complete our knowledge of caddisflies from Canadian springs, greater collecting effort is needed, particularly in the Maritime Provinces and the far north. The biology of most spring species, even those that are widespread, is little known. We hope that this synthesis will prompt studies of Trichoptera and other invertebrates in these interesting habitats.

Introduction

As part of an ongoing project on arthropod communites of special habitats in Canada, the Biological Survey of Canada (Terrestrial Arthropods), under the auspices of the Entomological Society of Canada and the National Museum of Natural Sciences, is developing and coordinating a national project on the faunas of springs. The long-term goal is to complete a survey of the arthropods of cold and warm water spring habitats in Canada, in order to further the knowledge of the systematics, zoogeography and ecology of these organisms (Williams 1983).

The "Springs Project" is a large enterprise comprising many parts, some of which are at more advanced stages than others. Extensive field collecting of spring communities remains to be done, but for certain taxa a nucleus of records of species collected from springs already exists. The Trichoptera are one such group. We have compiled, from various sources, over 175 records of species of caddisfly from cold water springs throughout Canada. Those data have led to some interesting generalizations specifically with regard to the following questions: 1) Are some species of Trichoptera restricted to spring habitats?; 2) Are spring species locally endemic or more widespread in distribution?; 3) Can the available knowledge of the biology of spring species explain their occurrence in these specialized habitats? The following list of Trichoptera is not complete, and records of this group from Canadian springs may not be wholly adequate for many years to come. Nevertheless, the list is extensive enough to allow certain tentative conclusions to be drawn relating to the goals of the Biological Survey, and to allow gaps in our knowledge to be clearly identified.

Materials and Methods

The records (Appendix I) of caddisflies from springs are derived from collections of

*A project of the Biological Survey of Canada (Terrestrial Arthopods).

larvae and data from some reared specimens. The most extensive source of information is the collection of identified specimens in the Department of Entomology of the Royal Ontario Museum. We searched out individual specimen vials with labels that stated a spring (eucrenon in the sense of Illies and Botosaneanu 1963; there are no records of caddisflies from limnocrenes or helocrenes in the sense of Bornhauser 1913) as the collection habitat. The second source of information was personal communications with researchers known to have collected from springs. The third source was records of spring species from the general scientific literature (Williams, 1988).

The entries in Appendix I are grouped alphabetically, by genus and species, within family groupings from the most primitive to the most advanced (after Wiggins, 1977). Each entry records the province in which the collection was made and, when known, the month collected and the water temperature. Finally, the source of the data is given in abbreviation: APN – A.P. Nimmo, Univ. Alberta (personal communication); GBW – Wiggins, 1977 and personal communication; S/M – Sinclair and Marshall, (1986 and personal communication); NEW – N.E. Williams, Univ. Toronto (personal collection); R/H – Roy and Harper, 1975; RJM – Mackay, 1969 and personal communication; ROM – Royal Ontario Museum Collections; WJG – W.J. Galloway, Brandon Univ. (personal communication); W/W – Williams and Williams, 1979; BJ – B. Jarvis, Univ. Saskatchewan (personal communication); MHC – M.H. Colbo, Memorial Univ. (personal communication); WTM – W.T. Momot, Lakehead Univ. (personal communication).

Results and Notes on the Biology of Species Commonly Collected from Springs

The 22 genera of caddisfly most commonly collected from Canadian springs are shown in Table I. The distributions of these genera fall into three main categories: (1) transcontinental; (2) predominantly western; and, (3) predominantly eastern. Absence of captures of widespread genera in certain provinces probably reflects lack of collecting; this is particularly noticeable for Nova Scotia, New Brunswick and Prince Edward Island. The high number of records for some genera is often primarily the result of large collections of particular species in the genus (Table II). For example, about half of the collections of larvae of *Hesperophylax* and *Psychoglypha* are represented by *H. designatus* and *P. subborealis*. In other instances, several congeneric species are recorded, for example *Neophylax aniqua, N. concinnus* and *N. ornatus*. It should be noted that the 15 records of *Pseudostenophylax* sp. (Appendix I) are almost certainly a mixture of the two known eastern species, *sparsus* and *uniformis*. They are difficult to separate as larvae and therefore their absence from Table II is somewhat artificial. They are probably both important spring species. A parallel situation occurs in the genus *Lepidostoma* and it is therefore impossible, at present, to determine which species are the most important in springs.

The following is a digest of what is known about the biology of the species listed in Table II. Comparison of this information may help to determine whether trends exist in the biology of spring inhabitants.

(1) Hesperophylax designatus (Walker) (Limnephilidae): Seven species in this genus occur in North America (Parker and Wiggins 1985). Five are western in distribution and *H. designatus* is widespread across the continent (Appendix 1). Wiggins (1977) reports that larvae of the genus, in general, seem to have a wide temperature tolerance and most species live in small streams. Larvae of *H. designatus* have been collected primarily from cold water springs and springfed brooks in a variety of localities, for example in Wisconsin (as *Platyphylax designatus*) (Vorhies 1905); in New York State (Lloyd 1921) and in Illinois (Ross 1944) although at high latitudes and elevations they also occur in lakes (Parker and Wiggins 1985). Early instar larvae in Wisconsin were found to be feeding on epilithic diatoms but later instars also fed on vascular plants such as water-milfoil and watercress; Parker and Wiggins (1985) concluded that the species is an opportunistic omnivore, Vorhies (1905) reported that the greatest abundance of larvae in Wisconsin was in late winter to early spring, and that emergence took place from mid April to the end of August

TABLE I. Genera of caddisfly commonly found in Canadian springs.

	Number of records by Province									
Genus*	BC	Alta	Sask	Man	Ont	Que	NB	Nfld	Tot	Distribution
Lepidostoma	2	1			13				16	transcontinental, most spp. western
Hesperophylax	2	4		5	5	1		2	19	widely distributed and common
Rhyacophila	3	2	1		4				10	widespread and common
Pseudostenophylax		1			13			1	15	widespread, few species
Neophylax	2				10		1		13	widespread
Limnephilus			1	1	4			1	15	widespread and common
Chyranda	2				1			2	5	single widespread species
Anabolia					3				3	northern and transcontinental, few species
Onocosmoecus	2				1	1			4	fairly widespread
Hydroptila				4					4	widespread
Psychoglypha	6	4	1		1		1		13	western, but *P. subborealis* is transcontinental
Parapsyche	3				6				9	greater diversity in west
Glossosoma	2				1				3	greater diversity in west
Ochrotrichia					3				3	primarily western, also southeastern
Neothremma	4	1							5	western only
Homophylax	3	1							4	western only
Anagapetus	2	1							3	western only
Allomyia	1	2							3	western only
Pycnopsyche					3				3	primarily eastern
Ironoquia					3				3	eastern only
Platycentropus					3				3	eastern only
Frenesia					4				4	eastern only

(*genera with less than 3 records have been omitted; distributional comments are based on records from all habitats and are derived from Wiggins (1977) and Cummins *et al.* (1984); the sequence of names is according to distribution; widespread, western, eastern).

although the peak was in mid to late April. Most overwinter in the larval stage but pupae and prepuape have ben found in late winter. Larvae of this species have been collected in springs and springbrooks (Appendix 1) at water temperatures from 1.0 to 9.0°C.

(2) Neophylax aniqua Ross (Limnephilidae): The genus *Neophylax* contains 15 species which are variously distributed in both eastern and western North America. Western species are found throughout montane areas. The larvae occur in streams and typically eat diatoms and fine particulate organic matter (FPOM) grazed from the surfaces of rocks. Larvae grow in the fall and winter and final instars seal off their cases in spring or early summer. Emergence generally occurs in late summer (Wiggins 1977). Five species of *Neophylax* (Appendix 1) have been recorded from Canadian springs. Beam and Wiggins (1987), in southern Ontario, found larvae were restricted to the cool source waters of spring streams. Data in the Appendix indicate that *N. aniqua* occurs in springs in Ontario and New Brunswick at water temperatures down to at least 6.0°C.

TABLE II. Species of caddisfly most frequently recorded from Canadian springs.

Species*	Number of records	Comments
Hesperophylax designatus	9	widespread
Neophylax aniqua	7	?eastern
Psychoglypha subborealis	6	widespread
Parapsyche apicalis	6	eastern
Chyranda centralis	3	widespread
Neothremma alicia	3	western
Ochrotrichia confusa	3	eastern
Parapsyche elsis	2	western
Rhyacophila vao	2	western
Neophylax concinnus	2	eastern
Anagapetus debilis	2	western
Onocosmoecus quadrinotatus	2	eastern

(*species with less than 2 records are omitted; comments derived from Ross (1944; 1956); Flint (1960); Wiggins (1977); and Unzicker *et al.* (1982).

(3) Neophylax concinnus McL. (Limnephilidae): Ross (1944) collected *N. concinnus* (cited as *N. autumnus* Vorhies) from at least four springs in Illinois. In the Ozarks of Arkansas, *N. concinnus* lives in temporary streams where the population survives the summer drought as aestivating larvae under rocks. It has been found in two springs in Ontario.

(4) Psychoglypha subborealis (Banks) (Limnephilidae): This species is also widespread across Canada (Appendix 1) but the remaining 14 members of the genus are restricted to western montane areas (Wiggins 1977). Larvae of the genus have been reported from a variety of cool water habitats including spring runs, cold northern streams and the edges of stream pools (Flint 1960; Wiggins 1977). Examination of the guts of *P. subborealis* larvae revealed FPOM and animal fragments (Winterbourn 1971). In the northeast, pupation has been observed during October along the margins of stream pools where pupae have been found buried several inches deep in areas of fine gravel and sand (Flint 1960). Emergence occurs late in the year in this locality, generally in October/November (Flint 1960). In contrast, in the Metolius River, Oregon, one mile from the spring source, emergence began in February with a peak in March and April; young larvae were collected in late February (Anderson 1967). In Alberta, Nimmo (1971) collected adults from September 10 to May 23. The water temperature range in Canadian springs in which larvae of *P. subborealis* have been collected (Appendix 1) is 5.5 to 12.2°C.

(5) Parapsyche apicalis (Banks) (Hydropsychidae): Seven species in the genus *Parapsyche* occur in North America. Five are restricted to the west, and two are eastern; *P. apicalis* belongs to the eastern group. Larvae of the genus are typically found in small cold streams (Wiggins 1977). This species has been recorded from the eastern U.S. and Canada (Flint 1961). He states that it commonly found in cold (below 10°C) springfed brooklets only a few feet wide. However, it has been collected from springs in Ontario with water temperatures of 11.0 to 18.0°C (Appendix 1). Mackay (1969) found it in a springfed stream in Quebec and suggested that, there, most larvae were univoltine although some individuals spent a second winter as larvae before emerging and thus, in part of the population, the life cycle exceeded a year in length. *P. apicalis* seems to be a good indicator of springs and springbrooks in the east.

(6) Parapsyche elsis Milne (Hydropsychidae): *Parapsyche elsis* belongs to the western group of species in the genus (Wiggins 1977). In Canada, to date, it has been found only in cold springs of British Columbia (Appendix 1). Smith (1968) recorded larvae of *P. elsis* in small- and medium-sized creeks in Idaho. There, the larvae overwintered as young or nearly mature individuals and pupae were found in June and August. Smith (1968) proposed a two year life cycle. Larvae of this species have been collected at water temperatures

at least as low as 5.5°C (Appendix 1). As for *P. apicalis* in the east, *P. elsis* seems to be a reasonably good indicator of cool spring habitats in the west.

(7) Chyranda centralis (Banks) (Limnephilidae): This species occurs in most parts of Canada, though it seems more common in the west (Wiggins 1977). The genus is monotypic. The larvae are typically found in small spring streams in pockets of allochthonous leaves (terrestrially-derived leaf litter) (Wiggins 1977). Guts of larvae from a springfed stream in Quebec contained leaf fragments, fungi, moss and FPOM (Williams and Williams 1979); larvae in this stream were collected in June in water temperatures of 2.5 - 9.0°C (Appendix 1). It has been found in two springs in Labrador.

(8) Neothremma alicia Banks (Uenoidae): Species of *Neothremma* are confined to, but are widespread in, the western mountains of North America where larvae occur in cold, high altitude springs and streams (Wiggins 1977). Mecom (1972) reported that the larvae of *Neothremma* eat mostly FPOM but also algae. *N. alicia* has been collected from two springs in British Columbia and from one in Alberta (Appendix 1).

(9) Ochrotrichia confusa (Morton) (Hydroptilidae): Larvae in the genus *Ochrotrichia* live in a wide range of water temperatures, in a wide range of running water habitats including cold spring runs (Ross 1944). The genus occurs in North America, Central and South America, and the West Indies (Flint 1972). Wiggins (1977) found larvae of this genus (species unidentified) living in a thin film of water flowing over rocks in a small spring stream in California. Larvae of *Ochrotrichia* have been found feeding on epilithic diatoms (Vaillant 1965). Larvae of *O. confusa* have been collected from three springs in Ontario (Appendix 1).

(10) Rhyacophila vao Milne (Rhyacophilidae): This species is reported to be common in the Cascade Mountains of the Pacific Northwest (Smith 1968). In Idaho, it seems to be somewhat tolerant of muddy and silty conditions in small relatively warm streams. Emergence there occurs from the end of July to the middle of August (Smith 1968). In Canada, it has been collected from a cold spring in British Columbia (Appendix 1). The genus *Rhyacophila* contains more than 100 North American species which are to be found in a broad range of lotic habitats. Most, however, are restricted to cool, rapid, clear streams of mountainous areas of the west (Ross 1944, Wiggins 1977).

(11) Anagapetus debilis Ross (Glossosomatidae): Six species are known in the genus *Anagapetus* and all are restricted to western montane areas where they are typically found in the cool headwaters of mountain streams (Wiggins 1977). Ross (1956) considered the genus to be "a virtual living fossil, the product of a line which has continued for a considerable period of geologic time with little change while offspring lines (i.e. Glossosomatini, Agapetini and Protoptilinae) have evolved at a faster rate". Ross proposed that a form of the single ancestral line that spread into the eastern ranges of the western mountains produced the species *debilis*. Little appears to be known of its biology. Anderson and Bourne (1974) found that *A. bernea* Ross fed chiefly on periphyton in Oak Creek, Oregon where it was most common in the headwater region. Most larval growth occurred during the winter when the water temperature was between 2 and 12°C. *A. debilis* was collected in water at 5.5°C from a spring in British Columbia in July (Appendix 1).

(12) Onocosmoecus quadrinotatus Banks (Limnephilidae): The genus *Onocosmoecus* is widespread in western montane areas but this species ranges at least from Newfoundland to Wisconsin (Wiggins 1977). Larvae of this genus typically live in cool standing water, often in pockets of plant debris (Flint 1960), although Winterbourn (1971) found a western species in Marion Lake, British Columbia. Flint (1960) collected larvae of *O. quadrinotatus* in cold, stony-bottomed streams, especially in pools and other quiet-water areas. He suggested that, in Massachusetts, the species overwinters as eggs and that final instar larvae appear by late June. Adult emergence occurs in the fall; northern populations emerge earlier than southern ones. Larvae in springfed streams in Quebec are recorded as feeding on other insects, moss, wood, leaves and fungi (Williams and Williams 1979). Larvae of *O. quadrinotatus* have been found in springs in Ontario and Quebec (Appendix 1). Wiggins and Richardson (1986) have proposed that all existing names of *Onocosmoecus* be synonymized under *O. unicolor* Banks.

Discussion

Several interesting conclusions can be drawn from an examination of the distributions of the species and genera (Tables I and II). First, many of the species appear to be predominantly associated with springs even though they may have wide geographic ranges, (e.g. *Hesperophylax designatus* and *Chyranda centralis*). Second, some entire genera are restricted to springs and springbrooks, e.g. *Anagapetus* and possibly *Neothremma*. Third, many genera that occur in springs are endemic to the west or exhibit a greater diversity of species in the west, e.g. *Psychoglypha, Parapsyche* and *Lepidostoma*. Pennak (1958) argued that because of the topographic isolation of running water faunas in the west, we should expect this region to support unique populations of aquatic invertebrates with high degrees of speciation, especially in habitats of "unusual" character such as springs.

The spread of *Hesperophylax designatus* and *Psycholglypha subborealis* across Canada, while related species remained in western or western montane areas, may have been through a process akin to island-hopping between adjacent cold springs and springbrooks. Ross (1956) proposed such a mechanism to explain how *Rhyacophila angelita* Banks spread eastwards; it may have been able to spread across the plains between the two mountain ranges by surviving in non-monane habitats, possibly the cold, lowland meltwater streams that would have existed at the margins of the Pleistocene glaciers. Why a large number of its congeners did not follow suit may be explained by subtle differences in larval microhabitat or adults' flight capabilities. Ross and Ricker (1971) similarly hypothesized that the genus *Allocapnia* (winter stonefly) dispersed from the Appalachians to the Ozarks along a corridor of deep valleys with springfed streams that formed after crustal uplift during the Pliocene. This uplift increased local gradient and thus erosion which subsequently produced the steep-sided valleys. Breaches in previous water tables along the valley walls produced a series of springs that formed a dispersal corridor for cold water-adapted species.

Those species restricted to springs must be well adapted to these cold water habitats. Based on the limited biological information available, features common to these species and to those found predominantly in springs are: 1) univoltinism – low water temperature in summer may preclude more than one generation per year and in a few species the life cycle may last for two years, e.g. *Parapsyche elsis* and some individuals of *P. apicalis;* and 2) ability of larvae to grow adequately under consistently low temperatures. There is no consistent pattern to the diets of species inhabiting springs; periphyton grazers. FPOM gatherers, predators and feeders on both autochthonous and allochthonous vascular plant material are represented. The overwintering stage in the life cycle is also variable among species, as eggs, early instar and late instar larvae and prepupae have been so recorded. A point worth making here is that winter temperatures in springs may, in fact, be higher, because of groundwater temperature, than in adjacent streams, so that the term "overwintering" with its usual connotations of reduced metabolism may be misleading. To a certain extent higher winter water temperatures may "compensate" for low summer water temperatures in the context of larval growth.

Some species that occur in springs may be regarded, perhaps, as facultative crenophiles because they are found mostly in more variable lotic habitats, including some that dry up, and even ponds (e.g. *Ptilostomis ocellifera*). Some other species (e.g. *Neophylax aniqua*) appear to be obligate crenophiles or occur mostly in these habitats. Nevertheless, some (e.g. *Hesperophylax designatus*) have a wide temperature tolerance – the biological significance of which is unclear. Spring species belong to virtually all of the caddisfly families of the world although those of the leptocerid branch of the Limnephiloidea (e.g. Beraeidae, Molannidae and Leptoceridae) are less well represented. Various genera and species may have independently developed adaptations to life in springs: the ancestral caddisfly larvae is thought by some scientists to have been a tube-dwelling detritivore inhabiting the shores of lentic or lotic – depositional habitats (Weaver and Morse 1986). However, others propose that cool lotic habitats, including springs themselves, may have been the ancestral habitat from which the Trichoptera spread (Ross 1956, Wiggins 1977).

In order to assess the comprehensiveness of the records of genera from springs, we compared those cited in Wiggins (1977) as living in springs in North America with those in the Appendix. Of those genera known from Canada, and so noted by Wiggins (1977), only three do not appear in the Appendix: *Apatania* (Limnephilidae), *Philocasca* (Limnephilidae) and *Agarodes* (Sericostomatidae). Thus these have yet to be collected from springs in Canada but *Apatania zonella* (Zett.) has been recorded from the cold waters of Lake Hazen on Ellesmere Island (Corbet 1966); species of *Philocasca* have been recorded from spring streams in Alberta (Wiggins 1977); and a species of *Agarodes* has been collected from a springfed stream in Ontario (ROM record). In addition to those genera, Wiggins (1977) lists nine that are associated with springs in the U.S. but which have not been recorded at all in Canada. These are: *Desmona, Goereilla, Goerita, Lepania, Moselyana* (Limnephilidae); *Parthina* (Odontoceridae); *Xiphocentron* (Psychomyiidae); *Fattigia, Gumaga* (Sericostomatidae). Most of these genera contain just one or two species and, with the exception of *Fattigia* and *Goerita,* they are all western in distribution.

Although interesting inferences can be drawn from the data collected (Appendix 1) regarding the occurrence and distribution of Trichoptera in Canadian coldwater springs, these conclusions are tentative and incomplete. To extend them, greater collecting effort is needed, particularly in the Maritime Provinces and the far north (Yukon, N.W.T. and the Arctic Archipelago). Alongside this need for more collecting, we make a plea to collectors for greater precision in recording the habitat sampled. In the process of compiling the Appendix, we came across a large number of records that stated "springfed stream, spring run, spring seepage area, springbrook or cold headwaters". It was felt that these could not be included because of ambiguity of definition and interpretation. We recommend, in future, that detailed notes accompany records of species stating clearly the type of spring (Rheocrene, Limnocrene, Helocrene; see Williams 1983), how far the specimens were found from the point of issue of the groundwater, the temperature of both the water and the air, water depth and current speed. If possible, this information should be supplemented with notes on substrate type and composition, and riparian vegetation (photographs are useful), and, where time and facilities permit, an analysis of water chemistry (particularly dissolved oxygen and carbon dioxide levels, pH, hardness, alkalinity, dissolved organic carbon, sulphide levels, and levels of other major ions – especially calcium, magnesium, sodium, nitrate and phosphate).

It is clear also, that the biology of most spring species, even those of nearctic and holarctic distribution, is scarcely known. Without such knowledge, unique aspects of the physiology and ecology of insects from springs cannot be assessed, appreciated or applied.

Acknowledgments

We thank the various people who supplied us with published and unpublished records of caddisflies from springs (see Methods). We owe a special debt of gratitude to G.B. Wiggins who kindly allowed access to the excellent Royal Ontario Museum (R.O.M.) collections and commented on drafts of this manuscript. The R.O.M. material was collected by G.B. Wiggins, T. Yamamoto, I.M. Smith, D.W. Barr, H. Frania, B.P. Smith and A. Odum, and museum personnel were responsible for larval identification both directly and through association with reared adults. F. Warburton, I. Alexandru and P. Schefter painstakingly went through all the vials recording those specimens from springs. G.K. Dunn provided technical assistance and H.V. Danks reviewed the manuscript. The Natural Sciences and Engineering Research Council of Canada provided some funds for the project as did the Summer Internship Programme of the Scarborough Campus, University of Toronto.

References

Anderson, N.H. 1967. Biology and downstream drift of some Oregon Trichoptera. Canadian Entomologist, 99:507-521.

Anderson, N.H. and J.R. Bourne. 1974. Bionomics of three species of glossosomatid caddisflies (Trichoptera: Glossosomatidae) in Oregon. Canadian Journal of Zoology, 52:405-411.

Beam, B.D. and G.B. Wiggins. 1987. A comparative study of the biology of five species of *Neophylax* (Trichoptera: Limnephilidae) in southern Ontario. Canadian Journal of Zoology, (In Press).

Bornhauser, K. 1913. Die Tierwelt der Quellen in der Umgebung Basels. Internationale Revue der gesamten Hydrobiologie und Hydrographie Supplement, 5. 90pp.

Corbet, P.S. 1966. Parthenogenesis in caddisflies (Trichoptera). Canadian Journal of Zoology, 44:981-982.

Cummins, K.W., G.B. Wiggins and J.C. Morse. 1984. Summary of ecological and distributional data for Trichoptera. pp. 302-311 *In:* R.W. Merritt and K.W. Cummins (eds), An introduction to the aquatic insects of North America, 2nd Edition. Kendal/Hunt Publ. Co., Dubuque, Iowa, 722pp.

Flint, O.S. 1960. Taxonomy and biology of nearctic limnephilid larvae (Trichoptera), with special reference to species in eastern United States. Entomologica Americana, 40:1-117.

Flint, O.S. 1961. The immature stages of the Arctopsychinae occurring in eastern North America (Trichoptera: Hydropsychidae). Annals of the Entomological Society of America, 54:5-11.

Flint, O.S. 1972. Studies of Neotropical caddisflies, XIII: The genus *Ochrotrichia* from Mexico and Central America (Trichoptera: Hydroptilidae). Smithsonian Contributions to Zoology, 118, 28pp.

Illies, J. and L. Botosaneanu. 1963. Problemes et methodes de la classification et de la zonation ecologique des eaux courantes, considerées surtout du point de vue faunistique. Mitteilungen der internationale Vereinigung für theoretische and angewandte Limnologie, 12:1-57.

Lloyd, J.T. 1921. The biology of North American caddisfly larvae. Bulletin of the Lloyd Library, 21, 124pp.

Mackay, R.J. 1969. Aquatic insect communities in Mont St. Hilaire. Journal of the Fisheries Research Board of Canada, 26:1157-1183.

Mecom, J.O. 1972. Feeding habits of Trichoptera in a mountain stream. Oikos, 23:401-407.

Nimmo, A.P. 1971. The adult Rhyacophilidae and Limnephilidae (Trichoptera) of Alberta and eastern British Columbia and their post-glacial origin. Quaestiones entomologicae, 7:3-234.

Parker, C.R. and G.B. Wiggins. 1985. The nearctic caddisfly genus *Hesperophylax* Banks (Trichoptera: Limnephilidae). Canadian Journal of Zoology, 63:2443-2447.

Pennak, R.W. 1958. Some problems of freshwater invertebrates in the western States. pp.223-230 *In:* C.L. Hubbs (ed) Zoogeography. American Association for the Advancement of Science, Washington, 509 pp.

Roy, D. and P.P. Harper. 1975. Nouvelle mentions de trichoptères du Québec et description de *Limnephilus nimmoi* sp. nov. (Limnephilidae). Canadian Journal of Zoology, 53:1080-1088.

Ross, H.H. 1944. The caddisflies, or Trichoptera, of Illinois. Bulletin of the Illinois Natural History Survey, 23., 326pp.

Ross, H.H. 1956. Evolution and classification of the mountain caddisflies. University of Illinois Press, Urbana. 213pp.

Ross, H.H. and W.E. Ricker. 1971. The classification, evolution and dispersal of the winter stonefly genus *Allocapnia.* Illinois Biological Monographs, 45, 167pp.

Sinclair, B.J. and S.A. Marshall. 1986. The madicolous fauna in southern Ontario. Proceedings of the Entomological Society of Ontario, 117:9-14.

Smith, S.D. 1968. The *Rhyacophila* of the Salmon River drainage of Idaho, with special reference to the larvae. Annals of the Entomological Society of America, 61:655-674.

Unzicker, J.D., V.H. Resh and J.C. Morse. 1982. Trichoptera. pp. 1-138. *In* A.R. Brigham, W.U. Brigham and A. Gnilka. (eds). Aquatic insects and oligochaetes of North and South Carolina. Midwest Aquatic Enterprises, Mahomet, Illinois, 837 pp.
Vaillant, F. 1965. Les larves de Trichopteres hydroptilides mangeuses de substrat. Proceedings of the 12th International Congress of Entomology, London 1964, p. 165.
Vorhies, C.T. 1905. Habits and anatomy of the larva of the caddis-fly, *Platyphylax designatus*, Walker. Transactions of the Wisconsin Academy of Science, Arts and Letters, 15:108-123.
Weaver, J.S. and J.C. Morse. 1986. Evolution of feeding and case-making behaviour in Trichoptera. Journal of the North American Benthological Society, 5:150-158.
Wiggins, G.B. 1977. Larvae of the North American caddisfly genera (Trichoptera) University of Toronto Press, 401pp.
Wiggins, G.B. and J.S. Richardson. 1986. Revision of the *Onocosmoecus unicolor* group. Psyche, 93:187-216.
Williams, D.D. 1983. National survey of freshwater springs. Bulletin of the Entomological Society of Canada, 15:30-34.
Williams, D.D. 1988. Spring habitats and their faunas: an international bibliography. (in prep).
Williams, N.E. and D.D. Williams. 1979. Distribution and feeding records of the caddisflies (Trichoptera) of the Matamek River region, Quebec. Canadian Journal of Zoology, 57:2402-2412.
Winterbourn, M.J. 1971. The life histories and trophic relationships of the Trichoptera of Marion Lake, B.C. Canadian Journal of Zoology, 49:623-635;.

(Received 24 November, 1986; accepted 10 April, 1987)

APPENDIX I

Records of caddisflies collected from Canadian coldwater springs

Family/Species	Spring	Province	Month collected	Water temp. (C)	Source
Philopotamidae					
Wormaldia sp.	X	B.C.	June/July	8.9	ROM
Hydropsychidae					
Arctopsyche sp.	X	B.C.	July	6.7	ROM
Diplectrona modesta Banks	X	Ont.	all year	11.0-18.0	NEW
Parapsyche almota Ross	X	B.C.	July	–	ROM
Parapsyche apicalis (Banks)	X	Ont	all year	11.0-18.0	NEW
Parapsyche apicalis (Banks)	X4	Ont	all year	–	S/M
Parapsyche apicalis (Banks)	X	Ont	May	–	WTM
Parapsyche elsis Milne	X2	B.C.	July	5.5-12.2	ROM
Rhyacophilidae					
Rhyacophila ?acropedes Ross	X	Ont	winter	?5.0	RJM
Rhyacophila vao Milne	X	Sask	Apr/Nov	4.0	BJ
Rhyacophila vao Milne	X	B.C.	July	–	ROM
Rhyacophila vobara Milne	X	Alta	July-Oct	–	APN
Rhyacophila sp.	X	Alta	Aug	–	ROM
Rhyacophila sp.	X2	B.C.	July	5.5-12.2	ROM
Rhyacophila sp.	X4	Ont	all year	–	S/M
Glossosomatidae					
Anagapetus debilis Ross	X	Alta	July-Oct	–	APN
Anagapetus debilis Ross	X2	B.C.	July	5.5	ROM
Glossosoma wenatchee Ross&Spencer	X	B.C.	July	–	ROM

Family/Species	Spring	Province	Month collected	Water temp. (C)	Source
Glossosoma sp.	X	B.C.	July	12.2	ROM
Glossosoma sp.	X	Ont	Aug	16.0	ROM
Hydroptilidae					
Ochrotrichia confusa (Morton)	X3	Ont	all year	–	S/M
Palaeagapetus celsus (Ross)	X	Que	–	–	R/H
Palaeagapetus nearcticus Banks	X2	B.C.	–	–	GBW
Phryganeidae					
Oligostomis ocellifera (Walker)	X	Ont	June	–	ROM
Oligostomis sp.	X	Ont	all year	–	S/M
Ptilostomis ocellifera (Walker)	X	Ont	May	–	ROM
Brachycentridae					
Amiocentrus aspilus (Ross)	X2	B.C.	July	5.6	ROM
Eobrachycentrus gelidae Wiggins	X	B.C.	July	–	ROM
Micrasema bactro Ross	X	B.C.	July	–	ROM
Limnephilidae					
Allomyia sp.	X	B.C.	July	5.5	ROM
Allomyia sp.	X2	Alta	Aug	5.0	ROM
Anabolia consocia (Walker)	X	Ont	June	–	ROM
Anabolia sp.	X2	Ont	June	15.0	ROM
Asynarchus sp.	X	B.C.	June	–	ROM
Chyranda centralis (Banks)	X	B.C.	June	–	ROM
Chyranda centralis (Banks)	X2	Lab	June	–	MHC
Chyranda sp.	X	B.C.	July	–	ROM
Chyranda sp.	X	Ont	June	6.0	ROM
Clostoeca disjuncta (Banks)	X	B.C.	–	–	GBW
Cryptochia sp.	X	Alta	July-Oct	–	APN
Dicosmoecus atripes Hagen	X	B.C.	July	12.2	ROM
Ecclisocosmoecus scylla (Milne)	X	B.C.	July	5.5	ROM
Frenesia difficilis (Walker)	X	Ont	July	–	ROM
Frenesia difficilis (Walker)	X	Ont	all year	11.0-18.0	NEW
Frenesia missa (Milne)	X	Ont	July	–	ROM
Frenesia sp.	X	Ont	June	–	ROM
Hesperophylax designatus (Walker)	X	Que	June	1.0	W/W
Hesperophylax designatus (Walker)	X	Ont	June	5.0	ROM
Hesperophylax designatus (Walker)	X	Ont	all year	–	S/M
Hesperophylax designatus (Walker)	X	Man	June	–	ROM
Hesperophylax designatus (Walker)	X2	Lab	June	–	MHC
Hesperophylax ?designatus (Walker)	X2	Man	Nov-Aug	6.0-9.0	WJG
Hesperophylax ?designatus (Walker)	X	Ont	winter	?5.0	RJM
Hesperophylax sp.	X2	Man	June	–	ROM
Hesperophylax sp.	X2	Ont	June	5.0-15.0	ROM
Hesperophylax sp.	X3	Alta	Aug	6.5-9.5	ROM
Hesperophylax sp.	X	Alta	June	–	ROM
Hesperophylax sp.	X	B.C.	June	–	ROM
Hesperophylax sp.	X	B.C.	June	–	ROM
Homophylax sp.	X	B.C.	July	–	ROM
Homophylax sp.	X2	B.C.	June	–	ROM
Homophylax sp.	X	Alta	Aug	–	ROM
Ironoquia sp.	X3	Ont	June	11.1-15.0	ROM
Lenarchus sp.	X	Man	June	–	ROM
Limnephilus moestus Banks	X	Ont	June	5.0	ROM
Limnephilus rossi (Leonard & Leonard)	X	Sask	June	–	ROM

Family/Species	Spring	Province	Month collected	Water temp. (C)	Source
Limnephilus sp.	X2	Ont	May-June	5.0-15.0	ROM
Limnephilus sp.	X	Lab	June	–	MHC
Limnephilus spp.	X	Man	June	–	ROM
Neophylax aniqua Ross	X	N.B.	Sept	–	ROM
Neophylax aniqua Ross	X2	Ont	June-Sept	6.0	ROM
Neophylax aniqua Ross	X4	Ont	all year	–	S/M
Neophylax concinnus McL.	X2	Ont	May-Sept	15.0	ROM
Neophylax ornatus Banks	X2	Ont	Oct	–	ROM
Neophylax rickeri Milne	X	B.C.	July	–	ROM
Neophylax splendens Denning	X	B.C.	July	–	ROM
Onocosmoecus quadrinotatus Banks	X	Que	June	6.0	W/W
Onocosmoecus quadrinotatus Banks	X	Ont	July	–	ROM
Onocosmoecus schmidi (Wiggins)	X2	B.C.	July	–	ROM
Platycentropus radiatus (Say)	X2	Ont	June	–	ROM
Platycentropus sp.	X	Ont	Aug	–	ROM
Pseudostenophylax sparsus (Banks)	X	Ont	all year	–	S/M
Pseudostenophylax sp.	X8	Ont	Apr-Aug	6.0-11.1	ROM
Pseudostenophylax sp.	X	Alta	July	–	ROM
Pseudostenophylax sp.	X4	Ont	all year	–	S/M
Pseudostenophylax sp.	X	Lab	June	–	MHC
Psychoglypha avigo Ross	X	Alta	July	–	ROM
Psychoglypha avigo (Ross)	X	Alta	July-Oct	–	APN
Psychoglypha prithus (Milne)	X	Alta	July	–	ROM
Psychoglypha subborealis (Banks)	X	Ont	July	–	ROM
Psychoglypha subborealis (Banks)	X	Alta	Aug	6.5	ROM
Psychoglypha subborealis (Banks)	X	Sask	July	–	ROM
Psychoglypha subborrealis (Banks)	X	N.B.	Sept	–	ROM
Psychoglypha subborealis (Banks)	X2	B.C.	July	5.5-12.2	ROM
Psychoglypha sp.	X4	B.C.	June/July	–	ROM
Pycnopsyche sp.	X3	Ont	June	6.7-15.0	ROM
Uenoidae					
Neothremma alicia Banks	X2	B.C.	July	5.5	ROM
Neothremma alicia Banks	X	Alta	June	–	ROM
Neothremma sp.	X2	B.C.	July	6.7-12.2	ROM
Goeridae					
Goeracea genota (Ross)	X	B.C.	June	–	ROM
Lepidostomatidae					
Lepidostoma sommermanae Ross	X	Ont	all year	–	S/M
Lepidostoma vernale (Banks)	X	Ont	all year	11.0-18.0	NEW
Lepidostoma sp.	X4	Ont	all year	–	S/M
Lepidostoma sp.	X	Alta	June-July	–	ROM
Lepidostoma sp.	X7	Ont	Apr-Oct	5.0-15.0	ROM
Lepidostoma sp.	X2	B.C.	June-Oct	12.2	ROM
Theliopsyche spp.	X	Que	–	–	GBW
Beraeidae					
Beraea fontana Wiggins	X	Ont	Oct	–	ROM
Molannidae					
Molanna sp.	X	Ont	June	–	ROM

(X = one or more specimens recorded from a single location; X2 = one or more specimens recorded from two locations; etc. Abbreviations are described in the text).

THE CANADIAN ORTHOPTEROID INSECTS SUMMARIZED AND UPDATED, INCLUDING A TABULAR CHECK-LIST AND ECOLOGICAL NOTES

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Abstract *Proc. ent. Soc. Ont.* 118:25-45 (1987)

Nomenclatural changes which affect orthopteroid species found in Canada are discussed and valid names are given. General ecological notes are included together with a tabular check-list which indicates the distribution of species for each province or territory, as well as Alaska, and includes ecological data for each species.

Introduction

Several works on the orthopteroid insects of northern North America have appeared in recent years. These include: Brooks (1958) on the species found in the prairie provinces of Canada; Vickery (1961) on Nova Scotian species; Vickery (1967, 1969) species of Alaska, Yukon and Mackenzie District, Northwest Territories; Vickery and Kevan (1967) and Vickery and Kerr (1975), for Ontario; Vickery *et al.*(1974) for Quebec and the Atlantic Provinces; Vickery (1984) for the Yukon Territory; and Vickery (in press) rationalizing recent work. A monograph of the orthopteroid insects of Canada by Vickery and Kevan (1983) included the species found in Canada, Alaska, Greenland and the northern tier of states in the United States of America. This monograph was modified and issued by Agriculture Canada in the series "Insects and Arachnids of Canada" (Vickery and Kevan 1986). In the latter publication, the sequence of taxa of all hierarchical levels was altered and does not conform to that recognized by Vickery and Kevan (1983). A check-list which was to be included to indicate the arrangement accepted by the authors was deleted, without consultation with the authors, from the 1986 publication, thus making necessary publication of the check-list included in this paper.

Otte (1981, 1984) published two books covering three subfamilies of Acrididae occurring in the geographical area from Arctic Canada and Alaska to Panama in Central America. Otte has access in the Academy of Natural Sciences of Philadelphia, to large series of many species, including many holotypes and other type specimens, and was able to make a number of nomenclatural changes. We agree with some, but not all of these changes. Very extensive collecting of specimens in western Canada by the first author, during the summer of 1985, made possible objective decisions and conclusions regarding the changes made by Otte.

Consequently, it has become necessary to resolve the apparent disparity in the points of view of Otte (1981, 1984) and Vickery and Kevan (1983, 1986). The discussion considers all of the species added to, or deleted from the Canadian orthopteroid fauna, as well as discussion of the nomenclatural changes and the reasons for acceptance or rejection of changes proposed by Otte (1981, 1984) and others. In the tabular arrangement each taxon which differs, or has been proposed to differ, from the name used in the monograph by Vickery and Kevan (1983) is marked by asterisk, and the changes are explained in order in the Discussion.

General Ecological Notes

It is appropriate to preface the tabular arrangement with some general ecological notes at ordinal, superfamily or subfamily levels.

ORDER DICTUOPTERA: This order includes three suborders, which superficially appear to be a rather strange aggregation, as habitus, habits and habitats are diverse.

SUBORDER BLATTODA: This suborder includes all of the cockroaches. Almost all the species found in Canada have been brought into the country accidentally and have been very successful in becoming established in buildings which are heated during the winter months; they could not survive outside. These are known as domiciliary species. One genus, *Parcoblatta,* is an exception. It contains free-living species found in wooded areas in southern Ontario and in southwestern Quebec. The native species are not pests, although they may cause minor annoyance by seeking shelter in the fall in summer cottages.

SUBORDER MANTODEA: The "praying mantids", more appropriately called "preying mantids", are all predaceous on insects and other small animals. Only one species is native, the small brownish, ground-dwelling *Litaneutria minor* (Scudder), which occurs in extreme southern Alberta and British Columbia and ranges southward to Mexico. The others, one species in each of the genera *Mantis* and *Tenodera,* are of rather recent introduction, and have not, and probably will not, extend their ranges beyond southern parts of Quebec, Ontario and British Columbia. Population levels are low as the species are close to their geographic survival limits. Their value as predators of pest insects is minimal in Canada.

SUBORDER TERMITODEA: This suborder is called Order Isoptera by some authors. These insects are actually or potentially important economically wherever they occur in Canada. They can eat and, because of their gut flora of flagellate protozoans, digest cellulose and they normally attack wood. The most serious pest species, *Reticulitermes flavipes* Banks, is living near its northern climatic limit and is largely, but not entirely, dependent upon artificial heat in order to survive during the winter months. It, like all the other termite species in Canada, except one genus, has been imported accidentally. The exception, *Zootermopsis* with two species in British Columbia, is native and although these species normally attack wet, decaying wood in forests, they are capable of infesting timbers which are in direct contact with the soil. All termites are social animals and a colony may contain only a few or a great many thousands of individuals.

ORDER NOTOPTERA: These are called rock-crawlers, *Grylloblatta* species, that occur in cold areas in scree, rock and ice caves, etc., in the western mountains. This order of insects was discovered in Canada as new to science by E.M. Walker of Toronto. The insects apparently develop very slowly and are predators of a wingless crane fly. Their importance lies in their scientific and historical interest but they have no economic significance (Vickery and Kevan 1983).

ORDER DERMAPTERA: The insects in this order commonly are called earwigs. They are characterized by their curved posterior appendages. Most, if not all, of the species are accidental introductions. Like some other insect species, these creatures, when introduced into a new area, tend to procreate rapidly to very high population levels. This is especially true of the European Earwig, *Forficula auricularia* (L.). Although their food is usually other insects, when they occur in such great numbers they also attack plants often destroying the flowers of dahlia, marigolds and other flowering plants. They also find a way to enter houses, where they do little if any damage, but certainly are objectionable. Sooner or later, usually during a period of about 15 years, the population declines to a low level so that their presence is scarcely noticed. The decline is probably caused by attacks by local predaceous insects such as certain beetles, which take advantage of the increased food supply.

ORDER CHELEUTOPTERA OR PHASMATOPTERA: These are the stick insects

and they are relatively rare with one genus and one species, *Diapheromera femorata* (Say), in Canada. It is rare in southern Quebec and southeastern Manitoba but is more common in southern Ontario. It feeds on oak leaves and has caused severe defoliation of black oak in southern Ontario on a few occasions.

ORDER GRYLLOPTERA: The true Grylloptera, an order composed of crickets, camel crickets, katydids and related groups, is represented in Canada by many native species. No species are known from north of the "tree line" and, in Canada, most occur in a relatively narrow strip of territory along the United States border.

SUBORDER TETTIGONIODEA: This suborder includes camel crickets, katydids, etc.

Family Raphidophoridae: The camel (or cave) crickets, mainly *Ceuthophilus* species, are nocturnal, wingless, woodland inhabitants which most people never see. Occasionally, specimens may be found in damp areas of basements or cellars but they do no damage in such situations. Other genera, *Pristoceuthophilus* and *Tropidischia*, occur in Canada only in British Columbia. *Udeopsylla* is found only in Manitoba and is not economically important.

Family Stenopelmatidae: The wingless "Jerusalem crickets", two species of *Stenopelmatus* found in extreme southern British Columbia, are usually considered to be rare curiosities, although there are some reports of damage to roots of seedlings and to developing potato tubers.

Family Prophalangopsidae: Two species of *Cyphoderris* live in southwestern Alberta and southern British Columbia. Males produce sound to attract females. They are known to climb lodgepole pine trees and to feed upon the pollen produced by staminate flowers (Morris and Gwynne 1979). They are not economically important but are interesting as *Cyphoderris* includes the sole remaining representatives of this very ancient group of insects, known mainly from fossils. A Canadian fossil representative is known by isolated wings from Palaeogene deposits of southern Alberta (Kevan and Wighton 1981, 1983).

Families Phaneropteridae and Pseudophyllidae: These are "false" and "true" katydids, respectively, most of which can fly well. Almost all species are phytophagous, and most feed upon shrubs, weeds or trees and produce little if any economic injury. A very few species attack other insects. They are widely known for the "songs" they produce, the males of each species stridulating, producing a sound which varies in pitch, duration and in pulse sequences, so that it attracts only the females of its own species. A competent observer, after sufficient study, can identify many species of Grylloptera by sound alone without ever seeing them.

Family Tettigoniidae: This family includes eight genera in Canada, some of which can fly although most have reduced wings. The males use their wings almost exclusively to produce sound. Except for the wingless camel crickets and their relatives mentioned above, stridulation by males to attract females for mating is the rule rather than the exception in Grylloptera. Some species, notably *Anabrus simplex* Haldeman, the "Mormon Cricket", at times becomes a serious pest of crops. Other species occasionally may cause crop damage. *Metrioptera roeselii* (Hagenbach), which was introduced into Quebec from Europe, probably on military aircraft near the end of World War II, has extended its range in Quebec and Ontario as well as deep incursion into the eastern United States (Vickery 1965). It has not become a serious pest of crops.

Family Conocephalidae: These are the so-called "meadow grasshoppers". They occur all across Canada, although there are many more species (12:3) in the east than in the west. In general they are found in rank, humid vegetation where they feed upon a mixed diet of seeds and herbage. Two genera, *Orchelimum* and *Conocephalus* are common. Females oviposit in plant material but cause little if any damage.

SUBORDER GRYLLODEA: This suborder contains all of the true crickets. Only four of the many families occur in Canada and two of these are rare or are confined to rather restricted distribution. One species of Myrmecophilidae is found only in British

Columbia. It is an ant mimic, living in ant colonies, and is entirely dependent upon the host ants for its livelihood. The Family Trigonidiidae is represented by a single species, *Anaxipha exigua* (Say) which occurs in Canada only in extreme southern Ontario. It inhabits mud flats and nearby vegetation along streams and marshes, and is not of economic significance.

Family Gryllidae, Subfamily Gryllinae: The common black field crickets, *Gryllus* species, occur throughout southern Canada. One species *G. veletis* (Alexander and Bigelow), a relatively solitary species, is found only in the spring. Later in the season, *G.pennsylvanicus* (Burmeister), a much more gregarious species, becomes numerous. It is known to occur in all Canadian provinces although *G. veletis* is not known from the Atlantic Provinces. A single living specimen found in Port-aux-Basques, Newfoundland, is known to have been an accidental introduction. *G. pennsylvanicus* has occasionally been classed as a pest in the past because of its habit of chewing through the binder twine, causing wheat sheaves to fall apart. It has also been accused of damaging ripening tomatoes and other crops, though the reports have been sporadic and in most cases, the injury was slight. The beneficial service the insect provides in destroying egg pods of pest species of grasshoppers outweighs any damage it might cause.

The house cricket, *Acheta domesticus* (L.), is another imported species. Although it is almost entirely domiciliary, living in heated buildings, it is sometimes able to survive winter outside in particularly favourable locations. Some people enjoy the "singing" of the males in their dwellings, but most people object and demand information on the methods of driving them out of the inaccessible places in which they hide.

Subfamily Nemobiinae: Three genera of small "ground" and "wood" crickets (Vickery and Johnstone 1973), cause no problems and, indeed, like their larger cousin, *G. pennsylvanicus,* are more helpful than harmful. One species, *Allonemobius fasciatus* (DeGeer) is known to destroy the pupal stages of certain Diptera, (*Rhagoletis* species), which attack ripening fruit.

Family Oecanthidae: The tree crickets are known mainly by their nocturnal stridulation. Females lay their eggs in plant stems and, although most of the plants are those we class as weeds, one tree cricket, *Oecanthus nigricornis* F. Walker, causes injury to tobacco, raspberry and blackberry, and may also damage new growth on twigs of fruit trees.

ORDER ORTHOPTERA: These are the true grasshoppers and locusts. The suborders Tetrigodea and Tridactylodea are not of economic significance. The Tetrigidae are small, unobtrusive creatures, nearly always found near water, where they feed upon algae and possibly some mosses. The Tridactylidae are rare in Canada, though they may be quite numerous in isolated spots along muddy banks of streams. Apparently, they ingest sand particles and are nourished by minute fragments of organic matter and perhaps microscopic algae found on the sand.

SUBORDER ACRIDODEA:

Superfamily Acridoidea: This suborder and superfamily contain the most important economic pests of any of the orthopteroid insects.

FAMILY ACRIDIDAE:

Subfamily Cyrtacanthacridinae: This subfamily contains the notorious genus *Schistocerca.* One species *S. gregaria* (Forskål), occurs in Eurasia and Africa. All other species live in the Americas. One of these, *S. americana* (Drury), does not breed in Canada but does migrate into Canadian territory occasionally. *S. emarginata* (Scudder) is resident in the prairie provinces close to the United States border. It occurs in a variety of habitats, but prefers dry areas. Its favourite food plant is wild liquorice but when it is numerous will feed also upon beans, sweet clover, alfalfa and several non-economic plants.

Subfamily Melanoplinae: This subfamily includes some economically important species that are capable of causing severe damage to crops. Two tribes are represented

but only two species of the tribe Podismini are known to occur in Canada. One of these, *Bohemanella frigida* (Boheman) is an Holarctic species which, in North America, is found only in the far north on Arctic tundra (Vickery 1984). A second species, *Dendrotettix quercus* Packard was reported once in Canada on the north shore of Lake Erie. Several subsequent attempts to find it there were unsuccessful. It occurs in Michigan, Wisconsin and neighbouring states.

The tribe Melanoplini contains the genus *Melanoplus* and a number of related genera. Only one of these latter, *Phoetaliotes* (one species, *P. nebrascensis* (Thomas)), is considered to be economically important. Damage in the past has been sporadic but the species has potential to be destructive to grasses and crops.

Melanoplus contains a greater number of species than any other genus of orthopteroid insects in Canada. Although a few species, *M. sanguinipes* (Fabricus), *M. packardii* (Scudder), *M. bivittatus* (Say) and *M. femurrubrum* (DeGeer), are graminivorous and are responsible for quite frequent severe damage to crops, most of the other species either cause no economic damage at all or only occasional, very minor injury. One species, *M. spretus* (Walsh), exhibited the features attributed to a true locust species as it was capable of long distance migration and occurred in vast numbers. This species became extinct about 1902-03 but the reason for its sudden extinction has not yet been ascertained. There is no clear pattern of distribution of the species of *Melanoplus,* which varies from occurrence throughout Canada and beyond into Alaska and other states south of the Canada-United States border, while other species have very restricted distribution in Canada. Some species occur mainly in the United States and barely extend their distribution northward into Canada. Some species occur only in the east; others are found only in the west. The habitats and food-plant preferences of the species are diverse. Two species of the genus, *M. gaspesiensis* Vickery and *M. madeleineae* Vickery and Kevan, are found only in Quebec, the former at the summit of Mount Albert in the Gaspe region (Vickery 1970), and the latter only on the Magdalen Islands (Vickery and Kevan 1978, 1983, 1986; Kevan and Vickery 1978).

The Tabular Check-list

This section includes the accepted scientific names and sequence of taxonomic arrangement as recognized by the first author. The nomenclatural changes made by Otte (1981, 1984) that affect taxa which occur in Canada, and with which we are in agreement, are included. The check-list of Scudder and Vickery (1985) is now outdated. The following list indicates clearly the species which are known to occur in each of the Canadian provinces and territories. It also provides a guide to curators in arranging the taxa in their museums or collections.

The symbols (letters) under the vertical geographical headings are as follows:

X indicates a native species;
N indicates an alien species that has become established;
A indicates adventive species that, so far as we are aware, have not become established in Canada;
E indicates that the species is extinct, at least in the area in Canada where it had been known;
R indicates that the species has not occurred naturally but was reared in laboratories. We are not aware of any species in this category that has escaped and managed to become established in Canada.

The column headed ECOLOGY employs lower case letters to indicate food preferences, habits or habitats of the species concerned.

a – species which occur in dry, arid or sandy areas;
aa – species which occur at high altitude;
d – domiciliary species, which persist during Canadian winters only in heated buildings;

f – usually forbivorous but includes also species found on bushes and shrubs in forested or in open areas;
fr – forest dwellers, non-economic species;
ft – mainly forest dwellers, foliage feeders on trees sometimes causing defoliation;
g – graminivorous species, not usually considered to be pests;
h – greenhouse pests;
i – this letter, following any of the others, indicates species that can cause significant plant injury;
in – this combination indicates inquiline species, found only in the nests of ants;
m – mesic, found mainly near water or swampy areas;
n – this letter, following any of the others, indicates species that are nocturnal; it may appear alone opposite a higher category taxon to indicate that the entire group is mainly nocturnal;
o – omnivorous species, those which normally feed on both plant and animal material, many are scavengers;
p – predaceous species, those which hunt, kill and eat other invertebrates;
pp – generally predaceous, but at high population levels also feed on plants;
r – species found in grassy areas, may or may not be graminivorous;
s – species that usually live in the soil in burrows;
sc – species that live in leaf-litter in forested areas – or in caves;
t – species found only on Arctic tundra;
w – wood-feeding species – termites;
? – adventives, and a few others of which the habits, habitats or food preferences in this region (if survival is possible) are not known.

For many species, the ecological data is given by combinations of the above letters; e.g., **gfi** indicates a species which is mainly graminivorous, but also in part forbivorous and can cause serious economic injury to plants; **fra** indicates a species found in dry to arid forested areas.

Subfamily Locustinae: This subfamily is called Oedipodinae by most authors. There is no general agreement on acceptance of Locustinae, the oldest name for the group, over the more recent name, Oedipodinae. It is represented in Canada by 19 genera. It is often referred to as "The Band-winged" grasshoppers, although there are species included which have colourless wings, and another subfamily, the Gomphocerinae, has a few species which do have colour-banded hind-wings. All genera, except one, are included in the Tribe Locustini. In general, species in these genera live in dry locations. Males of all species produce sound, which is different in each species. This can be stridulation while on a substrate or, more commonly, crepitation in flight. The distribution is wide-spread, some species occurring throughout Canada, but others have very restricted ranges. One species, *Camnula pellucida* (Scudder), is capable of causing damage to cereal and other crops wherever it occurs in numbers. It is classed as one of the three most important economic species of grasshoppers in Canada (Vickery and Kevan 1983). Some other species of locustine grasshoppers, in the genera *Trimerotropis* and *Circotettix*, are potential crop pests, but only occasional and localized damage has been reported.

The genus *Stethophyma* is in the anomalous position of being included in the Subfamily Locustinae, Tribe Epacromiinae, by some authors, including Vickery and Kevan (1983, 1986), but is removed to the Subfamily Gomphocerinae by Otte (1981). The method of sound production is typically locustine, though Otte (1981) considers the lack of the femoral stridulatory pegs, the presence of which is typical of the Gomphocerinae, to be a secondary condition. Contrary to other genera of the Locustinae, the species of *Stethophyma* in Canada prefer swampy or marshy areas, or at least locations near water and usually in fairly dense vegetation.

Subfamily Hyalopteryginae: The single representative of this subfamily is *Metaleptea brevicornis* (Johansson). It is mainly a tropical species with very great range

extending from southern Ontario southward through Central America and it occurs widely in South America. It inhabits swampy areas. Otte (1981) places this species in the Subfamily Acridinae in the "Hyalopteryx Genus Group."

This species was chosen as part of the emblem of the former "Pan-American Acridological Society" and has been retained since the society became global in scope in 1986 as "The Orthopterists' Society".

Subfamily Gomphocerinae: Most of the included species are rather small and are characterized by their slanting faces, with an acute angle between the top of the head and the face. The males of the species found in Canada stridulate by rubbing a row of pegs on the hind femur against a "scraper" on the edge of the tegmen. In most cases the sound is of low intensity and cannot be heard at distances of more than a few meters, some much less than that.

Several of the species are graminivorous and may cause crop damage if they occur at high levels of population. In contrast to the Locustinae, many members of the Gomphocerinae show marked preference for damp areas or occur in rank vegetation where the humidity is high.

Some species, like *Chorthippus c. curtipennis* (Harris) have very wide distribution in all provinces and territories. Other species are very localized, such as *Bruneria yukonensis* Vickery, which occurs in only a few localities in the Yukon.

Discussion

In the past a number of authors have made changes in nomenclature at all levels and have not given any information to assist readers in evaluating these changes. Otte (1981, 1984) provided such information as he deemed to be necessary, which is a great improvement over the work of some of the authors who preceeded him.

It is necessary to explain the changes contained in this paper. The following notes are given in the same order in which the taxa or names of taxa in the tabular list (those marked with asterisks) differ from the previous work of Vickery and Kevan (1983, 1986) and in some cases from the work of Otte (1981, 1984).

Subfamily Ceuthophilinae

Pristoceuthophilus gaigei Hubbell was recorded by Vickery and Kevan (1983:337). It has now been placed as a synonym of *P. cercalis* Caudell by Hubbell (1985).

Ceuthopilus g. gracilipes (Haldeman) was found at Delhi, Ontario, 14-VII-1983 by H.H. Cheng, the first record for Canada. The specimen is in the Canadian National Collection.

FAMILY CONOCEPHALIDAE

Belocephalus subapterus Scudder is the adventive species reported in Canada, not *B. sabalis* Davis, as listed by Vickery and Kevan (1983).

Pseudorhynchus concisus (F. Walker) is a new Canadian adventive record from British Columbia. It is not established, nor is likely to become established in Canada.

FAMILY GRYLLOTALPIDAE

Scapteriscus acletus Rehn & Hebard has been found as adventive (Canada Department of Agriculture, 1977) but we do not know the province.

FAMILY ACRIDIDAE: Subfamily Melanoplinae

Melanoplus. The genus requires revision. The first author has unpublished cytological data which indicates that it should be subdivided.

Melanoplus foedus Scudder and *Melanoplus stonei* Rehn are difficult to separate. Males can be distinguished from *M. packardii* Scudder only by comparison of genitalia; see figures 23 and 24 in Brooks (1958) and figures 552-555 in Vickery and Kevan (1983, 1986). The genitalia of *M. foedus* and *M. stonei* are very much alike, but *M. foedus* has blue hind tibiae and is found in Manitoba, Alberta and British Columbia; *M. stonei* has red hind tibiae and occurs from New Brunswick west to Manitoba.

Melanoplus packardii packardii Scudder has blue hind tibiae and has been recorded from

Manitoba to British Columbia. *M.p. brooksi* Vickery has red tibiae and both sexes are easily distinguished by the very dark dorsal bars on the hind femora. It occurs only in northern Saskatchewan, Alberta and probably British Columbia. It is a forest and parkland dweller; *M.p. packardii* is an inhabitant of open prairies, and lacks the intense dark dorsal bars on the hind femora.

M. flavidus Scudder is easily confused with *M. bowditchi canus* Hebard. Comparison of male genitalia is the only satisfactory method of determining males of the two species; see figures 22 and 25 in Brooks (1958) and figures 556, 557, and 558, 559 in Vickery and Kevan (1983, 1986). We have not found a satisfactory method of distinguishing between females of these species and those of *M.p. packardii,* though *M.p. brooksi* can be separated by the dorsal femoral bars.

FAMILY ACRIDIDAE: Subfamily Locustinae (Oedipodinae)

Otte (1984) has continued the use of the name Oedipodine for the "bandwinged" grasshoppers, although noting that Locustinae is the oldest name. We do not agree that Locustinae should not be used merely because it has been misused in the past, the reason given by Dirsh (1975), and followed by Otte (1984). The group remains the same, however, regardless of the name and family-group names do not have age priority.

Xanthippus vitellinus Saussure. This species was recorded by Vickery and Kevan (1983, 1986) as occurring in British Columbia. Otte (1984) synonymized this name under *Agymnastus ingens* (Scudder), a species which does not occur in Canada. Specimens in the Lyman Collection, determined by Hebard as *X. vitellinus,* are not *A. ingens* but *Cratypedes lateritius* (Saussure). Additional specimens of *C. lateritius* were obtained by the first author from Dr. J.A. Garland, collected at Penticton, British Columbia in 1985.

Xanthippus corallipes subspecies, with one exception, were placed in synonymy under the nominate subspecies by Otte (1984). The exception is *X. brooksi* Vickery, which he raised to species. We agree with the synonymy except for the taxon *X.c. buckelli* Hebard. Strohecker (1952) stated that most of the "so-called" subspecies should be considered as synonymous with *X. corallipes* but that *buckelli* was valid.

Xanthippus aquilonius Otte, 1984: 112-113, pl. 8b. Otte (1984) described *Xanthippus aquilonius* from southern British Columbia. Four paratypes have been examined. These show characteristics as listed by Hebard (1928) in his description of *X. corallipes buckelli.* I have not seen the holotypes of either *buckelli* or *aquilonius.*

Cratypedes lateritius (Saussure). Recorded by Otte (1984), and confirmed by Vickery, this species is found in the Okanagan Valley of British Columbia (see under *Xanthippus vitellinus* above).

Dissosteira pictipennis Bruner. Otte (1984) has shown this species in Alberta on a distribution map. We have not seen specimens from Canada. We doubt that it breeds in Canada and class it as an accidental adventive.

Trimerotropis campestris McNeill. This species has been transferred to the genus *Spharagemon* by Otte (1984). Although Vickery and Kevan (1983, 1986) had noted the similarity of this species to species of *Spharagemon,* we were at first unwilling to accept this drastic change as placement of the species in *Trimerotropis* has been accepted by many workers for many years. During 1985, the first author and his wife collected 30 specimens of this species east of Val Marie, Saskatchewan, and others at other localities. There is no doubt that all of the specimens are conspecific, although in some of them the median carina of the pronotum is clearly cut by two sulci (as in *Trimerotropis)* and others in which only one sulcus cuts the carina (as in *Spharagemon.*) We accept the placement of *campestris* McNeill in *Spharagemon* on the basis that the number of sulci cutting the median pronotal carina can no longer be considered as a valid criterion for generic separation. *T. longicornis* E.M. Walker was removed from synonymy with *T. campestris* by Vickery (1979). Otte (1984) placed *T. longicornis* in symphony with *Spharagemon campestris.*

We now agree that the name *T. longicornis* was applied to an aberrant form which has yellow-green hind tibiae rather than the normal red hind tibiae of *campestris*.

Scirtetica. Otte (1984) placed this generic name in synonymy under *Spharagemon* on the grounds that the features said to distinguish the two genera are inconsistent. The resemblance of *Scirtetica* to *Spharagemon* was noted without additional comment by Vickery and Kevan (1983, 1986).

Metator nevadensis (Bruner). The distribution map of Otte (1984) does not show this species from any locality in Canada but it does occur in Canada. The Lyman Collection has 8 males and 6 females from localities in British Columbia.

Trachyrhachys kiowa (Thomas). Vickery and Kevan (1983) indicated that the named subspecies probably represented variations along a cline. Otte (1984) listed the subspecific names *fuscifrons* (Stål) and *thomasi* (Caudell) as synonyms of the nominate *T. kiowa*. We agree and have deleted the subspecific designations in this paper.

Conozoa sulcifrons Scudder. We believe that Otte (1984) is correct in placing *C. wallula* (Scudder 1881) as a synonym of *Conozoa sulcifrons* (Scudder 1876), although we have not seen the type specimens.

Conozoa texana (Bruner) is indicated for a locality in British Columbia on the distribution map for the species by Otte (1984:171). We have not seen specimens of *C. texana* from Canadian localities. Several collections of Orthoptera from British Columbia were sent by E.R. Buckell in the 1920's to Morgan Hebard, Philadelphia Academy of Natural Sciences, where Otte is now curator. *C. texana* may have been in one of the collections, but was never identified as that species by Hebard. The separation between *C. texana* and *C. sulcifrons* is not consistent throughout the range of the two species and we include *C. texana* as a somewhat doubtful record.

Trimerotropis sordida E.M. Walker. Otte (1984) placed *T. sordida* as a synonym of *T. gracilis* (Thomas). The relationship between the two is of long standing, *T. sordida* having been considered as a subspecies of *T. gracilis* by many authors, but not by Vickery and Kevan (1983, 1986). Otte indicated that additional work is necessary and we agree with him. For the time being, however, we place *T. sordida* as a valid species.

Trimerotropis diversellus Hebard. The prairie "subspecies" *Trimerotropis pallidipennis salina* McNeill has been shown by Otte (1984) to be misidentified and is actually *Trimerotropis diversellus* Hebard. *T. salina* McNeill is valid at species rank but does not occur in Canada. All Canadian specimens labelled as *Trimerotropis pallidipennis salina* McNeill are *T. diversellus*. *T. pallidipenis* (Burmeister) occurs in British Columbia.

Trimerotropis cincta (Thomas) and *T. koebeli* (Bruner) are listed on the basis of distribution maps of Otte (1984:210) which show both of these species occurring in British Columbia, in spite of the fact that he states that the two species "are entirely allopatric". He also states that the two species are "almost indistinguishable". We suspect misidentification of some slightly aberrant forms of *T. fontana* Thomas, a species which occurs in British Columbia and which Otte states "may be confused with *koebeli* and *cincta*" Four specimens determined as *koebeli* by Otte, have been examined but are not **definitely** one species or the other.

Circotettix Scudder, 1876. We accept the synonymy of *Aerochoreutes* Rehn, 1921, with *Circotettix* as stated by Otte (1984). We also agree that the subspecies name *strepitus* Rehn, 1921, is synonymous with *carlinianus* Thomas, 1870. If Otte (1984) had not placed *strepitus* as a synonym of *carlinianus*, we would have taken this action, following examination of a large series taken in 1985 over the entire Canadian range of the species.

Stethophyma. Otte (1981) placed *Stethophyma* as an aberrant genus in the Subfamily Gomphocerinae. The stridulatory apparatus is composed of a serrated intercalary vein on the tegmen and a smooth ridge on the hind femur, not the row of femoral pegs which is typical of the Gomphocerinae. Vickery and Kevan (1983, 1986)

placed the genus, as in this paper, in the Tribe Epacromiini of the Subfamily Locustinae. We believe this to be the most appropriate placing for *Stethophyma* and its Palaearctic relatives.

FAMILY ACRIDIDAE: Subfamily Gomphocerinae

Boopedon nubilum (Say) was collected in the Big Muddy Valley of southern Saskatchewan by Vickery in 1985. Hebard (1932) and Vickery and Kevan (1983) stated that *B. numilum* would probably be found eventually in Saskatchewan as it occurred in Montana close to the Canadian border.

FAMILY TRIDACTYLIDAE

Ellipes m. minutus (Scudder). The range of this tiny tridactylid has been extended westward as it was collected at Sprague Creek, Manitoba in 1985 by R. Roughly, University of Manitoba (personal communication 1985).

References

Brooks, A.R. 1958. Acridoidea of Southern Alberta, Saskatchewan and Manitoba (Orthoptera). Canadian Entomologist, Supplement 9, 92 pp.

Canada Department of Agriculture. 1977. Intercepted plant pests 1976-77. Canada Department of Agriculture, Plant Quarantine Division Report, Ottawa. i + 39 pp.

Dirsh, V.M. 1975. Classification of the acridomorphoid insects. E.W. Classey Ltd., Faringdon, England, v-vii + 171 pp.

Hebard, M. 1932. Notes on Montana Orthoptera. Proceedings Academy of Natural Sciences of Philadephia, 84: 251-257.

Hubbell, T.H. 1985. Unfinished business and beckoning problems. Florida Entomologist 68: 1-10.

Kevan, D.K.McE. and V.R. Vickery. 1978. The orthopteroid insects of the Magdalen Islands with notes from adjacent regions. Annals Entomological Society of Quebec, 22: 193-204.

Kevan, D.K. McE. and D.C. Wighton. 1981. Palaeocene orthopteroids from south-central Alberta, Canada. Canadian Journal of Earth Sciences, 18: 1824-1837.

Kevan, D.K.McE. and D.C. Wighton. 1983. Further observations on North American Tertiary Orthopteroids (Insecta:Grylloptera). Canadian Journal of Earth Sciences, 20: 217-224.

Morris, G.K. and D.T. Gwynne. 1979. Geographical distribution and biological observations of *Cyphoderris* (Orthoptera: Haglidae) with a description of a new species. Psyche, 85 (1978): 147-167.

Otte, D. 1981. The North American Grasshoppers. Volume 1. ACRIDIDAE. Gomphocerinae and Acridinae. Harvard University Press, 275 pp.

Otte, D. 1984. The North American Grasshoppers. Volume 2. ACRIDIDAE. Oedipodinae. Harvard University Press, 366 pp.

Scudder, G.G.E. and D.K. McE. Kevan. 1984. A check-list of the orthopteroid insects recorded from British Columbia. Journal Entomological Society of British Columbia, 81: 76-79.

Scudder, G.G.E. and V.R. Vickery. 1985. A tabular check-list of Canadian orthopteroid insects. Note, Lyman Entomological Museum and Research Laboratory, 13: 1-19.

Strohecker, H.F. 1952. Description of New Species and Notes on North American Orthoptera. American Midland Naturalist, 48: 683-688.

Vickery, V.R. 1961. The Orthoptera of Nova Scotia. Proceedings Nova Scotia Institute of Science, 25: 1-70.

Vickery, V.R. 1965. Factors governing the distribution and dispersal of the recently introduced grasshopper, *Metrioptera roeseli* (Hgb.) (Orthoptera Ensifera). Annals Entomological Society of Quebec, 10: 165-172.

Vickery, V.R. 1967. The Orthoptera of Alaska, Yukon and the Mackenzie district of the Northwest Territories. Transactions American Entomological Society, 93: 249-278.

Vickery, V.R. 1969. Two new species of Sub-Arctic American Orthoptera. Entomological News, 80: 265-272.
Vickery, V.R. 1970. A new species of *Melanoplus* (Orth:Acrid.) from Quebec. Annals Entomological Society of Quebec, 15: 6-13.
Vickery, V.R. 1984. The orthopteroid insects of Yukon. Note, Lyman Entomological Museum and Research Laboratory, 10: i-iv + 1-42.
Vickery, V.R. 1987. The orthopteroid insects in northern North America: updating and rationalizing recent work. Canadian Entomologist, 119: (in press).
Vickery, V.R. and D.E. Johnstone. 1973. The Nemobiinae (Orthoptera:Gryllidae) of Canada. Canadian Entomologist, 105: 623-645.
Vickery, V.R., D.E. Johnstone and D.K.McE. Kevan. 1974. The orthopteroid insects of Quebec and the Atlantic Provinces of Canada. Memoir Lyman Entomological Museum and Research Laboratory, 1: i, 1-204.
Vickery, V.R. and G.E. Kerr. 1975. Additional records of Ensifera (Grylloptera) in Ontario. Proceedings Entomological Society of Ontario, 105: 96-100.
Vickery, V.R. and D.K.McE. Kevan. 1967. Records of the orthopteroid insects in Ontario. Proceedings Entomological Society of Ontario, 97: (1966): 13-68.
Vickery, V.R. and D.K.McE. Kevan. 1978. A new species of *Melanoplus* (Orthoptera: Acrididae: Melanoplini) from the Magdalen Islands, Quebec. Annals Entomological Society of Quebec, 22: 188-192.
Vickery, V.R. and D.K.McE. Kevan. 1983. A monograph of the orthopteroid insects of Canada and adjacent regions. Memoir Lyman Entomological Museum and Research Laboratory, 13 (1): i-xxii + 1-679 pp; (2): i-iv + 681-1462 pp.
Vickery, V.R. and D.K.McE. Kevan. 1986. The Grasshoppers, Crickets and related Insects of Canada and adjacent regions. Ulonata: Dermaptera, Cheleutoptera, Notoptera, Dictuoptera, Grylloptera and Orthoptera. The Insects and Arachnids of Canada, Part 14. Publication Agriculture Canada, 1777(1985): 918 pp.

(Received 11 December, 1986; accepted 16 June, 1987)

Tabular Check-list of Canadian orthopteroid insects
Taxa marked with an asterisk (*) are discussed and explained in Discussion

	Alaska	Yukon	N.W.T.	B.C.	Alta.	Sask.	Man.	Ont.	Que.	N.B.	P.E.I.	N.S.	Nfld.	Ecology
ORDER DICTUOPTERA														
SUBORDER BLATTODEA														
SUPERFAMILY BLATTOIDEA														
FAMILY BLATTIDAE														
Subfamily Blattinae														
Blatta orientalis Linnaeus				N	N	N		N	N			N	N	d
Periplaneta americana (Linnaeus)				N	N	N	N	N	N			N	N	d
P. australasiae (Fabricius)				N		N		N	N			N	N	d
P. brunnea (Burmeister)									A			A		d
P. fuliginosa (A. -Serville)				A					A					d
Subfamily Polyzosterinae														
Eurycotis floridana (F. Walker)												A	A	d
E. opaca (Brunner v.W.)									A					d
SUPERFAMILY BLABEROIDEA														
FAMILY BLABERIDAE														
Subfamily Blaberinae														
Archimandrita tessellata Rehn									A					d
Blaberus giganteus (Linnaeus)						R		R	AR					d
B. discoidalis A. -Serville									R					d
B. craniifer Burmeister				R										d
FAMILY NAUPHOETIDAE														
Subfamily Panchlorinae														
Panchlora nivea (Linnaeus)	A			A	A	A		A	A	A		A		d
P. latipennis (Saussure & Zehntner)				A										d
Subfamily Nauphoetinae														
Nauphoeta cinerea (Olivier)									A					d
Rhyparobia maderae (Fabaricius)					A					A				d
Subfamily Pycnoscelinae														
Pycnoscelis surinamensis (Linn.)				N				A	N?					d
P. indicus (Fabricius)									R					d
FAMILY DIPLOPTERIDAE														
Subfamily Diplopterinae														
Diploptera punctata (Escholtz)									R					d
FAMILY EPILAMPRIDAE														
Subfamily Epilamprinae														
Epilampra maya maya Rehn				A										d
Subfamily Poroblattinae														
Nauclidas nigra (Brunner v.W.)												A		d
N. rufipes (Brunner v.W.)				A										d

	Alaska	Yukon	N.W.T.	B.C.	Alta.	Sask.	Man.	Ont.	Que.	N.B.	P.E.I.	N.S.	Nfld.	Ecology
SUPERFAMILY ECTOBIOIDEA														
FAMILY NYCTIBORIDAE														
Subfamily Nyctiborinae														
Nyctibora laevigata (P. de B.)								A	A					d
N. noctivaga Rehn				A	A			A	A					d
FAMILY BLATTELLIDAE														
Subfamily Pseudophyllodromiinae														
Neoblattella sp.				A										d
Supella longipalpa (Fabricius)				N	N	N		N	N				A	d
Subfamily Blattellinae														
Blattella germanica (Linnaeus)	N	N	N	N	N	N		N	N	N	N	N	N	d
Parcoblatta pennsylvanica (De Geer)								X	X					fr
P. virginica (Brunner v.W.)								X						fr
Parcoblatta uhleriana (Saussure)								X						fr
P. caudelli Hebard								A						fr
Symploce pallens (Stephens)								R	R					d
SUBORDER TERMITODEA														
SUPERFAMILY TERMITOIDEA														
FAMILY TERMOPSIDAE														
Subfamily Termopsinae														
Zootermopsis nevadensis (Hagen)				X										w
Z. angusticollis (Hagen)				X										w
FAMILY KALOTERMITIDAE														
Subfamily Kalotermitinae														
Incisitermes snyderi (Light)									A					w
Cryptotermes brevis (F. Walker)				N			A	A?					w	
FAMILY RHINOTERMITIDAE														
Subfamily Heterotermitinae														
Reticulitermes tibialis Banks					X									w
R. hesperus Banks				X										w
R. flavipes (Kollar)								X?						w
R. virginicus (Banks)								A						w
SUBORDER MANTODEA														
SUPERFAMILY MANTOIDEA														
FAMILY MANTIDAE														
Subfamily Amelinae														
Litaneutria minor (Scudder)				X										P
Subfamily Mantinae														
Mantis religiosa (Linnaeus)				N				N	N					p
Tenodera aridifolia sinensis Saussure								N?	A					p

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ORDER NOTOPTERA														
SUPERFAMILY GRYLLOBLATTOIDEA														
FAMILY GRYLLOBLATTIDAE														
Subfamily Grylloblattinae														
Grylloblatta c. campodeiformis E. Walker				X	X									p
G.c. athapaska Kamp				X										P
G.c. nahanni Kamp				X										p
G. scudderi Kamp				X										p
ORDER DERMAPTERA														
SUBORDER FORFICULOIDEA														
SUPERFAMILY SPONGIPHOROIDEA														
FAMILY ANISOLABIDIDAE														
Subfamily Anisolabidinae														
Anisolabis maritima (Bonelli)				N				A	A					m
Euborellia annulipes (Lucas)				N				A	A					m
FAMILY SPONGIPHORIDAE														
Subfamily Labiinae														
Labia minor (Linnaeus)				N	N		N	N	N	N		N		n
Marava arachidis (Yersin)									A					d
SUPERFAMILY FORFICULOIDEA														
FAMILY FORFICULIDAE														
Subfamily Forficulinae														
Chelidurella acanthopygia (Gene)								A						?
Doru aculeatum (Scudder)								X						m
D. taeniatum (Dohrn)								A						m
Forficula auricularia Linnaeus				N		N		N	N			N	N	pp
ORDER CHELEUTOPTERA														
SUPERFAMILY NECROSCIOIDEA														
FAMILY HETERONEMIIDAE														
Subfamily Heteronemiinae														
Diapheromera femorata (Say)						X	X	X						ft
ORDER GRYLLOPTERA														
SUBORDER TETTIGONIODEA														
SUPERFAMILY STENOPELMATOIDEA														
FAMILY STENOPELMATIDAE														
Subfamily Stenopelmatinae														
Stenopelmatus fuscus Haldeman				X										an
S. longispina Brunner v.W.				X										an

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SUPERFAMILY														
RHAPHIDOPHOROIDEA														
FAMILY RHAPHIDOPHORIDAE														
Subfamily Rhaphidophorinae														
Tachycines anynamorus Adelung						N		N	N					h
Subfamily Tropidischiinae														
Tropidischia xanthostoma (Scudder)				X										
Subfamily Ceuthophilinae														n
Pristoceuthophilus pacificus (Thomas)				X										fr
P. celatus (Scudder)				X	X?									fr
**P. cercalis* Caudell				X	X									fr
Ceuthophilus brevipes Scudder								X	X	X		X	X	fr
C. agassizii (Scudder)				X	X									a
C. pallescens Bruner					X	X	X							frc
**C.g. gracilipes* (Haldeman)								X						frc
C. meridionalis Scudder								X						fr
C. pallidipes E.M. Walker							X	X	X					fr
C. latens Scudder								X						fr
C. maculatus (Harris)						X	X	X	X	X		X		fr
C. pallidus Thomas						X	X							fr
C. uhleri Scudder								X						fr
C.g. guttulosus F. Walker									X			X		fr
C.g. thomasi Hubbell								X	X					fr
C. fusiformis Scudder					X	X	X							fr
C. vicinus Hubbell				X										?
C. alpinus Scudder				X	X	X								aa
Udeopsylla robusta (Haldeman)							X							sni
SUPERFAMILY HAGLOIDEA														
FAMILY PROPHALANGOPSIDAE														
Subfamily Cyrtophyllitinae														
Cyphoderris monstrosa Uhler				X	X									fr
C. buckelli Hebard				X										fr
SUPERFAMILY TETTIGONIOIDEA														
FAMILY PHANEROPTERIDAE														
Subfamily Phaneropterinae														
Phaneroptera g. gracilis Burmeister				A										?
Scudderia septentrionalis (A.-S.)								X	X					
S. pistillata Brunner v.W.				X	X	X	X	X	X	X		X		f
S. curvicauda (De Geer)							X	X	X	X	X	X		f
S.f. furcata Brunner v.W.				X				X	X			X		f
S. fasciata Beutenmüller								X	X					f
S. texensis Saussure & Pictet								X	X					f
Amblycorypha oblongifolia (DeGeer)								X	X					f
Microcentrum rhombifolium (Saussure)				A				X						f
Stilpnochlora couloniana (Saussure)					A									?

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FAMILY PSEUDOPHYLLIDAE														
Subfamily Cyrtophyllinae														
Pterophylla camellifolia (Fabricius)								X						f
Jamaicana subguttata (F. Walker)									A					?
FAMILY TETTIGONIIDAE														
Subfamily Tettigoniinae														
Tribe Decticini														
Anabrus simplex Haldeman				X	X	X	X							si
A. longipes Caudell				X										sf
A. cerciata Caudell				X										sf
A. spokan Rehn & Hebard				X?										sf
Peranabrus scabricollis (Thomas)				X										ao
Neduba steindachneri (Hermann)				X										fn
Apote robusta Caudell				X										fn
Atlanticus testaceus (Scudder)								X						f
A. monticola Davis								X						f
Steiroxys sp.				X	X									ar
Sphagniana sphagnorum (F. Walker)			X	X	X	X	X	X	X					m
Metrioptera roeselii (Hagenbach)								N	N					g
FAMILY CONOCEPHALIDAE														
Subfamily Conocephalinae														
Tribe Copiphorini														
**Belocephalus subapterus* Scudder					A									?
Neoconocephalus ensiger (Harris)								X	X	X		X		g
N. lyristes (Rehn & Hebard)								X						m
N. robustus (Scudder)								X						af
N. triops (Linnaeus)				A					A					?
**Pseudorhynchus concisus* (F. Walker)				A										?
Tribe Conocephalini														
Orchelimum vulgare Harris						X	X	X	X					ma
O. gladiator Bruner						X	X	X	X					m
O. silvaticum McNeill								X?						fr
O. nigripes Scudder								X						m
O. concinnum Scudder								X						m
O. delicatum Bruner								X						m
O. campestre Blatchley								X						m
O. volantum McNeill								X						m
Conocephalus fasciatus (De Geer)				X	X	X	X	X	X	X	X	X		ma
C. brevipennis (Scudder)								X	X					ma
C. strictus (Scudder)								X						fa
C. nigropleurum (Bruner)								X	X					m
C. attenuatus (Scudder)					X	X	X	X						m
C. saltans (Scudder)					X	X	X	X						ma

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SUBORDER GRYLLODEA														
SUPERFAMILY GRYLLOTALPOIDEA														
FAMILY GRYLLOTALPIDAE														
Subfamily Gryllotalpinae														
Neocurtilla hexadactyla (Perty)								X						sni
**Scapteriscus acletus* Rehn & Hebard														gi
S. vicinus Scudder				A										gi
SUPERFAMILY GRYLLOIDEA														
FAMILY GRYLLIDAE														
Subfamily Gryllinae														
Gryllus pennsylvanicus Burmeister				X	X	X	X	X	X	X	X	X		ro
G. veletis (Alex & Bigelow)				X	X	X	X	X	X				A	s
G. assimilis (Fabricius)													A	d
Acheta domesticus (Linnaeus)				N		N		N	N		N	N	N	d
Gryllodes supplicans (F. Walker)									R				A	d
Subfamily Nemobiinae														
Tribe Pteronemobiini														
Allonemobius fasciatus (De Geer)				X	X	X	X	X	X	X	X	X	X	rwo
A. allardi (Alexander & Thomas)				X		X	X	X	X	X		X		ro
A. griseus (E.M. Walker)					X	X	X	X	X					ra
A. maculatus (Blatchley)								X						fa
Neonemobius palustris (Blatchley)							X	X	X			X		m
Eunemobius c. carolinus (Scudder)								X	X	X		X		m
FAMILY TRIGONIDIIDAE														
Subfamily Trigonidiinae														
Anaxipha exigua (Say)								X						m
FAMILY MYRMECOPHILIDAE														
Subfamily Myrmecophilinae														
Myrmecophilus oregonensis Bruner				X										in
FAMILY OECANTHIDAE														
Subfamily Oecanthinae														**n**
Oecanthus niveus (De Geer)								X						f
O. fultoni T.J. Walker				X				X	X					f
O. rileyi Baker				X										f
O. californicus Saussure				X										ft
O. nigricornis F. Walker				X	X	X	X	X	X					fi
O. quadripunctatus Beutenmüller				X	X		X	X	X					fi
O. argentinus Saussure				X	X	X	X							f
O. pini Beutenmüller								X						t

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ORDER ORTHOPTERA														
SUBORDER ACRIDODEA														
SUPERFAMILY ACRIDOIDEA														
FAMILY ROMALEIDAE														
Subfamily Romaleineae														
Romalea guttata (Houttuyn)								A						ma
Brachystola magna (Girard)													A	a
FAMILY ACRIDIDAE														
Subfamily Oxyinae														
Oxya hyla intricata (Stål)								A						?
Subfamily Cyrtacanthacridinae														
Schistocerca americana (Drury)								A	A					mai
S. nitens nitens (Thunberg)												A		mai
Schistocerca emarginata (Scudder)					X	X	X							mai
S.g. gregaria (Forskål)									R					gi
Subfamily Melanoplinae														
Tribe Melanoplini														
Subtribe Dactylotina														
Hesperotettix viridis pratensis Scudder				X	X	X	X							afr
Subtribe Melanoplina														
Aeoloplides t. turnbulli (Thomas)					X	X								ao
Hypochlora alba (Dodge)					X	X	X							af
Phoetaliotes nebrascensis (Thomas)				X	X	X	X							grf
Paroxya hoosieri (Blatchley)								X						m
**Melanoplus viridipes eurycercus* Hebard								X						f
M.o. oregonensis (Thomas)				X	X									aa
M.o. triangularis Hebard				X	X									aa
M. mancus (Smith)								X	X					fa
M. islandicus Blatchley							X	X	X					f
M. montanus (Thomas)				X	X									aa
*M.*n.sp.nr. *montanus*				X										a
M. washingtonius (Bruner)				X	X?									aa
M. huroni Blatchley				X	X	X	X	X	X					fr
M.p. punctulatus (Scudder)								X	X					f
M. bivittatus (Say)				X	X	X	X	X	X	X	X	X	X	goi
M.d. differentialis (Thomas)								N						fo
M. dawsoni (Scudder)				X	X	X	X	X	X					gra
M. gladstoni Scudder					X	X	X							gr
M. confusus Scudder				X	X	X	X	X	X					fo
Melanoplus f. femurrubrum (De Geer)				X	X	X	X	X	X	X	X	X		gfi
Melanoplus gordonae Vickery	X													?
M.b. borealis (Fieber)	X	X	X	X	X	X	X	X	X	X	X	X	X	mgf
M. gaspesiensis Vickery									X					fa
M. madeleinae Vickery & Kevan									X					mg
M. sanguinipes (Fabricius)	X	X	X	X	X	X	X	X	X	X	X	X	X	gri

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M. spretus (Walsh)					E	E	E							gri
M. bruneri Scudder	X	X	X	X	X	X	X	X	X					fg
M. infantilis Scudder				X	X	X	X							fg
M. alpinus Scudder				X	X									gaa
M.k. kennicottii Scudder	X	X	X	X	X	X								f
M.o. occidentalis (Thomas)				X	X	X								f
M. ruggelesi Gurney				X										fo
M. fasciatus (F. Walker)	X	X	X	X	X	X	X	X	X	X	X	X	X	fo
M. keeleri luridus (Dodge)					X	X	X	X	X	X		X		fo
**M.f. foedus* Scudder				X	X	X	X							mf
**M. stonei* Rehn							X	X	X	X				fr
**M.p. packardii* Scudder				X	X	X	X							fgi
**M.p. brooksi* Vickery					X	X								fr
**M. flavidus* Scudder					X	X	X							fga
**M. bowditchi canus* Hebard						X	X							fa
M.a. angustipennis (Dodge)					X	X	X	X						fa
M.c. cinereus Scudder				X										fa
Tribe Podismini														
Subtribe Podismina														
Bohemanella f. frigida (Boheman)	X	X	X											t
Dendrotettix quercus Packard								X						fri
Subtribe Bradynotina														
Buckellacris n. nuda (E.M. Walker)				X	X									fa
B. hispida (Bruner)				X										fa
B.c. chilcotinae (Hebard)				X										f
Bradynotes obesa (Thomas)				X										aa
Asemoplus montanus (Bruner)				X	X									fra
Subtribe Miramellina														
Booneacris g. glacialis (Scudder)									X	X	X?	X?		f
B.g. canadensis (E.M. Walker)								X						f
B. variegata (Scudder)								X						f
***Subfamily Locustinae (Oedipodinae)**														
Tribe Locustini														
Locusta migratoria migratorioide (R.&F.)									R					gi
Arphia sulphurea (Fabricius)								X						ro
A. conspersa Scudder	X	X	X	X	X	X	X	X						fro
A.p. pseudonietana (Thomas)				X	X	X	X	X						gra
Chortophaga viridifasciata (De Geer)				X	X	X	X	X	X	X		X		gr
Encoptolophus sordidus (Burmeister)								X	X					gr
E. costalis (Scudder)					X	X	X							gr
Camnula pellucida (Scudder)	X	X	X	X	X	X	X	X	X	X	X	X		gri
Pardalophora apiculata (Harris)				X	X	X	X	X	X	X				frf
P. haldemanii (Scudder)							X							gr
**Xanthippus corallipes* (Haldeman)					X	X	X							ga
**X. buckelli* Hebard				X										g?a

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X. aquilonius Otte				X										g?
X. brooksi Vickery		X	X											g?
Xanthippus montanus (Thomas)						X	X							fra
Cratypedes neglectus (Thomas)				X	X	X	X							gra
C. lateritius (Saussure)				X										gra
Dissosteira carolina (Linnaeus)	A			X	X	X	X	X	X	X	X	X		fo
D. spurcata Saussure				A										fo
D. pictipennis Bruner				A										gai
Spharagemon equale (Say)				X	X	X								fa
S. bolli bolli Scudder						X	X	X	X					fa
S. collare (Scudder)				X	X	X	X	X	X					ra
S. campestris (McNeill)				X	X	X	X							fa
S.m. marmorata (Harris)								X						fa
Psinidia f. fenestralis (A.-Serv.)								X?	E					wr
Metator pardalinus (Saussure)					X	X	X							gr
M. nevadensis (Bruner)				X										gr
Trachyrhachys kiowa (Thomas)				X	X	X	X							gra
Derotmema haydenii (Thomas)					X	X								wgr
Conozoa sulcifrons (Scudder)				X										fr
C. texana (Bruner)				X										fra
Trimerotropis gracilis (Thomas)				X	X	X								fa
T. sordida E.M. Walker					X	X								
T. huroniana E.M. Walker								X						gra
T. sparsa (Thomas)				X	X									gra
T. pallidipennis (Burmeister)				X										gra
T. diversellus Hebard				X	X	X	X							gra
T. maritima interior E.M. Walker								X						fa
T. agrestis McNeill					X	X	X							oa
T. pistrinaria Saussure				X	X	X								fa
T. latifasciata Scudder					X	X								gra
T. cincta (Thomas)				X										fg
T. koebeli (Bruner)				X										fg
T. fontana Thomas				X										fg
T. verruculata (Kirby)			X	X	X	X	X	X	X	X	X	X	X	ffr
T. suffusa Scudder				X	X?									ffr
Circotettix u. undulatus (Thomas)				X										ao
C.r. rabula Rehn & Hebard				X	X	X	X							ao
C. carlinianus (Thomas)				X	X	X	X							gr
Derotmema h. haydenii (Thomas)					X	X								gra
Hadrotettix trifasciatus (Say)					X	X	X							fa
Tribe Epacromiini														
Stethophyma lineatum (Scudder)	X	X	X	X	X	X	X	X	X	X	X	X	X	m
S. gracile (Scudder)				X	X	X	X	X	X	X	X	X	X	m
Subfamily Hyalopteryginae														
Metaleptea b. brevicornis (Johannsen)								X						m

	Alaska	Yukon	N.W.T.	B.C.	Alta.	Sask.	Man.	Ont.	Que.	N.B.	P.E.I.	N.S.	Nfld.	Ecology
Subfamily Gomphocerinae														
Tribe Chrysochraontini														
Acrolophitus h. hirtipes (Say)					X	X								fa
Syrbula admirabilis (Uhler)								N						gr
Opeia obscura (Thomas)					X	X	X							gr
Mermiria bivittata (A.-Serville)					X	X	X							gr
Pseudopomala brachyptera (Scudder)				X	X			X						gr
Chloealtis conspersa Harris				X	X	X	X	X	X					gra
C. abdominalis (Thomas)	X	X	X	X	X	X	X	X	X					frg
Tribe Gomphocerini														
Chorthippus c. curtipennis (Harris)	X	X	X	X	X	X	X	X	X	X	X	X	X	gwa
Bruneria brunnea (Thomas)				X	X	X	X							gr
B. yukonensis Vickery		X												gr
Aeropedellus clavatus (Thomas)			X	X	X	X	X							gra
A. arcticus Hebard	X	X	X											t
Amphitornus coloradus (Thomas)					X	X	X							gra
Eritettix simplex tricarinatus (Thomas)					X	X	X							gra
Psoloessa d. delicatula (Scudder)					X	X	X							gra
P.d. buckelli Rehn				X										gra
**Boopedon nubilum* (Say)						X								gr
Aulocara elliotti (Thomas)				X	X	X	X							gri
A. femoratum Scudder					X	X								gri
Agenotettix deorum (Scudder)				X	X	X	X							gr
Phlibostroma quadrimaculatum (Thomas)					X	X	X							gr
Cordillacris occipitalis (Thomas)					X	X	X							gra
C. crenulata (Bruner)					X									gr
Tribe Orphulellini														
Orphulella speciosa (Scudder)					X	X	X	X	X	X				wgr
O.p. pelidna (Burmeister)					X	X	X	X						gr
O.p. desereta Scudder				X										gr
SUBORDER TETRIGODEA														
SUPERFAMILY TETRIGOIDEA														
FAMILY TETRIGIDAE														
Subfamily Tetriginae														
Nomotettix c. cristatus (Scudder)								X	X	X	X	X		fra
Tetrix subulata (Linnaeus)	X	X	X	X	X	X	X	X	X	X	X	X	X	wfr
Tetrix brunneri (Bolivar)	X	X	X	X	X	X	X	X	X	X		X		wfr
T. arenosa angusta (Hancock)							X	X	X	X		X		f
T.o. ornata (Say)		X	X	X	X	X	X	X	X	X	X	X		wa
T.o. occidua Rehn & Grant				X										wa
Paratettix cucullatus (Burmeister)								X						w
FAMILY BATRACHIDEIDAE														
Subfamily Batrachideinae														
Tettigidea lateralis (Say)							X	X	X	X		X		wa
SUBORDER TRIDACTYLODEA														
SUPERFAMILY TRIDACTYLOIDEA														
FAMILY TRIDACTYLIDAE														
Subfamily Tridactylinae														
Neotridactylis apidialis (Say)								X						w
**Ellipes m. minutus* (Scudder)							X	X						w

A SYNOPSIS OF THE DISTRIBUTION AND BIONOMICS OF THE CARRION BEETLES (COLEOPTERA: SILPHIDAE) OF THE CONTERMINOUS UNITED STATES

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Abstract *Proc. ent. Soc. Ont.* 118:47-81 (1987)

Detailed distribution maps are given for the first time for all the 28 species (in 7 genera) of the carrion beetles (Silphidae) in the conterminous United States. A lectotype is designated for *Oiceoptoma rugulosum* Portevin of the southeastern United States. Distribution patterns for all 32 species in the Nearctic region are summarized. Of these, one species originated in South America, but all others originated in either Eurasia or North America. Invasions of North America via a Tertiary or Pleistocene Bering Bridge occurred on at least 12 occasions. A summary of available data on the bionomics of all species is given, and indicates many opportunities for additional field and laboratory studies.

Introduction

Carrion beetles have long attracted the attention of entomologists and naturalists. The oldest known artistic representation of an insect, said to be a *Nicrophorus* carrion beetle, dates from the Magdalenian culture of Germany at 25,000 to 30,000 yBP (Kevan 1985). Carrion beetles are large and often conspicuously colored and may occur in great numbers at the carcasses of dead vertebrates in terrestrial environments. Their habits and feeding requirements offer many research opportunities involving ecological and behavioral topics.

The available literature on the bionomics and taxonomy of these beetles has recently been summarized for Canada and Alaska by Anderson and Peck (1985), and for Latin America by Peck and Anderson (1985). The exact distributions known for all species in the New World have been presented except for those in the conterminous United States. The purpose of this paper is to summarize the current knowledge of the distributions and bionomics of the Silphidae of the conterminous United States. Data on present distributions and bionomics are important as a basis for understanding the factors that control animal distributions, and how these distributions may have changed through the Pleistocene and Recent epochs as recorded in the fossil record (Coope, 1979; Miller and Peck, 1979; Morgan and Morgan, 1980; Schwert and Ashworth, 1986). Keys for the identification of the United States species, descriptions of adults and known larvae, and synonomies are given in Anderson and Peck (1985). Type designations are in Peck and Miller (1982). Another recent source of information is the bibliography by Young (1983).

Methods and Materials

Because we have found that many of the species of carrion beetles have been confused in the older literature, we present distributional data only from specimens seen by us, or by R.S. Anderson, S.E. Miller, A.F. Newton, Jr., and P.D. Perkins.

Detailed lists of specimen localities and complete labelling data are not presented, but this information is available from the first author as data sheets. The tribes Lyrosomini and Agyrtini have been transferred out of the Silphidae and given separate status as the family Agyrtidae (Lawrence and Newton, 1982; Lawrence, 1982) and are not considered here. Loans were not sought from all collections of United States' insects, but 56 collections have been used for what we believe is comprehensive coverage across the country. Questionable, possibly extra limital, records are mentioned in the text but are not shown on the maps. For this study, over 37,000 specimens have been examined during a 20 year

program of collecting and from loans. Specimens for this study were borrowed from or studied in the following institutions with the assistance of the curators indicated:

Academy of Natural Sciences, Philadelphia, PA; M.G. Emsley.
American Museum of Natural History, New York, NY; L.H. Herman.
Arizona State University, Tempe, AZ; F.F. Hasbrouck.
Auburn University, Auburn, AL; W. Clarke.
British Columbia Provincial Museum, Victoria, BC; R.A. Cannings.
California Academy of Sciences, San Francisco, CA; D.H. Kavanaugh.
California Department of Food and Agriculture, Sacramento, CA; F.G. Andrews.
Canadian National Collection, Ottawa, ON; A. Smetana and J.M. Campbell.
Carnegie Museum of Natural History, Pittsburgh, PA; G. Ekis.
Colorado State University, Fort Collins, CO; U.N. Lanham.
Cornell University, Ithaca, NY; L.L. Pechuman.
Field Museum of Natural History, Chicago, IL; H. Dybas and E.H. Smith.
Florida State Collection of Arthropods, Gainesville, FL; R.E. Woodruff.
Illinois Natural History Survey, Urbana, IL; M.W. Sanderson, D. Webb.
Montana State University, Bozeman, MT.; S. Rose.
Museum of Comparative Zoology, Harvard University, Cambridge, MA; A.F. Newton, Jr.
Natural History Museum of Los Angeles County, Los Angeles, CA; C.L. Hogue.
North Dakota State University, Fargo, ND; R. Kruger.
Ohio State University, Columbus, OH; M. Ivie and C.A. Triplehorn.
Oklahoma State University, Stillwater, OK; W.A. Drew.
Oregon State Department of Agriculture, Salem, OR; R.D. Westcott.
Oregon State University, Corvallis, OR; M.D. Schwartz and G.L. Parsons.
Peabody Museum, Yale University, New Haven, CT; C.A. Remington and D. Furth.
Purdue University, Lafayette, IN; R.D. Waltz.
San Diego Natural History Museum, San Diego, CA; S.E. Miller.
Santa Barbara Natural History Museum, Santa Barbara, CA; S.E. Miller.
South Dakota State University, Brookings, SD; E.U. Balsbaugh, Jr.
Texas A and M University, College Station, TX; H.R. Burke.
Texas Memorial Museum, Austin, TX; J. Reddell.
United States National Museum, Washington, D.C.; T.J. Spilman.
University of Arkansas, Fayetteville, AR; R.T. Allen.
University of Arizona, Tucson, AZ; F.G. Werner.
University of British Columbia, Vancouver, BC; R.A. Cannings.
University of California, Berkeley, CA; J.A. Chemsak.
University of California, Davis, CA; R.O. Schuster.
University of California, Riverside, CA; E.I. Schlinger.
University of Idaho, Moscow, ID; D.E. Foster, W.F. Barr.
University of Kansas, Lawrence, KS; P. Ashlock.
University of Nebraska, Lincoln, NE; B.C. Ratcliffe.
University of New Hampshire, Durham, NH; D. Chandler.
University of Texas, Austin, TX; J. Rawlings.
Washington State University, Pullman, WA; R. Zack.

The following individuals also provided material from their private collections: R.S. Anderson, J.L. and B.F. Carr, R.D. Cave, H. and A. Howden, W.L. Krinsky, S. McCleve, R.E. Nelson, A.F. Newton, Jr., S.B. Peck, C.L. Staines, K. Stephan, R. Turnbow, and J.E. Wappes.

Bionomic information is drawn from published literature, or from data on specimen labels, and our field work. Morphological variation is mentioned only for species in which it has been noted.

Species Accounts

Subfamily: SILPHINAE

Genus *Aclypea* Reitter

This genus contains 26 species in Europe and Asia, and two in North America. Of these two, *Aclypea opaca* (Linnaeus) is Holarctic. In North America it is known only from Alaska and the northwestern corner of the Northwest Territories (Anderson and Peck 1984; 1985).

Aclypea bituberosa (LeConte) – Map 1

The species is distributed from the southwestern part of the Northwest Territories and the western Canadian Provinces south to Nebraska, Colorado, Utah and California. The United States records come from grassland, open meadow, sub-montane shrub and steppe habitats. Both adults and larvae are phytophagous and eat native species of Solanaceae and Chenopodiaceae, introduced weeds, and at least twelve species of plants of agricultural or horticultural importance (Anderson and Peck 1984). Adults are active from March through November, but larvae occur in June and July. More data are given by Cooley (1917) and Anderson and Peck (1984).

Genus *Heterosilpha* Portevin

This genus is endemic to North America and contains the following two species.

Heterosilpha aenescens (Casey) – Map 2

The species is distributed only in the extreme western United States from Oregon to California and into northern Baja California. It appears to be more common at coastal than at inland localities. Adults have been collected in all months from February to December. Nothing is known of its habitat associations, seasonality, reproduction, feeding habits, or how it interacts with the more abundant *Heterosilpha ramosa* (Say), with which it is often confused (Miller and Peck 1979).

Heterosilpha ramosa (Say) – Map 3

The species is distributed from western Canada south to New Mexico, Arizóna, and southern California and into northern Baja California. Records from Elme and Laporte, Iowa; Urbana, Illinois; Lawrence, Kansas; and Brinkley, Arkansas (not shown on map) should be considered doubtful until confirmed by more collections. These eastern localities may represent a modern extension of the distribution into agricultural-steppe habitats recently created in these areas (Lindroth 1971), or may be valid as records of a Tall Grass Prairie fauna. Records from the United States come from open prairie, aspen-parkland, and shrub steppe habitats. Adults have been collected from March to October, and most frequently from May to August. They are frequently caught in carrion-baited pitfall traps, and occasionally in unbaited pitfall traps in agricultural fields. They are scavengers and may also be predators. Details of the bionomics have been presented by Brewer and Bacon (1975) for Colorado.

Genus *Necrodes* Leach

This genus contains two species in Europe and Asia, and one in North America.

Necrodes surinamensis (Fabricius) – Map 4

This species is distributed across southern Canada south to southern Florida and Texas in the east and to Utah, Oregon, and Washington in the west. The species occurs in forests, open shrub and grassland habitats. It is nocturnal and is commonly collected at lights, in blacklight (UV) traps and at carrion. Adults have been collected in all months of the year, but most collections are from May to August. Adults are active in the winter months in central Florida. The species feeds on fly maggots as well as carrion. The natural history has been studied in detail in Nebraska by Ratcliffe (1972), and

aspects of the feeding biology in Georgia by Young (1985). Variation occurs in the size of the elytral spots between northern and southern populations (Ratcliffe 1972).

Genus *Necrophila* Kirby and Spence

This genus contains 11 species in Asia and one in North America.

Necrophila americana (Linnaeus) – Map 5

The species is distributed from the southern parts of eastern Canada south through the eastern United States to Florida and east Texas. It is found in both open and forested habitats (Walker 1957). Adults are mostly diurnal (Shubeck 1971), and have been collected from March to September. They are most abundant from May to August. Adults were found to first appear in late May in New Jersey (Shubeck 1969) and New York (Pirone 1974) and in late March in Tennessee (Reed 1958). These authors found that reproduction and larval development occur from April to June; that egg to adult development takes 10-12 weeks, and that adults are the overwintering stage. Specimens from southern localities are more oval in body outline than those from the north. The elytral tips tend to be black in southern populations but are tipped with yellow in more northern populations. Size and shape of the pronotal spot also varies. Fisher and Tuckerman (1986) have noted an apparent mimicry of this beetle by a cuckoo bumble bee (*Psithyrus ashtoni* (Cresson)).

Genus *Oiceoptoma* Leach

The genus contains 4 species in Europe and Asia and three in North America.

Oiceoptoma inaequale (Fabricius) – Map 6

The species is distributed from the southern parts of Ontario and Quebec south to Florida and west to east Texas and North and South Dakota. Most collections are from deciduous forests but some records from the central states are from short-grass prairies. Adults have been collected from January to October. Adults are reproductively active in New Jersey in April and May (Shubeck 1976) and in Tennessee in February (Reed 1958). The adults are diurnal (Shubeck 1971). The very similar (sister) species, *O. rugulosum* Portevin, has often been confused with this species in the southern United States. A comparative study of habitat and morphological separation of these two species in their area of geographic overlap would be informative.

Oiceoptoma rugulosum Portevin – Map 8

Lectotype here designated bearing following labels: white printed label "Museum Paris/Savannah/Harper 5-43"; white handwritten label "E.U"; white label in red type "Type"; white handwritten label "Lectotype/*Silpha/inaequalis* var./*rugulosa* Port./[= *Oiceoptoma*/rugulosa (Port.)]/det R.B. Madge, 1983; and S. Peck lectotype label. In general collection of Muséum National d'Histoire Naturelle (MNHN), Entomology, Paris.

The species characters are given in Anderson and Peck (1985). It is distributed in the southeastern United States from coastal North Carolina through Florida to central Texas. It may occur north to Putnam County, Indiana (specimen in British Museum). Adults are active in the cooler months of the year from October to April. They are found in both forested and open habitats.

Oiceoptoma noveboracense (Forster) – Map 7

The species is distributed across the southern part of Canada east of the Rocky Mountains, and south to South Carolina, Georgia, Mississippi, and Texas, and west to Montana. The species occurs in both forests and in open field or prairie habitats. Adults have been collected from March to October. They are reproductively active in mid-April in New York (Pirone 1974) and New Jersey (Shubeck 1976), and in February in Tennessee (Reed 1958). Adults are diurnal (Shubeck 1971). Where *O. inaequale* and *O. noveboracense* overlap in geographic distribution, one of them is usually locally rare or absent.

Genus *Oxelytrum* Gistel

The genus contains eight species in Latin America, one of which occurs in south Texas.

Oxelytrum discicolle (Brullé)

The species is distributed from southern Brasil and Paraguay north along the Andes to Colombia and Central America to Mexico (Peck and Anderson 1985). It has been collected in the United States only once, at Lyford, Willacy County, Texas in June, 1969 (Davis 1980).

Genus *Thanatophilus* Leach

The genus contains 17 species in Africa, Europe, and Asia, and shares one species with Eurasia and North America. Five species occur only in North America; one of these is restricted to Canada, and one to Mexico. The World species have been reviewed by Schawaller (1981).

Thanatophilus coloradensis (Wickham) – Map 11

The species is known from Alaska and northern British Columbia, and as disjunct populations in the Rocky Mountains from Montana south to New Mexico. Adults have been collected from June to September. All collections are from treeline or above in arctic-alpine tundra habitats. Further details are given by Peck and Anderson (1982).

Thanatophilus lapponicus (Herbst) – Map 9

The species is distributed through Alaska and most of Canada (except for the high arctic islands), south into the northern tier of states, and along the Rocky Mountains to New Mexico and Arizona, and south along the Pacific states to southern California and northern Baja California. The species also occurs in Europe and Asia, where it can be injurious to furs, meats, and dried fish. The presumed sister species, *T. graniger,* occurs only in Mexico. *T. lapponicus* is often the numerically dominant silphid species in forested or open habitats, especially in the north and at high elevations. Adults have been collected from March to October.

Thanatophilus sagax (Mannerheim) – Map 11

The species is distributed across most of Canada and Alaska, and is known from only a few sites in the United States (in North and South Dakota, Wyoming, and Colorado). United States' records are from the months of April, May, and June. Habitat data are lacking, but Canadian records are mostly from debris or carrion along the shores of lakes, sloughs, and rivers. The similar species *T. trituberculatus* (Kirby), which is often confused with *T. sagax,* is distributed only in Canada and Alaska.

Thanatophilus truncatus (Say) – Map 10

The species is distributed in the southwestern portion of the United States from Nebraska to Texas and Arizona, and into central Mexico. The species lives in grasslands, arid scrub desert, oak-pinyon-juniper woodlands, pine forests, and montane meadows. Adults have been collected from May to October.

Subfamily: NICROPHORINAE

Genus *Nicrophorus* Fabricius

The genus contains about 50 species in Europe, northern Africa, and Asia east to the Solomon Islands in Australasia. There are 20 species in the New World, 15 of which occur in the United States. Two species are Holarctic. These beetles are large, and usually colorful. Their habit of burying small animal carcasses as provision for their young, and subsocial behavior and care of the young, have attracted much attention. The pioneer work

on their behavior is that of Pukowski (1933) on species in Europe, which has been summarized by Balduff (1935) and Milne and Milne (1944, 1976). Discovering the details of the bionomics and social behavior of the United States species presents abundant research opportunities (Peck 1982, 1986; Halffter *et al.* 1983).

New World *Nicrophorus* have been placed in species groups based on hypotheses about shared derived characters (Peck and Anderson 1985). These groups must eventually be based on the World fauna as a whole but are used here as indications of where similar and dissimilar bionomic characteristics may occur. Known larvae have been described and are keyed by Anderson (1982b).

The *orbicollis* species group

This group contains six species, five of which occur in Latin America, and one in the United States and Canada. Members of the group are hypothesized to possess a relatively high proportion of ancestral character states for the genus.

Nicrophorus orbicollis Say – Map 12

The species is distributed from southeastern Canada south to southern Florida and east Texas, and west to Nebraska and North Dakota. Records from Alpine, Texas, and Rifle, Colorado (not shown on map) need confirmation. This is the most commonly collected species in the eastern United States. Adults have been collected from the months of February to October, with most collections from June to August. Adults appear in late May in New York (Pirone 1974) and New Jersey (Shubeck 1976). Teneral adults appear in July and August and these overwinter. Adults are nocturnal (Shubeck 1971), and are often taken at light traps. They have been collected on both carnivore and human dung and on rotted fruits as well as at carrion. Most collections are from mesic forest habitats.

The *defodiens* species group

This group contains three species, all of which occur in the United States.

Nicrophorus defodiens Mannerheim – Map 13

The species is widely distributed across much of Canada and Alaska, across the northern United States, and south along the Appalachians to North Carolina; in the Black Hills of South Dakota; south along the Rocky Mountains to Colorado, and in the far west to central California. Records from Henderson County, Tennessee, and Noble, Oklahoma (not shown on map) need confirmation. Adults have been collected from May to October. The species is found primarily in dry boreal forests, but also in montane and coastal forests. Adults are crepuscular. They do not bury carcasses but only conceal them under litter. Leech (1934) gives some information on reproduction. Variation occurs on the elytral color pattern, and Pacific coastal populations may be entirely melanic (Anderson and Peck 1986).

Nicrophorus vespilloides Herbst – Map 15

The species is distributed across Canada and Alaska and occurs uncommonly in the northeastern and north central United States southward to Pennsylvania, Indiana, and Minnesota. Adults have been collected from May to August in the conterminous United States. The species also occurs widely in Europe and Asia in many different habitats (Horion 1949), and not just in dry coniferous forests as suggested by Pukowski (1933). In North America, the species is known almost exclusively from swampy or boggy areas in boreal forests Anderson (1982a) has suggested that the habitat differences are a result of competitive interactions with its presumed sister species, *N. defodiens*.

Nicrophorus sayi Laporte – Map 14

The species is distributed across southern Canada east of the Rocky Mountains south through the eastern United States to eastern Oklahoma and northern Alabama. Adults of

N. sayi are often the first *Nicrophorus* to appear in the spring in the northeastern states. They have been collected from March to October in the conterminous United States. Adults are nocturnal and are often collected at lights. Reproduction is in the early spring. Teneral adults appear in late summer, and these overwinter. The species occurs predominantly in forested habitats, but has been collected in open shrublands and grasslands.

The *investigator* species group

This group contains 5 species in North America.

Nicrophorus hybridus Hatch and Angell – Map 16

The species is distributed in the southern part of western Canada, south through the prairie states and along the Rocky Mountains to New Mexico and Arizona. The species occurs in prairie, montane meadow, and sage steppe habitats. Adults seem to be diurnally active. They have been collected in the United States from June to September. They overwinter as prepupae. This is the presumed sister species of *N. tomentosus*.

Nicrophorus tomentosus Weber – Map 20

The species is distributed across the southern part of eastern and central Canada south through much of the United States to Florida and New Mexico, and west to Colorado and Montana. Adults occur in many habitats from coniferous and deciduous forests to prairies and shrub steppe. Adults have been collected from May to October, but are most abundant in July and August. Adults first appear in late June in New Jersey (Shubeck 1976) and New York (Pirone 1974). The adults do not deeply bury carcasses, but place them in a shallow pit and cover them with litter. Winter is passed as third instar prepupal larvae. Adults are diurnal (Shubeck 1971) and may act as Batesian mimics of bumble bees (see also Fisher and Tuckerman 1986).

Nicrophorus investigator Zetterstedt – Map 17

The species is distributed across Canada and Alaska, occurs rarely in the northeastern United States, and commonly along the Rocky Mountains to New Mexico and Arizona, and in the Pacific Northwest. The species also occurs in Europe and Asia. It lives in a variety of forested and open habitats. Adults have been collected from May to October. They are day or night active depending on temperature. The species overwinters as prepupae. Variation occurs in the elytral color pattern, and Pacific coastal specimens may have very reduced color spots (Anderson and Peck 1986).

Nicrophorus nigrita Mannerheim – Map 18

The species is distributed from southern British Columbia through the Pacific coastal states to northern Baja California. It occurs on the California Channel Islands and on Guadelupe Island, Mexico. Records (not shown on map) from Cave Creek Canyon, Arizona, and Coolidge, New Mexico, need confirmation. Adults are nocturnal and are often collected at lights. Adults have been collected from February to November. Most collections have been made in coastal forests, but the species also occurs in open habitats. This is a presumed melanic sister species of *N. mexicanus*, and these have non-overlapping distributions.

Nicrophorus mexicanus Matthews – Map 19

The species is distributed in the southern Rocky Mountain states through Mexico to El Salvador. It occurs in habitats ranging from semi-arid shrub steppe to open pine forests in the United States. Adults have been collected from May to October in the United States. The species is nocturnal and is often caught in light traps. Zaragoza and Perez (1975) present an analysis of morphometrics and seasonality of a population near Mexico City. Halffter, Anduaga, and Huerta (1983) have studied the reproductive biology in Mexico.

The *marginatus* species group

This group contains 4 species in North America.

Nicrophorus carolinus (Linnaeus) – Map 21

The species occurs at one site in southern Alberta, Canada, and otherwise in the United States on the coastal plain of the southern Atlantic and Gulf states west through Texas to Arizona and north to Colorado and Nebraska. The species is found in open forests, grasslands, shrub steppe, and creosote bush desert. Adults have been collected from March to October, and most frequently in areas with loose or sandy soils. Variation occurs in the elytral color pattern. The color spots are reduced in the north central States, and the population at Tuba City, Arizona, includes entirely black individuals. Conley (1982) has investigated the relatively low efficiency of carrion-locating by the species in southern New Mexico.

Nicrophorus guttula Motschulsky – Map 22

The species is distributed from southern British Columbia and Manitoba, through Washington and Minnesota to Nebraska, and south New Mexico, Arizona, California, and northern Baja California. The species occurs in dry forests, prairies, and deserts. Adults are diurnal and have been found on carrion and on occasion on human and coyote dung. Adults have been collected from May to September. Adults show extensive variation in color of the antennal club and color pattern on the elytra. Pacific coastal populations in the south are predominantly melanic, and inland desert populations tend to have very large sized orange elytral markings (Anderson and Peck 1986). The presumed sister species is *N. obscurus*.

Nicrophorus obscurus Kirby – Map 24

The species is distributed from the southern Canadian Prairie Provinces into the north central United States. Records from Holiday, Pennsylvania; Algonquin, Illinois; and Fredericksburg, Virginia (not shown on map) need confirmation. The species is an inhabitant of prairies, and adults are active from March to September. Adults are diurnal and have been collected at human dung and carrion.

Nicrophorus marginatus Fabricius – Map 23

This is the most widespread *Nicrophorus* species in North America, occurring in southern Canada and Mexico, and in all of the United States except for the four most southeastern states. Most collections have been from open fields, montane meadows, prairies, desert woodlands and creosote bush or sagebrush deserts. Adults have been collected from February to October. They may be at least partly nocturnal as indicated by several having been caught at lights. Reproduction is from April to June, teneral adults appear in June and August, and these adults overwinter.

Incertae Sedis

Two species in North America can not be reliably placed in any of the above species groups. They probably have closer relationships with species of *Nicrophorus* in Europe or Asia.

Nicrophorus americanus Olivier – Map 25

The species has been collected in southeastern Canada and through much of the eastern United States. Adults of this species are among the largest and most distinctive beetles in the North American fauna, and have been collected from February to September. They have been recorded at carrion in Tennessee (Walker 1957) and Ohio, but most collections have been made with light traps, which shows that the species is nocturnal. The species is now very uncommon and may now be extinct over large parts of its range. It has been collected in the past 15 years with some frequency only in northwestern Arkansas,

and on Block Island, Rhode Island. Anderson (1982) and Davis (1980) have discussed the decreasing abundance of the species. The former suggested that the species is dependent on climax hardwood forests, but the population on treeless Block Island does not support this idea. In over 20 years of intensive collecting of carrion beetles, the senior author has never seen this species alive. Wells *et al.* (1983) have included the species in a book on endangered and threatened species of invertebrates and summarize available bionomic data.

Nicrophorus pustulatus Herschel – Map 26

The species is distributed from southern Canada east of the Rocky Mountains south in the eastern United States to Florida and Texas. Adults have most frequently been collected in forested habitats. They are nocturnal and are collected from March to October more commonly at lights than at carrion. Reproduction is in the spring. Teneral adults appear in mid to late summer, and these probably overwinter. Shubeck (1969) in New Jersey and Pirone (1974) in New York record the first appearance of the new adults in July. The rarity of the species at carrion-baited traps suggests that they may have a natural history different from that of other *Nicrophorus*.

Distribution Patterns

Distributional data show species of Silphidae to be generally widely distributed and to occur in many habitat types. That might be expected for species requiring carrion for feeding and reproduction; carrion probably being a limited resource widely scattered in space and time. Carrion resources are probably largely similar across the different habitat types in the major biomes.

In the northern United States the distribution patterns of at least some carrion beetles were changed in that they no longer occur where their Pleistocene fossils have been found (Morgan and Morgan 1980). Pleistocene fossils from the Rancho La Brea tar pits of southern California, however, are of the same species that occur today in the Los Angeles area (Miller and Peck 1979).

Many studies have sought, analysed, or reviewed patterns in the distributions of insects and other organisms in North America (e.g. Campbell 1980; Monroe 1956; Scudder 1979; Shelford 1963; Udvardy 1969). As a result of the present study we can here group the 32 species of Nearctic (United States, Canada, and Mexico) Silphidae for the first time into 14 broad categories of distributional patterns as follows:

Eastern Deciduous Forest Region. *Necrophila americana, Oiceoptoma inaequale, Oiceoptoma noveboracense, Nicrophorus orbicollis, Nicrophorus sayi, Nicrophorus tomentosus, Nicrophorus pustulatus, Nicrophorus americanus.*

Southern Coastal Plain Region. *Oiceoptoma rugulosum.*

Southeastern Coastal Plain and South Central States Regions. *Nicrophorus carolinus.*

Holarctic or Transcontinental Cool or Cold Temperate and Cordilleran Forest Regions. *Thanatophilus lapponicus, Nicrophorus defodiens, Nicrophorus vespilloides, Nicrophorus investigator.*

Transcontinental Warm Temperate Region. *Necrodes surinamensis, Nicrophorus marginatus.*

Western Boreal Forest Region. *Thanatophilus sagax, Thanatophilus trituberculatus.*

Western Arctic-Alpine Tundra Region. *Thanatophilus coloradensis.*

Alaskan Subarctic Region. *Aclypea opaca.*

Southwestern and/or Mexican Plateau (Semiarid) Region. *Thanatophilus truncatus, Thanatophilus graniger, Nicrophorus mexicanus.*

Mexican Plateau Edge (Moist Forest Region). *Nicrophorus olidus.*

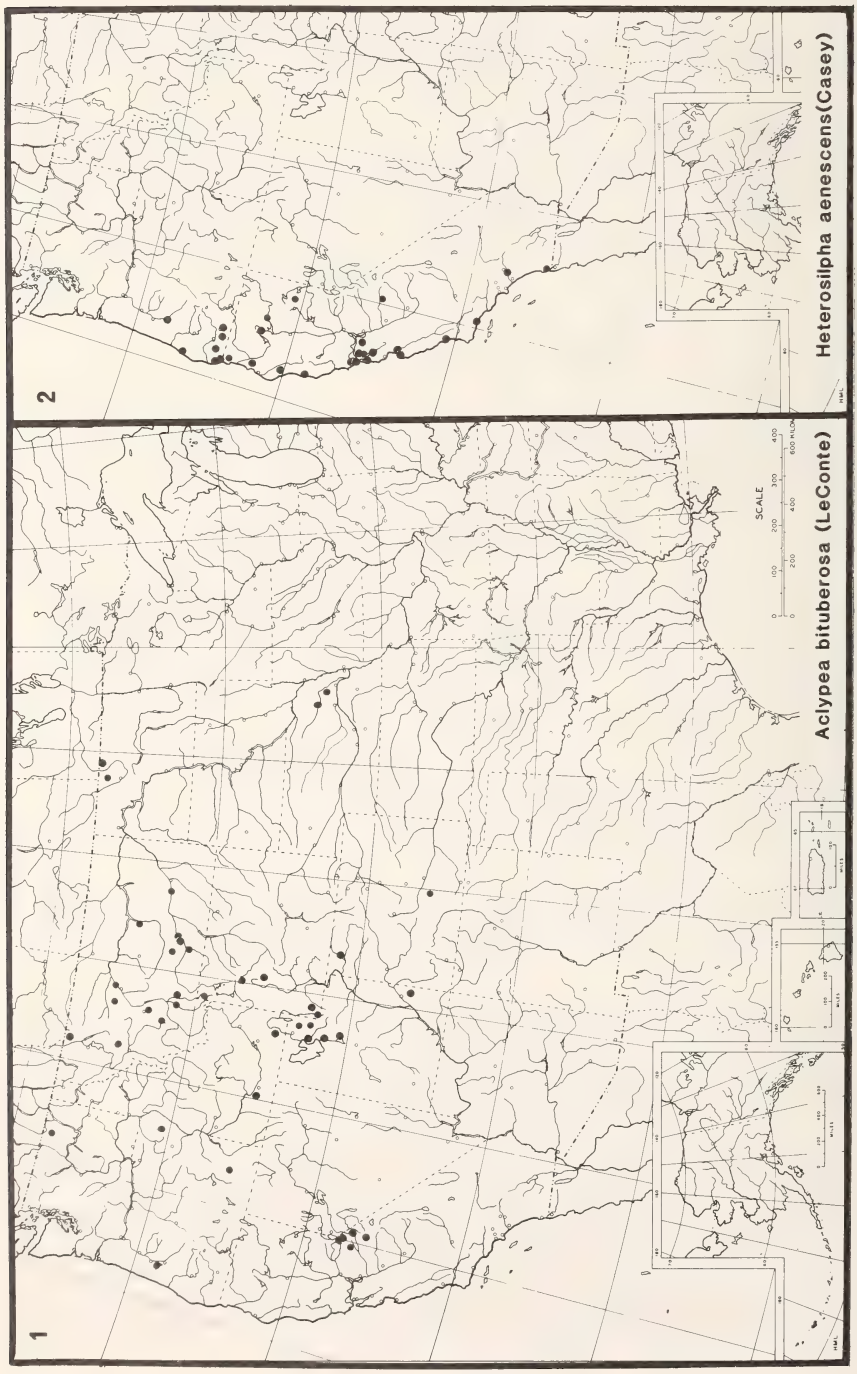
Central Prairie Region. *Nicrophorus hybridus, Nicrophorus obscurus.*

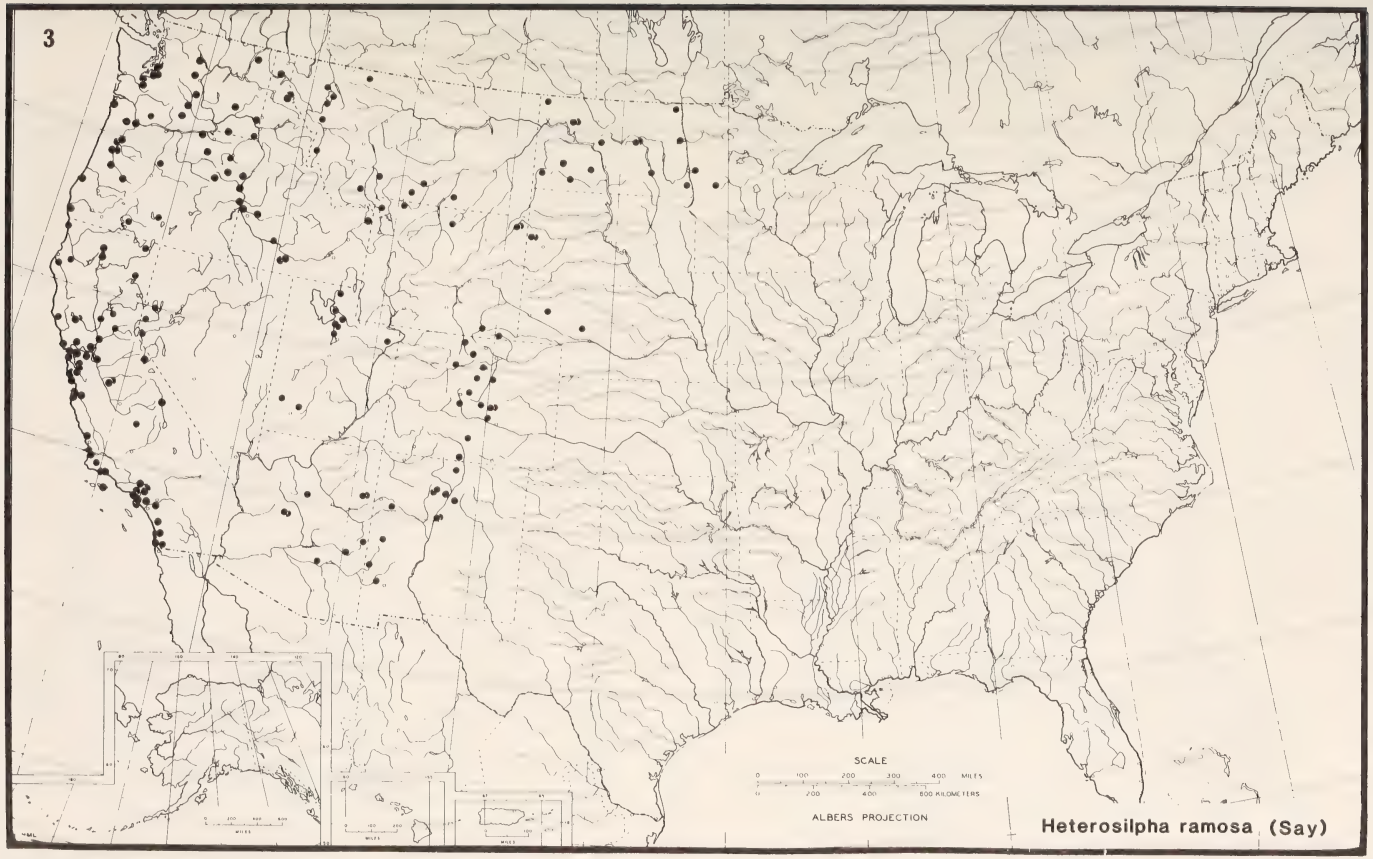
Western Mountain and Central Prairie Regions. *Aclypea bituberosa, Heterosilpha ramosa, Nicrophorus guttula.*

Pacific Coastal and Sierra-Cascade Mountain Region. *Heterosilpha aenescens, Nicrophorus nigrita.*

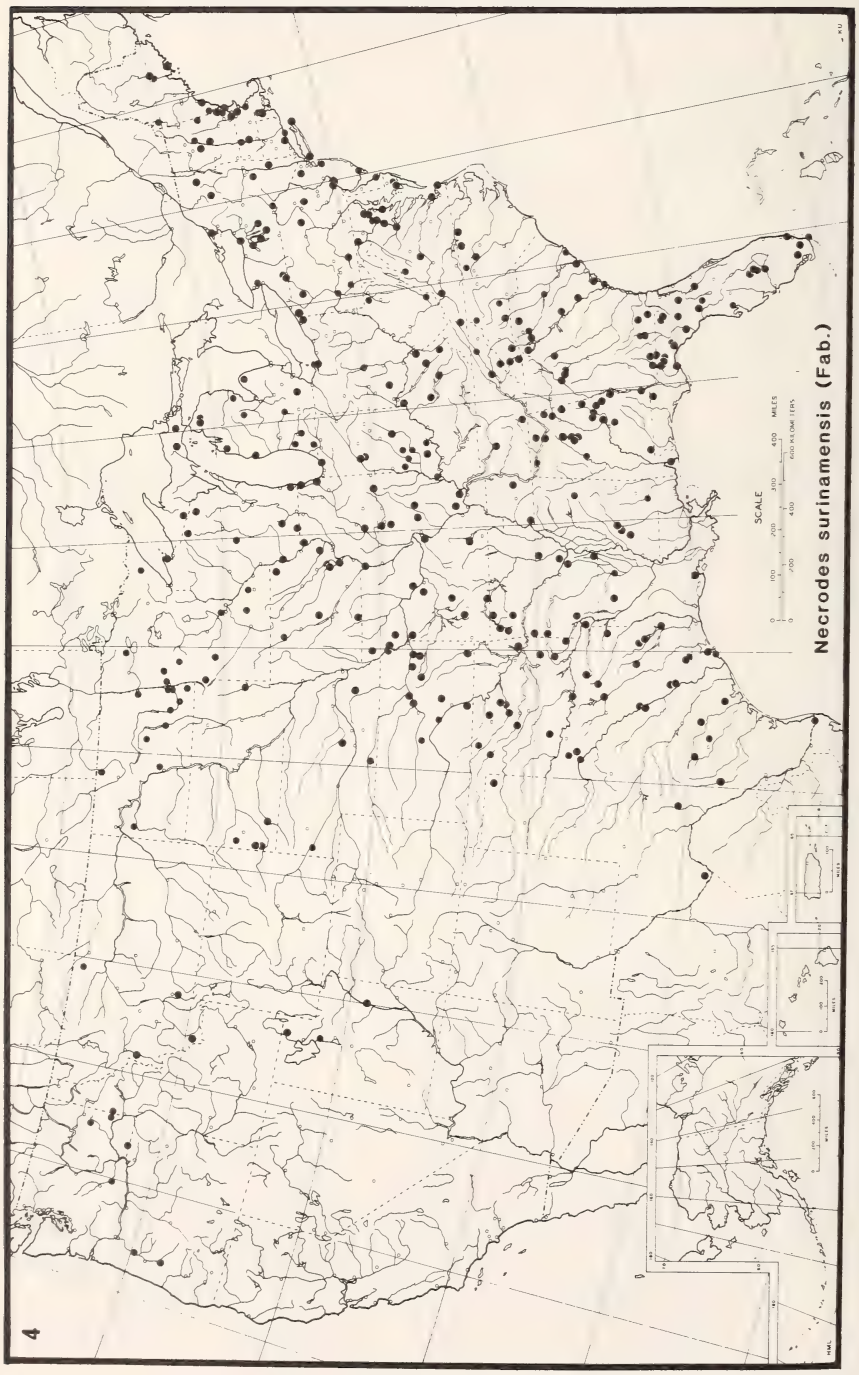
Neotropical Region into South Texas. *Oxelytrum discicolle.*

These patterns of distribution are consistent with those suggested in an earlier biogeographic discussion (Peck and Anderson 1985).

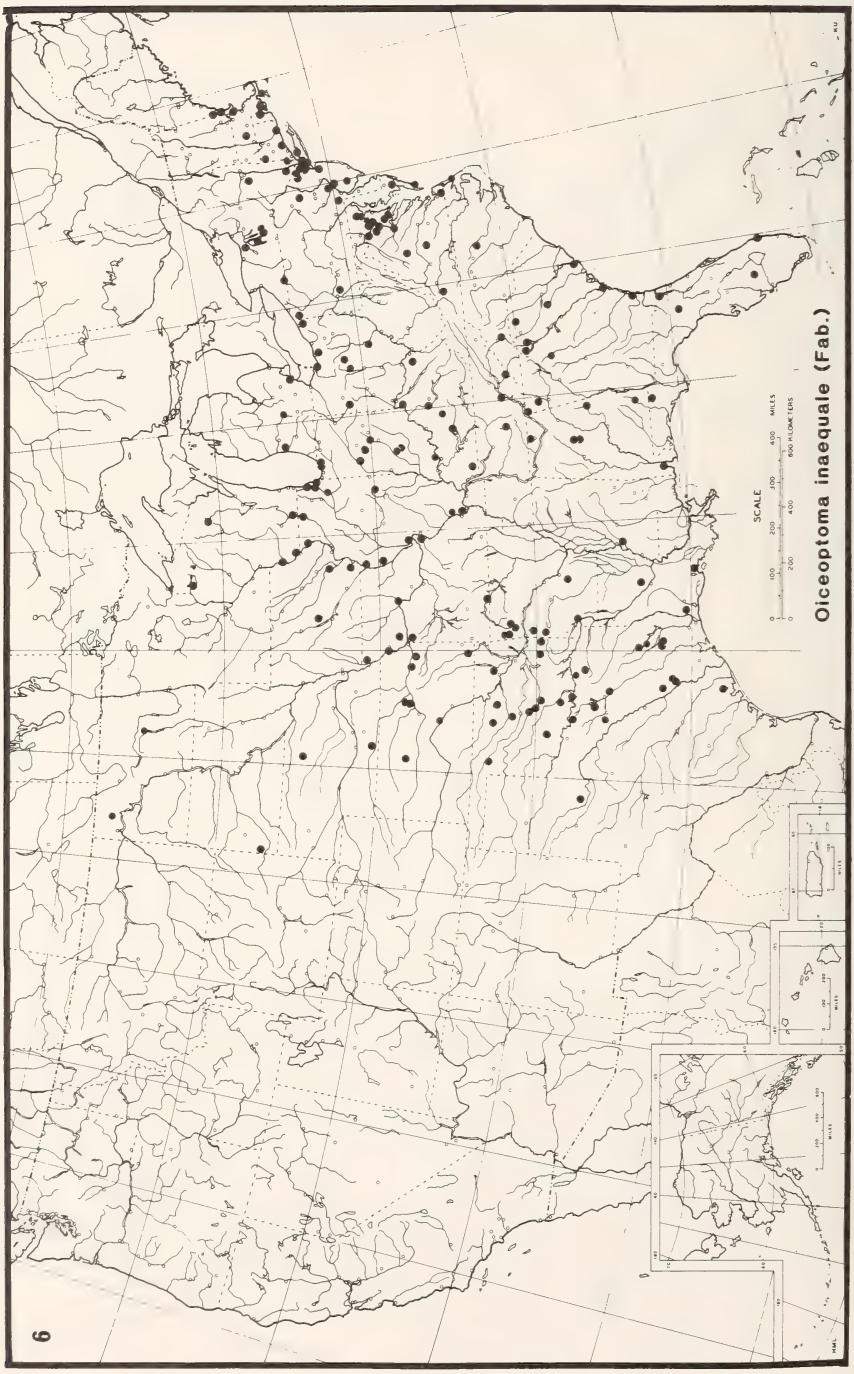




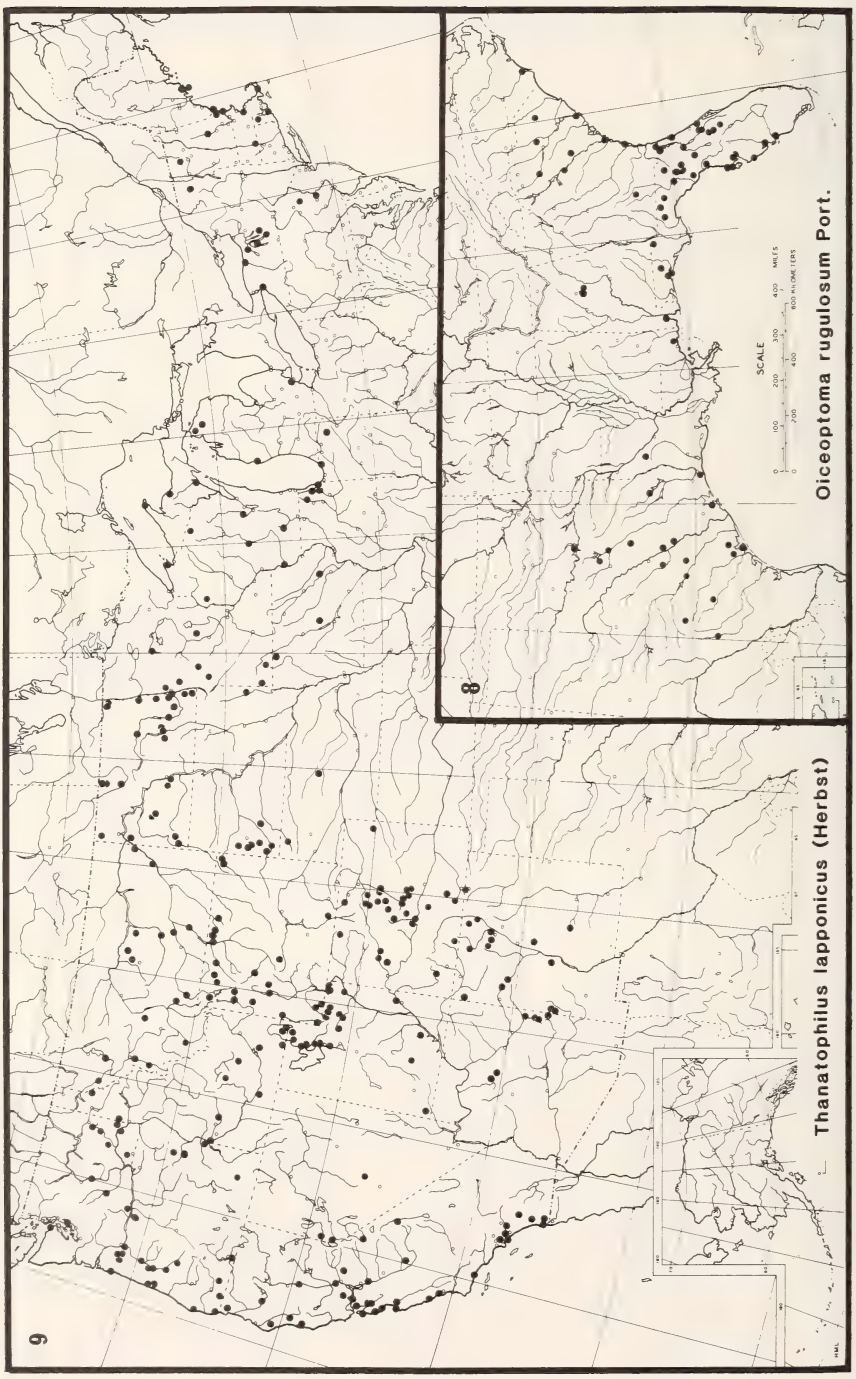
Maps 1 – 3. Locality records for Silphidae in the United States (see Anderson and Peck (1985) for records of *A. bituberosa* in Canada, and Peck and Anderson (1985) for records of *H. ramosa* in Mexico).

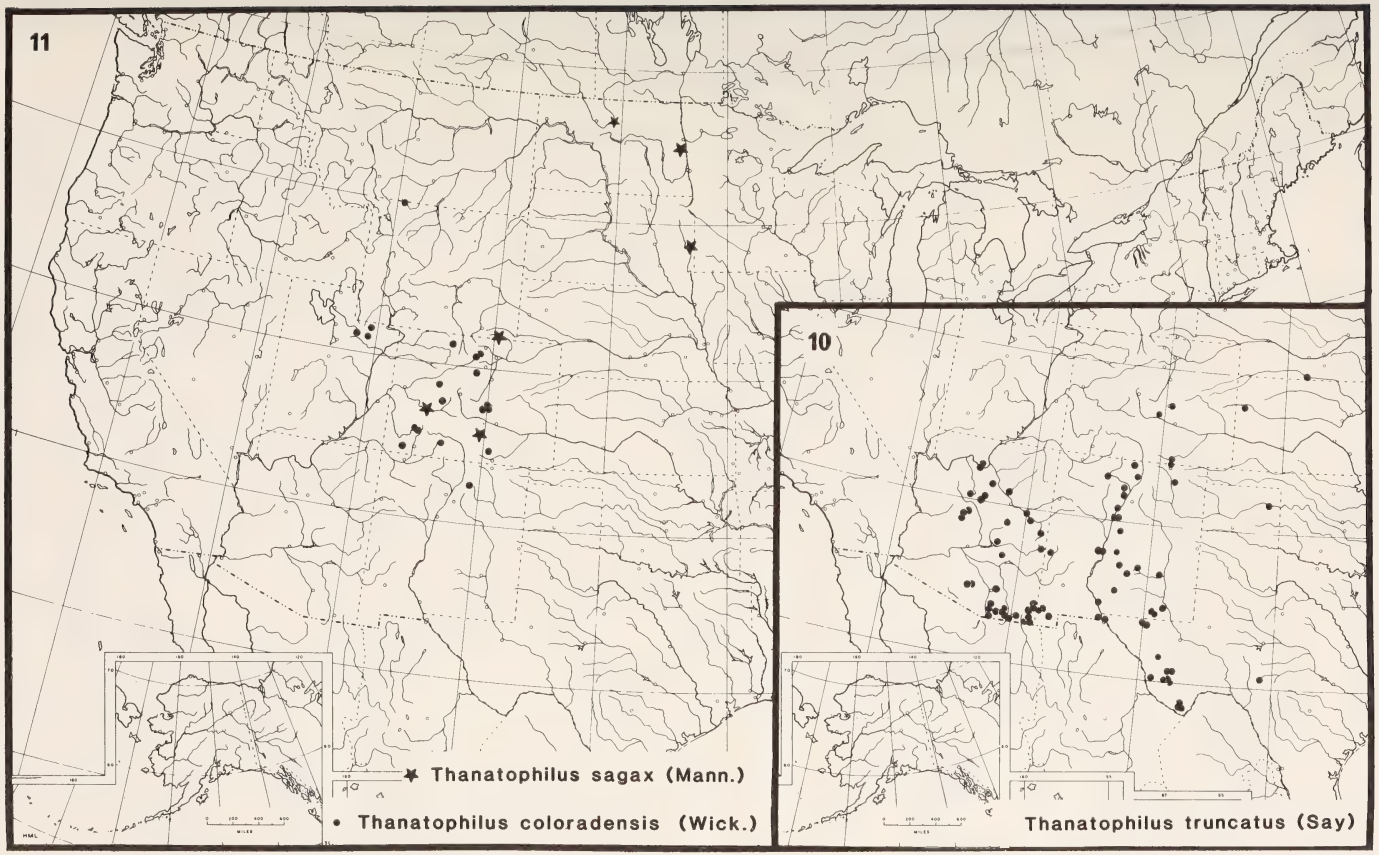

Necrodes surinamensis (Fab.)
SCALE
4

Maps 4 and 5. Locality records for Silphidae in the United States (see Anderson and Peck (1985) for records of *N. surinamensis* and *N. americanus* in Canada).

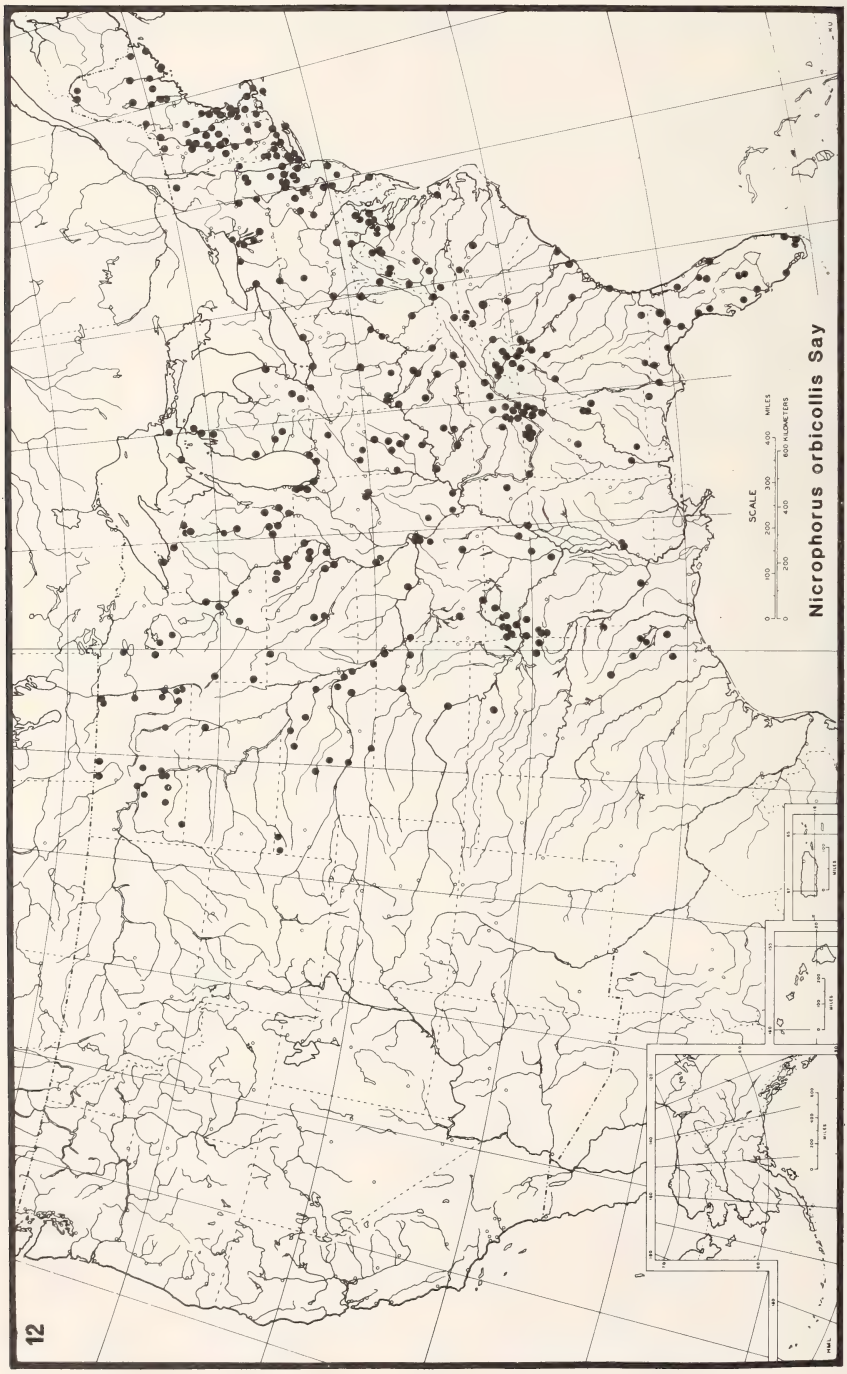

Oliceoptoma inaequale (Fab.)
SCALE
MILES
KILOMETERS
6

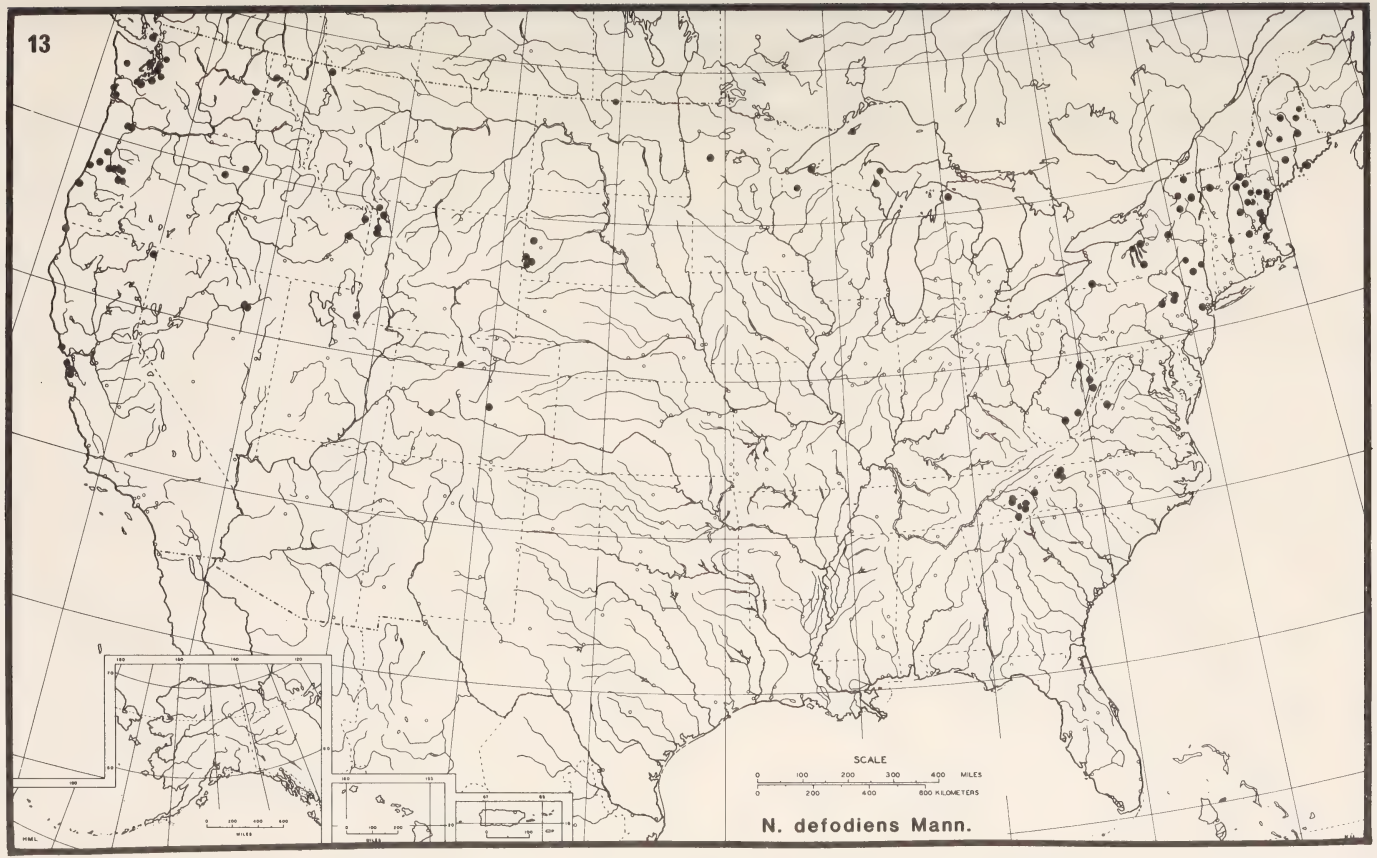
Maps 6 and 7. Locality records for Silphidae in the United States (see Anderson and Peck (1985) for records of *O. inaequale* and *O. noveboracensis* in Canada).


9
Thanatophilus lapponicus (Herbst)
8
Oiceoptoma rugulosum Port.
SCALE
MILES
KILOMETERS



Maps 8 – 11. Locality records for Silphidae in the United States (see Peck and Anderson (1985) for records of *T. truncatus* in Mexico; Peck and Anderson (1985) and Anderson and Peck (1985) for records of *T. lapponicus* in Alaska, Canada, and Mexico; and Anderson and Peck (1985) for records of *T. coloradensis* and *T. sagax* in Alaska and Canada.

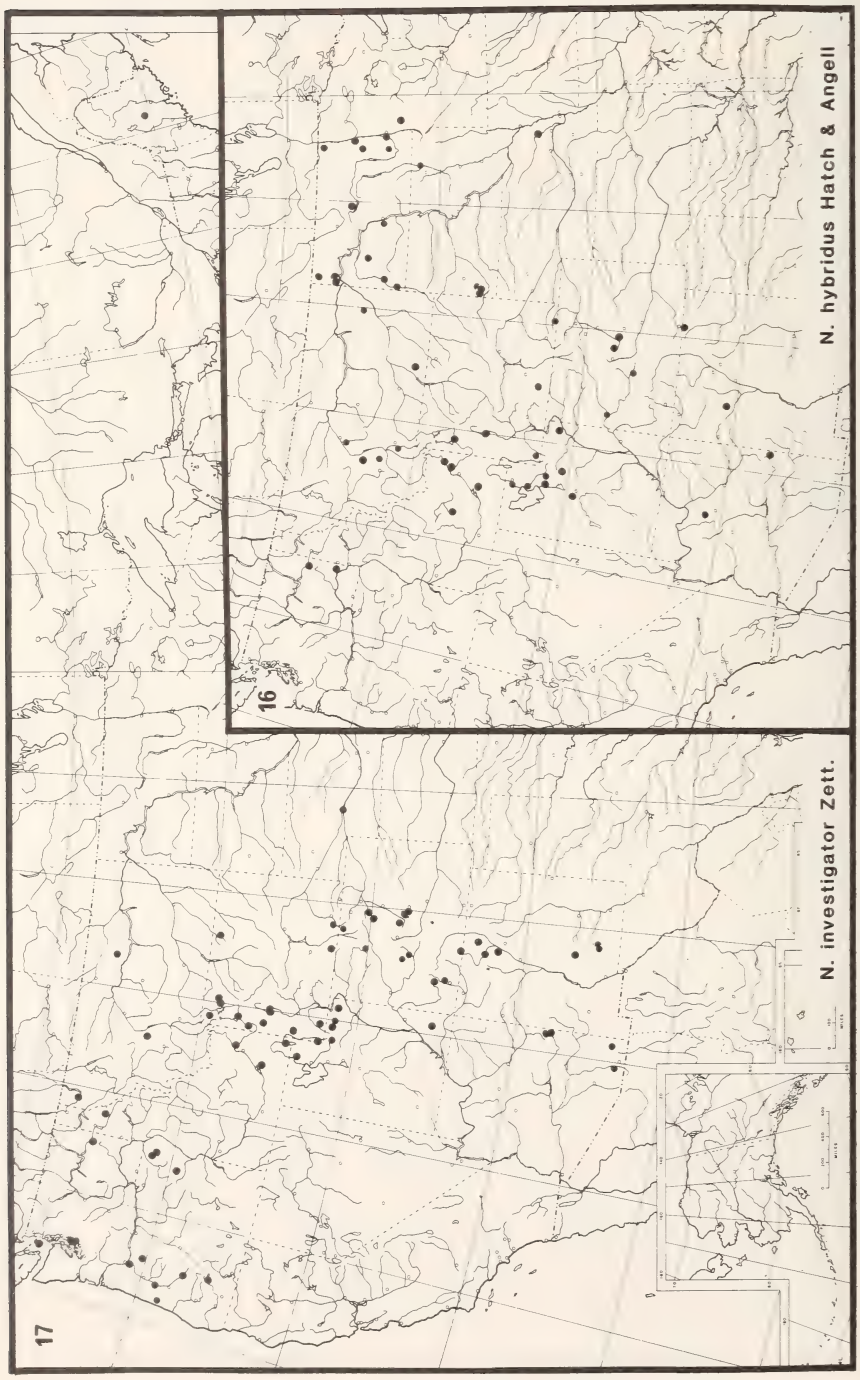

Nicrophorus orbicollis Say
SCALE
MILES
KILOMETERS
12



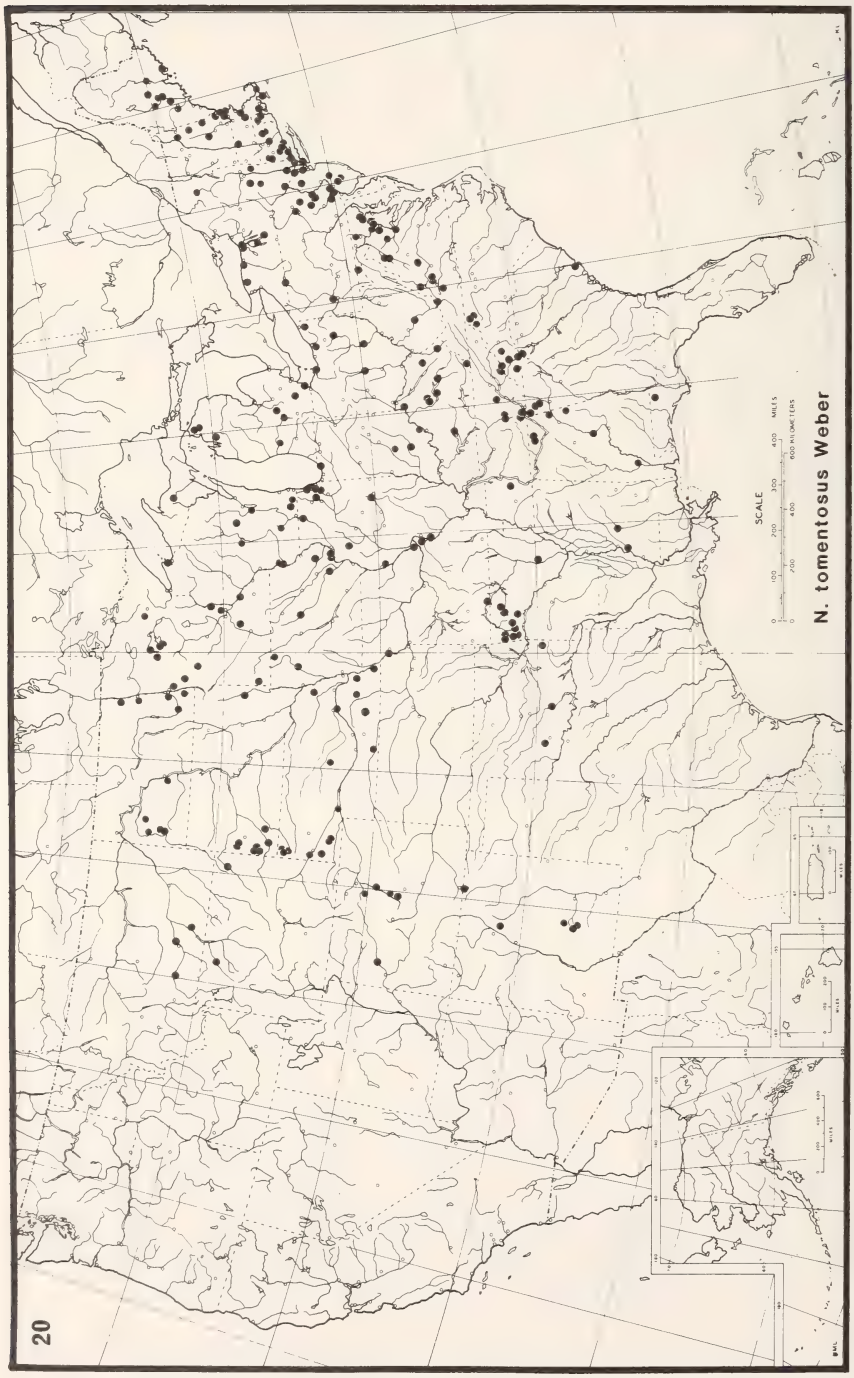
Maps 12 and 13. Locality records for Silphidae in the United States (see Anderson and Peck (1985) for records of *N. orbicollis* and *N. defodiens* in Alaska and Canada).


N. sayi Laporte
SCALE
14

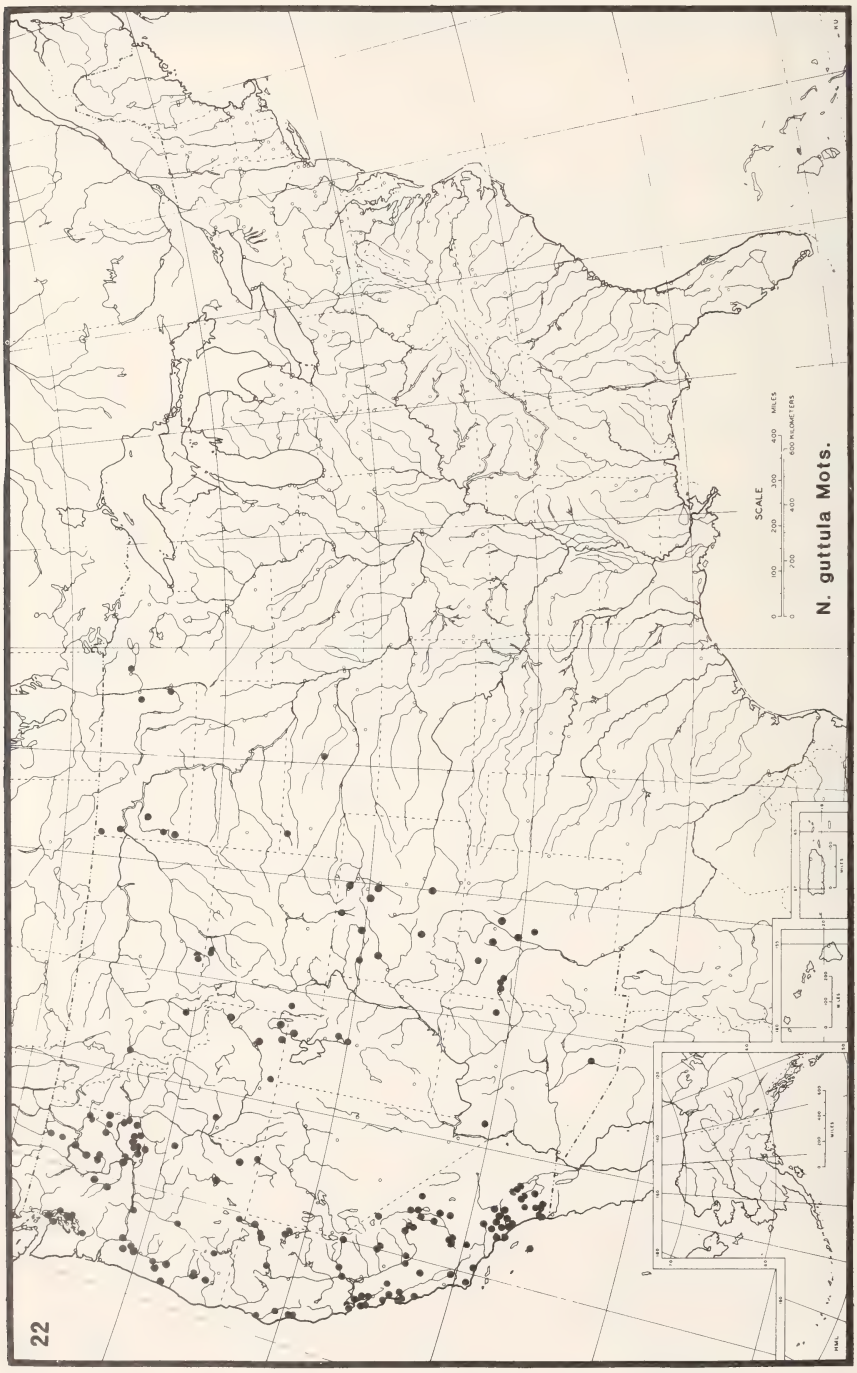
Maps 14 and 15. Locality records for Silphidae in the United States (see Anderson and Peck (1985) for records of *N. sayi* and *N. vespilloides* in Alaska and Canada).


N. hybridus Hatch & Angell
16
N. investigator Zett.
17

Maps 16 – 19. Locality records for Silphidae in the United States (see Anderson and Peck (1985) for records of *N. hybridus*, *N. investigator*, and *N. nigrita* in Canada, and Peck and Anderson (1985) for records of *N. nigrita* and *N. mexicanus* in Mexico).


N. tomentosus Weber
SCALE
20

Maps 20 and 21. Locality records for Silphidae in the United States (see Anderson and Peck (1985) for records of *N. tomentosus* in Canada).


N. guttula Mots.
SCALE
22

Maps 22 and 23. Locality records for Silphidae in the United States (see Anderson and Peck (1985) and Peck and Anderson (1985) for records of *N. guttula* and *N. marginatus* in Canada and Mexico.


N. obscurus Kirby
SCALE
24

Maps 24 and 25. Locality records for Silphidae in the United States (see Anderson and Peck (1985) for records of *N. obscurus* and *N. americanus* in Canada).

Map 26. Locality records for Silphidae in the United States (see Anderson and Peck (1985) for records of *N. pustulatus* in Canada).

Evolutionary Considerations

Patterns of distribution can suggest the likely course of dispersal and evolution in an insect group. Fossils are necessary documentation of the facts of the time and place of occurrence of earlier faunas. However, there is only a poor Paleozoic fossil record for beetles, though they occurred in some diversity. There is no Mesozoic fossil record of the Silphidae (Crowson 1981). *Mesecanus (= Mesagyrtes) communis* (Ponomarenko) from Jurassic deposits near Novospassk, USSR, is not a silphid but is in the related family Agyrtidae (Newton 1981). Nevertheless, it is assumed (because of the present diversity there) that the Silphidae also arose in the early Mesozoic, possibly in what would become the north temperate zone. Some lineages may have then spread to the southern parts of Pangea before these separated from Laurasia as Gondwanaland.

The only New World endemic genera of Silphidae are *Oxelytrum* and *Heterosilpha*. *Oxelytrum* probably arose from an ancestor from the south temperate zone (Gondwanaland) and diversified when South America was isolated. In this genus only *O. discicolle* spread out of South America into Central America, Mexico, and south Texas in the late Tertiary and/or Pleistocene (Peck and Anderson 1985). *Heterosilpha* may have originated from an unknown silphine ancestor in North America in Mesozoic or Tertiary time. All other Nearctic genera of Silphidae also occur in at least the Palearctic or Oriental regions. Because the centers of diversity of all these genera are in the Old World, we assume that the genera arose there. We therefore think it likely that the Eurasian ancestral stocks crossed into North America at least once in each of the five cases of *Aclypea, Necrodes, Necrophila, Oiceoptoma,* and *Thanatophilus*. We also assume that it is most likely that these Old World stocks crossed into North America in Mesozoic or Tertiary time via emergent lands in what is now the Bering Straits (Matthews 1980). The two silphine species common to Eurasia and North America *(Thanatophilus lapponicus* and *Aclypea opaca)* probably maintained gene flow across the Bering Bridge at times of low sea levels in Pleistocene time.

We also assume that the genus *Nicrophorus* originated in the Old World. Reconstructed phylogenies for the *Nicrophorus* of the New World have been tentatively proposed (Peck and Anderson 1985) and the species have been placed into groups. These phylogenies suggest that in the *orbicollis* group, one species remained in northeastern North America and 5 other species originated in Mexico and Central and South America. In the *defodiens* group, *N. vespilloides* is Holarctic and two species are Nearctic. In the *investigator* group, *N. investigator* is Holarctic and four species are Nearctic or in Central America. In the *marginatus* group four species are Nearctic. All that suggests to us that there was at least one ancestral entry into the Nearctic, probably also by the Tertiary Bering Bridge, in each of the *orbicollis, defodiens, investigator,* and *marginatus* groups and probably also for *N. americanus* and *N. pustulatus*. The two *Nicrophorus* species common to North America and Eurasia *(N. vespilloides,* and *N. investigator)* probably maintained gene flow across the Bering Bridge at times of low sea levels in Pleistocene time.

Phylogenetic analyses of all the silphine genera and *Nicrophorus* on a world basis is necessary before more accurate hypotheses can be made concerning the numbers of both North American invasions and subsequent speciation events.

Future Bionomic Studies

Silphids are large, attractive, and usually easy to catch with carrion-baited pit traps. They lend themselves easily to the quantitative study of habitat associations and seasonality, but in North America only in Ontario (Anderson 1982a), and New Jersey (e.g. Shubeck *et al.* 1977, 1981) have such studies been made. The natural history, life cycles and social biology of these beetles have been studied in detail for only a few species, and for no North American species of *Nicrophorus* other than *N. mexicanus* in Mexico (Halffter *et al.* 1983). Ecological interactions of a few *Nicrophorus* species have been studied only in Michigan (Wilson and Fudge 1984; Wilson and Knollenberg 1984; and Wilson *et al.* 1984). Shubeck (1968, 1975a, 1975b) and Shubeck *et al.* (1977, 1981) have studied some aspects of natural history on carrion beetles in New Jersey.

Many topics in carrion beetle biology need to be further studied. We suggest that some may be especially rewarding, and point to chemical defenses, pheromone release for assembly at carrion, digestive tract inactivation of rabies virus and anthrax bacillus, communication function and species specificity of stridulation (see Bredohl 1984), mimicry and warning coloration of the elytra, diffraction gratings and coloration, olfactory or visual sensitivity in locating carrion, antibacterial salivary secretions that may protect the carrion in brood balls, mutualistic associations with phoretic mites, and significance of geographic variation in color (references in Anderson and Peck 1985; Young 1983).

Acknowledgments

The field work of SBP has been supported for the past 15 years in part by the Natural Sciences and Engineering Research Council of Canada. The many museum curators and private collectors are thanked for loaning and contributing study material. Collecting permits have been granted by National, Provincial, and State agencies too numerous to mention for field work in parks, monuments, and preserves across Canada, Alaska, and the United States. Work on the Silphidae has been significantly helped by the contribution of data from studies by A.F. Newton, R.B. Madge, Phillip D. Perkins, and S.E. Miller. The manuscript has benefited by comments from R.S. Anderson, J.M. Campbell, Scott Miller, A.F. Newton, Jr., R.B. Madge, P.P. Shubeck, A. Smetana, D.S. Wilson, and anonymous reviewers.

References

Anderson, R.S. 1982a. Resource partitioning in the carrion beetle (Coleoptera: Silphidae) fauna of southern Ontario: Ecological and evolutionary considerations. Canadian Journal of Zoology, 60: 1314-1325.

Anderson, R.S. 1982b. Burying beetle larvae: Nearctic *Nicrophorus* and *Oriental Ptomascopus morio* (Silphidae). Systematic Entomology, 7: 249-264.

Anderson, R.S. 1982c. On the decreasing abundance of *Nicrophorus americanus* Olivier (Coleoptera: Silphidae) in eastern North America. Coleopterist's Bulletin, 36(2): 362-365.

Anderson, R.S. and S.B. Peck. 1984. Bionomics of Nearctic species of *Aclypea* Reitter: Phytophagous carrion beetles (Coleoptera: Silphidae). Pan-Pacific Entomologist, 60: 248-255.

Anderson, R.S. and S.B. Peck. 1985. The Carrion beetles of Canada and Alaska; (Coleoptera: Silphidae and Agyrtidae). The Insects and Arachnids of Canada, Part 13, Agriculture Canada. 121 pp.

Anderson, R.S. and S.B. Peck. 1986. Geographic patterns of colour variation in North American *Nicrophorus* burying beetles (Coleoptera: Silphidae). Journal of Natural History, 20: 282-297.

Balduf, W.V. 1935. The bionomics of entomophagous Coleoptera. J.B. Swift Publishing Co., St. Louis, 220 pp.

Bredohl, R. 1984. Zur Bioakustic mitteleuropäischer Totengräber (Coleoptera: Silphidae: *Necrophorus*). Entomologie Generalis, 10: 11-25.

Brewer, J.W. and T.R. Bacon. 1975. Biology of the carrion beetle, *Silpha ramosa*. Annals of the Entomological Society of America, 68: 786-790.

Campbell, J.M. 1980. Distribution patterns of Coleoptera in eastern Canada. Canadian Entomologist, 112: 1161-1176.

Conley, M.R. 1982. Carrion locating efficiency in burying beetles, *Nicrophorus carolinus* (L.) (Silphidae). Southwestern Naturalist, 27: 11-15.

Cooley, R.A. 1917. The spinach carrion beetle: *Silpha bituberosa*. Journal of Economic Entomology, 10: 94-102.

Coope, G.R. 1979. Late Cenozoic fossil Coleoptera: Evolution, biogeography, and ecology. Annual Review of Ecology and Systematics, 10: 247-267.

Crowson, R.A. 1981. The Biology of the Coleoptera. Academic Press, New York. 802 pp.

Davis, L.R., Jr. 1980. Notes on beetle distributions, with a discussion of *Nicrophorus americanus* Olivier and its abundance in collections (Coleoptera: Scarabaeidae, Lampyridae and Silphidae). Coleopterist's Bulletin, 34: 245-249.

Fisher, R.M. and R.D. Tuckerman. 1986. Mimicry of bumble bees and cuckoo bumble bees by carrion beetles (Coleoptera: Silphidae). Journal of the Kansas Entomological Society, 50: 20-25.

Halffter, G., S. Anduaga, and C. Huerta. 1983. Nidification des *Nicrophorus*. Bulletin de la Société Entomologique de France, 88: 648-666.

Horion, A. 1949. Faunistik der mitteleuropäischer Käfer. II. Klostermann, Frankfurt-am-Main.

Kevan, D.K. McE. 1985. Soil Zoology, then and now – mostly then. Quaestiones Entomologicae, 21: 371-462.

Lawrence, J.F. 1982. Coleoptera. In: S.P. Parker (ed.) Synopsis and classification of living organisms. Vol. 2. Pages 482-553. McGraw Hill Co., New York, NY.

Lawrence, J.F. and A.F. Newton, Jr. 1982. Evolution and classification of beetles. Annual Review of Ecology and Systematics, 13: 261-290.

Leech, H.B. 1934. The family history of *Nicrophorus conversator* Walker. Proceedings of the Entomological Society of British Columbia, 31: 36-40.

Lindroth, C. 1971. On the occurrence of a continental element in the ground beetle fauna of eastern Ontario (Coleoptera; Carabidae). Canadian Entomologist, 103: 1455-1462.

Matthews, J.V., Jr. 1980. Tertiary land bridges and their climate: Backdrop for development of the present Canadian insect fauna. Canadian Entomologist, 112: 1089-1104.

Miller, S.E. and S.B. Peck. 1979. Fossil carrion beetles of Pleistocene California asphalt deposits, with a synopsis of recent California Silphidae. Transactions of the San Diego Society of Natural History, 19(8): 85-106.

Milne, L.J. and M.J. Milne. 1944. Notes on the behavior of burying beetles (*Nicrophorus* spp.). Journal of the New York Entomological Society, 52: 311-327.

Milne, L.J. and M.J. Milne. 1976. The social behavior of burying beetles. Scientific American, 235 (2): 84-89.

Morgan, A.V. and A. Morgan. 1980. Faunal assemblages and distributional shifts of Coleoptera during the late Pleistocene in Canada and the northern United States. Canadian Entomologist, 112: 1105-1128.

Munroe, E. 1956. Canada as an environment for insect life. Canadian Entomologist, 88: 372-476.

Newton, A.F., Jr. 1981. New name for the extinct genus *Mesagyrtes* Ponomarenko (Coleoptera: Silphidae S.L.). Psyche, 88: 335.

Peck, S.B. 1982. The life history of the Japanese carrion beetle *Ptomascopus morio* and the origins of parental care in *Nicrophorus* (Coleoptera, Silphidae, Nicrophorini). Psyche, 89: 107-111.

Peck, S.B. 1986. *Nicrophorus* (Silphidae) can use large carcasses for reproduction. Coleopterist's Bulletin, 40: 44.

Peck, S.B. and R.S Anderson. 1982. The distribution and biology of the alpine-tundra carrion beetle *Thanatophilus coloradensis* (Wickham) in North America (Coleptera: Silphidae). Coleopterist's Bulletin, 36(1): 112-115.

Peck, S.B. and R.S. Anderson. 1985. Taxonomy, phylogeny, and biogeography of the carrion beetles of Latin America (Coleoptera: Silphidae). Quaestiones Entomologicae, 21: 247-317.

Peck, S.B. and S.E. Miller. 1982. Type designations and synonymies for North American Silphidae (Coleoptera). Psyche, 89: 151-156.

Pirone, D.J. 1974. Ecology of necrophilous and carpophilous Coleptera in a southern New York woodland (phenology, aspection, trophic and habitat preferences). Ph.D. thesis, Fordham University. 769 pp.

Pukowski, E. 1933. Öekologische Untersuchungen an *Necrophorus* F. Zeitschrift für Morphologie und Ökologie der Tiere, 27: 518-586.

Ratcliffe, B.C. 1972. The natural history of *Necrodes surinamensis*. Transactions of the American Entomological Society, 98: 359-410.

Reed, H.B. 1958. A study of dog carcass communities in Tennessee, with special reference to the insects. American Midland Naturalist, 59: 213-245.

Schawaller, W. 1981. Taxonomie und Faunistik der Gattung *Thanatophilus* (Coleoptera: Silphidae). Stuttgarter Beiträge zur Naturkunde Serie A (Biologie), 351: 1-21.

Scudder, G.G.E. 1979. Present patterns in the fauna and flora of Canada. pp. 87-179. In: Danks, H. (ed). Canada and its insect fauna. Memoirs of the Entomological Society of Canada, No. 108 573 pp.

Shelford, V.E. 1963. The Ecology of North America. Univ. Illinois Press, Urbana, Ill. 610 pp.

Shubeck, P.P. 1968. Orientation of carrion beetles to carrion: Random or non-random? Journal of the New York Entomological Society, 86: 253-265.

Shubeck, P.P. 1969. Ecological studies on carrion beetles in Hutcheson Memorial Forest. Journal of the New York Entomological Society, 77: 138-151.

Shubeck, P.P. 1971. Diel periodicities of certain carrion beetles. Coleopterist's Bulletin, 25: 41-46.

Shubeck, P.P. 1975a. Do diurnal carrion beetles use sight, as an aid to olfaction, in locating carrion? W.L. Hutcheson Memorial Forest Bulletin, 3: 36-39.

Shubeck, P.P. 1975b. Flight activity of certain carrion beetles: *Silpha noveboracensis*, Staphylinidae, Histeridae. W.L. Hutcheson Memorial Forest Bulletin, 3: 40-43.

Shubeck, P.P. 1976. Carrion beetle responses to poikilothermic and homiothermic carrion. Entomological News, 89: 265-269.

Shubeck, P.P., N.M. Downie, R.L. Wenzel, and S.B. Peck. 1977. Species composition of carrion beetles in a mixed-oak forest. W.L. Hutcheson Memorial Forest Bulletin, 4: 12-17.

Shubeck, P.P., N.M. Downie, R.L. Wenzel, and S.B. Peck. 1981. Species composition and seasonal abundance of carrion beetles in an oak-beech forest in the Great Swamp National Wildlife Refuge (N.J.). Entomological News, 92: 7-16.

Udvardy, M. 1969. Dynamic Zoogeography. Van Nostrand Reinhold, New York.

Walker, T.J. 1957. Ecological studies of the arthropods associated with certain decaying materials in four habitats. Ecology 38: 262-276.

Wells, S.M., R.M. Pyle, and N.M. Collins. 1983. The IUCN Invertebrate Red Data Book. International Union for the Conservation of Nature, Gland, Switzerland. 650 pp.

Wilson, D.S. and J. Fudge. 1984. Burying beetles: intraspecific interactions and reproductive success in the field. Ecological Entomology, 9: 195-203.

Wilson, D.S. and W.G. Knollenberg. 1984. Food discrimination and ovarian development in burying beetles (Coleoptera: Silphidae: *Nicrophorus*). Annals of the Entomological Society of America, 77: 165-170.

Wilson, D.S., W.G. Knollenberg, and J. Fudge. 1984. Species packing and temperature dependent competition among burying beetles (Silphidae, *Nicrophorus*) Ecological Entomology, 9: 205-216.

Young, O.P. 1983. The biology of the Silphidae (Coleoptera): a coded bibliography. University of Maryland Agricultural Experment Station, Deptartment of Entomology Miscellaneous Publication 981. 47 pp.

Young, O. 1985. Survival of a carrion beetle, *Necrodes surinamensis* (Coleoptera: Silphidae), on a diet of dead fall armyworm (Lepidoptera: Noctuidae) larvae. Journal of Entomological Science, 20: 359-366.

Zaragoza, Caballero, S. and H. Perez Ruiz. 1975. Varianza de *Nicrophorus mexicanus* Matt. (Coleoptera: Silphidae) y su correlacion ambiental de el Pedregal de san Angel, Distrio Federal, Mexico. Annals del Instituto Biologics Universidad Nacional Autonoma de Mexico 50, serie de Zoologia, (1): 459-475.

(Received 16 January 1987; accepted 19 September 1987)

PRIMARY TYPES OF CHALCIDOIDEA AND CYNIPOIDEA (HYMENOPTERA) IN THE CANADIAN NATIONAL COLLECTION

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Abstract *Proc. ent. Soc. Ont.* 118:83-108 (1987)

One hundred and sixty-one primary types of Chalcidoidea (150) and Cynipoidea (11) housed in the Canadian National Collection were examined and listed. These were contributed by the following authors: Yoshimoto (79), Provancher (15), Miller (13), Doganlar (7), Andrews (6), Bugbee (5), Peck (6), Ashmead (3), Heraty (3), Milliron (3), Schauff (3), Barron (2), Balduf (1), Barron and Bisdee (1), Boucek (1), Brues (1), Darling (1), Graham (1), Hansson (1), Hedqvist (1), Huggert (1), Noyes (1), Shorthouse and Ritchie (1), Viereck (1), Walker (1), Walley (1), Yoshimoto and Gibson (1) and Yoshimoto, Kozlov and Trjapitzin (1).

Introduction

The following is a catalogue of the primary types (holotypes, lectotypes and neotypes) of the Chalcidoidea and Cynipoidea which are housed in the Canadian National Collection (C.N.C.). These types are listed in alphabetical order by species-group names under their respective subfamilies and families. The classification follows Krombein, Hurd, Smith and Burks (1979) unless otherwise stated. The list of primary types is followed by an index of subspecies, species, genera, subfamilies, families and superfamilies.

The original reference is given for each type followed by the sex of the type, C.N.C. no., pertinent data on the label (e.g. location, date of collection, host, collector), condition of specimen (i.e. parts missing), presence of allotype and number of paratypes (females and males). A species (e.g. *elegans* Provancher *Phasgonophora*) that has been transferred to a different genus (e.g. *Trigonura*) is indicated as follows: *elegans* Provancher *Phasgonophora* / *Trigonura*. A specific name (e.g. *maculatipennis* Provancher *Chiloneurus*) that has been put into synonymy under another specific name (e.g. *fuscus* (Howard) *Encyrtus*) is shown as follows: *maculatipennis* Provancher *Chiloneurus* / *fuscus* (Howard) *Encyrtus*. Where a specific name has been put under synonymy with a different specific name, the original reference for the new name is also given. Occasionally, the name in the first heading of a type entry will differ slightly from the original combination (that name given in the body of each type entry together with the original reference) – this is because the first heading follows Krombein, Hurd, Smith and Burks (1979). Information not found on the specimen label but found in the original description or information in the original description that contradicts what is on the label is put in square brackets (e.g. Ottawa, [Ontario], or 3.VI.1984, [13.VII.1982]). For reasons of clarification or to point out an error, the occasional comment is included.

The collection of Chalcidoidea and Cynipoidea first began through the general collecting of the early entomologists. Staff members Peck (1935-1969), Yoshimoto (1969-) and Gibson (1972-) have been responsible for curating and adding to the collections of Chalcidoidea and Cynipoidea.

This catalogue is computerized and continuously updated as new primary types are entered into the C.N.C. A printout of these new entries may be obtained by contacting the Hymenoptera Section of the Biosystematics Research Centre (Agriculture Canada), K.W. Neatby Building, Central Experimental Farm, Ottawa, Ontario, K1A 0C6.

CHALCIDOIDEA

CHALCIDIDAE

Brachymeriinae

elegans Provancher *Phasgonophora* / *Trigonura*
Phasgonophora elegans Provancher, 1887, p. 191.
Lectotype female, C.N.C. no. 103; [Hull]. Parts missing: right hind leg beyond coxa. Lectotype designated by Burks, 1963, p. 1260.

ENCYRTIDAE

Encyrtinae

deceptor Miller *Copidosoma*
Copidosoma deceptor Miller, 1958, pp. 58-60.
Holotype male, C.N.C. no. 6516 [2156]; Cascade Valley, 22 miles northeast of Banff, Alberta, ex [reared from] *Recurvaria* sp. [on lodgepole pine]. Parts missing: left antenna on slide, genitalia on slide. Allotype female and 75 paratypes (females and males) in C.N.C. The C.N.C. no. given in the original description (2156) is incorrect.

ennomophagus Yoshimoto *Ooencyrtus*
Ooencyrtus ennomophagus Yoshimoto, 1975a, pp. 833-835.
Holotype female, C.N.C. no. 13542; [New Haven], Connecticut, VIII.1972, [4.VII.1973], ex [reared from] elm spanworm egg, H. [K.] Kaya and J. Anderson. Allotype male and 84 paratypes (females and males) in C.N.C.

flavigena Noyes *Bennettisca*
Bennettisca flavigena Noyes, 1980, pp. 181-182.
Holotype female, C.N.C. no. 19019; Santa Margarita Circular Road, Curepe, Trinidad, 9-23.VI.1974, F.D. Bennett, [Moericke trap].

glandiferellae Barron and Bisdee *Copidosoma*
Copidosoma glandiferellae Barron and Bisdee, 1984, pp. 1353-1355.
Holotype female, C.N.C. no. 17791; Expt. Farm, Ottawa, Ontario, 21.V.1980, [21.VI.1980], ex *Telphusa glandiferella* Zell. on *Lonicera* sp., [reared from *Deltophora glandiferella* on *Lonicera tatarica 'Alba'*, adults em. 12-14.VII.1980], Barron and Bisdee. Twenty-seven female paratypes in C.N.C.

innocuellae Barron *Copidosoma*
Copidosoma innocuellae Barron, 1970a, pp. 1338-1339.
Holotype female, C.N.C. no. 11437; Parkers Ridge, York County, New Brunswick, 10.VIII.1964, ex *Anacampsis innocuella* Z. [Zeller], F.I.S. Allotype male and 15 female and 3 male paratypes in C.N.C.

leptoglossi Yoshimoto *Ooencyrtus*
Ooencyrtus leptoglossi Yoshimoto, 1977d, pp. 1009-1010.
Holotype female, C.N.C. no. 15130; Athens, Clarke County, Georgia, em 2.IX.1971, ex eggs of *Leptoglossus corculus* (Say) on loblolly pine, G. [Gary] L. DeBarr. Allotype male and 94 paratypes (females and males) in C.N.C.

maculatipennis Provancher *Chiloneurus* / *fuscus* (Howard) *Encyrtus*
Comys fusca Howard, 1881, p. 363.
Chiloneurus maculatipennis Provancher, 1887, pp. 203-204.
Lectotype female, C.N.C. no. 96; Hull, 12.VI., [Harrington]. Parts missing: both antennae, right hind wing, left front leg beyond coxa glued to point, right hind leg beyond coxa. Lectotype designated by Burks, 1963, pp. 1256-1257, who also points out that the insect glued to the left of the lectotype (on its back) is the paralectotype female.

nearctica Miller *Parablastothrix*
Parablastothrix nearctica Miller, 1965b, p. 751.
Holotype female, C.N.C. no. 8800; Jackson, Mississippi, III.1964, ex *Coptodisca* sp. [Lepidoptera], on *Vaccinium arboreum* [Marsh], B. Mather.

pallipes Provancher *Copidosoma* / *Cerchysius*
Copidosoma pallipes Provancher, 1887, p. 205.
Lectotype female, C.N.C. no. 95; [Ottawa, (Harrington)]. Parts missing: left antenna beyond 2nd segment, right antenna beyond 3rd flagellomere. Lectotype designated by Burks, 1963, p. 1257.

richardsi Barron *Psyllaephagus*
Psyllaephagus richardsi Barron, 1970b, pp. 1507-1511.
Holotype female, C.N.C. no. 11104; Constance Bay, Ontario, 7.IX.1969, em. 12.IX.1969 ex [reared from] *Aphalara steironemicola* Richards on *Steironema ciliatum* (L.), [8-23.IX.1969], J.R. Barron. Allotype male and 7 female and 4 male paratypes in C.N.C.

Tetracneminae

scutellata Miller *Gibberella* / *bicoloripes* Girault *Paraleurocerus*
Paraleurocerus bicoloripes Girault, 1915, pp. 172-173.
Gibberella scutellata Miller, 1961, p. 496.
Holotype female, C.N.C. no. 7418; Tuskett, [Tusket], Nova Scotia, 18.VII.1959, em. 30.VII.1959, ex *Lithocolletis* sp. on *Alnus crispa* [(Art.) Pursh], C.D. Miller. Parts missing: right hind wing, right hind leg beyond 4th tarsal segment. Allotype male in C.N.C. Tusket is mispelled (Tuskett) on the holotype label.

EUCHARITIDAE

Eucharitinae

barberi Heraty *Pseudometagea*
Pseudometagea barberi Heraty, 1985, pp. 70-72.
Holotype male, C.N.C. no. 19642; Pinery Pk., Grand Bend, Ont., 14.VII.1980, Kevin [N.] Barber. Parts missing: both antennae beyond pedicel mounted on slide.

liburna Heraty *Pseudochalcura*
Pseudochalcura liburna Heraty, 1986, pp. 190-191.
Holotype female, C.N.C. no. 19644; Big Pine Key, Monroe Co., Florida, 9.VII.1971, W.H. Pierce. Parts missing: last flagellomere of left antenna.

nefrens Heraty *Pseudometagea*
Pseudometagea nefrens Heraty, 1985, pp. 83-84.
Holotype female, C.N.C. no. 19643: Medicine Hat, Alberta, 14.VII.1956, O. Peck.

EULOPHIDAE

Entedontinae

According to Yoshimoto (personal communication), *Derostenus* is a valid genus and species that fall under *Derostenus* do not belong under *Achrysocharella;* Yoshimoto (pers. comm.) also places *Euderus* under the subfamily Euderinae.

adelphae Peck *Pediobius*
Pediobius adelphae Peck, 1985, pp. 665-666.
Holotype female: Merivale [Ottawa], Ont., 6.VII.1956, ex *Bucculatrix adelpha*, [T.N.] Freeman and [G.] Lewis. Parts missing: left front leg beyond part of first tarsal segment. Allotype male in C.N.C.

albipes Yoshimoto *Derostenus (Nearctostenus)*
Derostenus (Nearctostenus) albipes Yoshimoto 1973a, pp. 1056-1057.
Holotype female, C.N.C. no. 13055; Williamsville, Missouri, 10.IX-5.X.1969, [17-29.IX-5.X.1969], J.T. Becker, Malaise trap. Allotype male in C.N.C.

albus Yoshimoto *Achrysocharoides*
Achrysocharoides albus Yoshimoto, 1977a, pp. 913-914.
Holotype female, C.N.C. no. 14081; Ottawa, Ontario, 17.II.1971, [ex *Phyllonorycter* sp.].

aluta Yoshimoto *Chrysocharis (Kratochviliana)*
Chrysocharis (Kratochviliana) aluta Yoshimoto, 1973b, pp. 1328-1329.
Holotype female, C.N.C. no. 12946; Harwood, [Hardwood], Ontario, 13.IV.1967, [13.VI.1967], ex *Profenusa* sp. on *Quercus borealis* [*Quercus (=borealis) rubra* L.]. Allotype male in C.N.C. Harwood is misspelled (Hardwood) in the original description.

arienascapus Miller *Enaysma (Pentenaysma)* / *Achrysocharoides*
Enaysma arienascapus Miller, 1962, pp. 1050-1052.
Holotype female, C.N.C. no. 7582; Gatineau Park, Hull, Quebec, 26.I.1961, ex *Lithocolletis* sp. on *Viburnum* sp., G. Lewis. Allotype male in C.N.C. New combination by Yoshimoto, 1977a, p. 919.

baliosa Yoshimoto *Chrysonotomyia*
Chrysonotomyia baliosa Yoshimoto, 1980, pp. 1042-1044.
Holotype female, C.N.C. no. 16058; Bridgetown, Nova Scotia, 2.IX.1912, [21.IX.1912], G.E.S.

beckeri Yoshimoto *Chrysocharis (Chrysocharis)* / *Zaommomyia*
Chrysocharis (Chrysocharis) beckeri Yoshimoto, 1973c, pp. 1386-1387.
Holotype female, C.N.C. no. 12949; Williamsville, Missouri, 17-29.V.1970, J.T. Becker, Malaise trap. New combination by Hansson, 1986, pp. 249-250.

bellincus Yoshimoto *Chrysocharis (Chrysocharis)*
Chrysocharis (Chrysocharis) bellincus Yoshimoto, 1973c, p. 1390.
Holotype female, C.N.C. no. 12951; Parke Reserve, 950ft., Kam. Co., Quebec, 18.VIII.1957, [1.VIII.1957], W.R.M. Mason. Parts missing: left front leg beyond trochanter, left hind leg beyond tibia, right front leg beyond 1st tarsal segment, right hind leg beyond femur. Allotype male in C.N.C.

beus Schauff *Paracrias*
Paracrias beus Schauff, 1985a, pp. 107-108.
Holotype female, C.N.C. no. 18013; Voltzberg Nat. Res. [San.], Foengoe Island, Surinam, Jan.-Feb. 1982, [Feb. 1982], Jim [James] Carpenter, pan trap. Parts missing: both antennae and both left wings on slide. Schauff misquoted data on holotype label.

bisulcus Yoshimoto *Achrysocharoides*
Achrysocharoides bisulcus Yoshimoto, 1977a, pp. 915-916.
Holotype female, C.N.C. no. 14082; Pt. Pelee, Ontario, em. 1.VIII.1963, [1.VII.1963], ex *Lithocolletis celtisella* [*Phyllonorycter celtisella* (Chambers)] on *Celtis occidentalis* [L.], C.D. [F.] Miller. Allotype male in C.N.C.

borealis Yoshimoto *Chrysonotomyia (Achrysocharella)*
Chrysonotomyia (Achrysocharella) borealis Yoshimoto, 1978a, pp. 705-706.
Holotype female, C.N.C. no. 15303; Shoreacres, British Columbia, 30.V.1974, [25.V.1973], em. 25.VI.1974, [ex *Coleophora laricella* Hubner], G. Miller. Allotype male in C.N.C.

carioca Miller *Enaysma (Pentenaysma)* / *Achrysocharoides*
Enaysma carioca Miller, 1962, p. 1043.

Holotype female, C.N.C. no. 7578; Gatineau Park, Hull, Quebec, 29.I.1961, ex *Lithocolletis sp.* on *Carya cordiformis* (Wangh.) K. Koch, G. Lewis. Parts missing: left front wing, right hind leg beyond 1st tarsal segment. Allotype male in C.N.C. New combination by Yoshimoto, 1977a, pp. 923-925.

clarkae Yoshimoto *Chrysocharis (Chrysocharis)*
Chrysocharis (Chrysocharis) clarkae Yoshimoto, 1973c, pp. 1392-1394.
Holotype female, C.N.C. no. 12952; One Sided Lake, Ontario, 20.VI.1960, S.M. Clark. Allotype male in C.N.C.

clypeata Miller *Enaysma (Pentenaysma) / Achrysocharoides*
Enaysma clypeata Miller, 1962, pp. 1047-1050.
Holotype male, C.N.C. no. 7581; Gatineau Park, Hull, Quebec, 19.I.1961, ex *Lithocolletis* sp. on maple [*Acer saccharum* Marsh], G. Lewis. New combination by Yoshimoto, 1977a, p. 918.

coptodiscae Yoshimoto *Chrysocharis (Kratochviliana)*
Chrysocharis (Kratochviliana) coptodiscae Yoshimoto, 1973b, pp. 1329-1330.
Holotype female, C.N.C. no. 12947, [12647]; Hedley, 5800 ft., British Columbia, 14.VIII.1934, A.N. Gartrell. Allotype male in C.N.C. The C.N.C. no. given in the original description (i.e. 12647) is incorrect.

cuspidigaster Yoshimoto *Chrysocharis (Kratochviliana)*
Chrysocharis (Kratochviliana) cuspidigaster Yoshimoto, 1973b, pp. 1330-1332.
Holotype female, C.N.C. no. 12948; Chapleau, [Ontario], 23.VIII.1965, ex *Lithocolletis salicifoliella* [Chambers], [F.I.S.]. Allotype male in C.N.C.

elmaellae Doganlar *Chrysocharis (Nesomyia)*
Chrysocharis (Nesomyia) elmaellae Doganlar, 1980a, pp. 122-126.
Holotype female, C.N.C. no. 19011; New Westminster, British Columbia, 24.VII.1978, ex *Phyllonorycter elmaella* Doganlar and Mutuura. Allotype male in C.N.C.

freemani Yoshimoto *Derostenus (Nearctostenus)*
Derostenus (Nearctostenus) freemani Yoshimoto, 1973a, pp. 1055-1056.
Holotype female, C.N.C. no. 13054; Lake Simcoe, Ontario, 5.V.1966, ex *Nepticula* sp., [F.I.S.]. Allotype male in C.N.C.

gahani Miller *Enaysma (Pentenaysma) / Achrysocharoides*
Enaysma gahani Miller, 1962, pp. 1041-1043.
Holotype female, C.N.C. no. 7486; Gatineau [Park, Hull, Quebec], 8.VIII.1960, ex *Lithocolletis* sp. on beech [*Fagus grandifolia* Ehrhl.], C.D. [F.] Miller. Allotype male in C.N.C. New combination by Yoshimoto, 1977a, p. 928.

gracillariae Yoshimoto *Chrysonotomyia (Achrysocharella)*
Chrysonotomyia (Achrysocharella) gracillariae Yoshimoto, 1978a, pp. 710-712.
Holotype female, C.N.C. no. 15304; Ottawa, Ontario, 13.VII.1960, ex *Gracillaria* sp. on blueberry, G. Lewis. Allotype male in C.N.C.

hirsutiventris Yoshimoto *Chrysocharis (Kratochviliana)*
Chrysocharis (Kratochviliana) hirsutiventris Yoshimoto, 1973b, pp. 1321-1322.
Holotype female, C.N.C. no. 12942; Ohio, [Yarmouth Co.], Nova Scotia, 26.VII.1959, ex *Lithocolletis malimalifoliella* [ex *Lithocolletis blancardella* F. (= *malimalifoliella* Braun)] on Malus, C.D. [F.] Miller. Allotype male in C.N.C.

hirtiscapus Miller *Enaysma (Pentanaysma) / Achrysocharoides*
Enaysma hirtiscapus Miller, 1962, p. 1047.
Holotype female, C.N.C. no. 7580; Bells Corners, Ontario, 31.III.1959, ex *Lithocolletis tiliacella* Chamb. on *Tilia americana,* G. Lewis. Allotype male in C.N.C. New combination by Yoshimoto, 1977a, p. 922.

incerta Yoshimoto *Chrysocharis (Kratochviliana)*
Chrysocharis (Kratochviliana) incerta Yoshimoto, 1973b, pp. 1320.
Holotype female, C.N.C. No. 12940; Wiarton, Ontario, 11.X.1960, ex *Nepticula lindquist* [lindquisti], Freeman, on birch, F.I.S. Parts missing: right antenna beyond 2nd segment, right middle leg beyond coxa with tibia glued to point.

intricatus Yoshimoto *Achrysocharoides*
Achrysocharoides intricatus Yoshimoto, 1977a, p. 912.
Holotype female, C.N.C. no. 14080; Aylmer, Quebec, 13.VIII.1968, ex *Gracillaria* sp. Allotype male in C.N.C.

kaulbarsi Yoshimoto *Thripoctenoides*
Thripoctenoides kaulbarsi Yoshimoto, 1981, pp. 723-725.
Holotype female, C.N.C. no. 16509; Riceville, Ontario, 22.VI.1979, M. Kaulbars.

levipectis Yoshimoto *Chrysocharis (Chrysocharis)*
Chrysocharis (Chrysocharis) levipectis Yoshimoto, 1973c, pp. 1403-1404.
Holotype female, C.N.C. no. 12954; Lac Brule, Quebec, 13.VIII.1951, swept from sandy meadow, O. Peck. Parts missing: right hind leg beyond tibia.

liocephalatus Peck *Pediobius*
Pediobius liocephalatus Peck, 1985, pp. 675-676.
Holotype female, C.N.C. no. 15515; St. Williams, Ontario, 22,26.VIII.1961, [28.VIII.1961], 9.IX.1961, host *Gracinella* prob. *fraxinella* [*Caloptilia* probably *cuculipennella* on *Fraxinus americana,* F.I.S.]. Allotype male in C.N.C.

magniclavatus Peck *Pediobius*
Pediobius magniclavatus Peck, 1985, pp. 672-673.
Holotype female, C.N.C. no. 15516; One Sided Lake, Ontario, 1.VII.1960, S.M. Clark. Allotype male in C.N.C.

milleri Yoshimoto *Chrysocharis (Kratochviliana)*
Chrysocharis (Kratochviliana) milleri Yoshimoto, 1973b, pp. 1327-1328.
Holotype female, C.N.C. no. 12945; Ottawa, Ontario, 13.VII.1961, [11.VIII.1961], ex sawfly on *Ulmus glabra* Hudson, C.D. [F.] Miller. Allotype male in C.N.C.

minuta Hansson *Zaommomyia*
Zaommomyia minuta Hansson, 1986, pp. 250-251.
Holotype female, C.N.C. no. 19313; 5 km. S. Coldspring, San Jacinto Co., Texas, 22.V.1983, M. Kaulbars.

myricae Miller *Enaysma (Pentenaysma) / Achrysocharoides*
Enaysma myricae Miller, 1962, pp. 1043-1047.
Holotype female, C.N.C. no. 7579; Kingston, Nova Scotia, 2.III.1961, [12.IX.1960], ex *Lithocolletis* sp. on *Myrica* sp. [*Myrica gale* L.], G. Lewis. Allotype male in C.N.C. New combination by Yoshimoto, 1977a, pp. 925-928.

nearctica Yoshimoto *Mestocharis*
Mestocharis nearctica Yoshimoto, 1976d, pp. 756-757.
Holotype female, C.N.C. no. 15020; Edmonton, Alberta, 8.VI.1946, [6.VI.1946], W.R.M. Mason. Parts missing: right middle leg beyond femur. Allotype male in C.N.C.

ocellatus Peck *Pediobius*
Pediobius ocellatus Peck, 1985, pp. 666-667.
Holotype female, C.N.C. no. 15517; Sebright-Lindsay, [Victoria County], Ontario, 22.III.1963, ex *Lithocolletis corylisella* [ex *Phyllonorycter corylisella* (Gracillariidae) F.I.S.]. Parts missing: abdomen glued to point.

protolithocolletidis Yoshimoto *Chrysocharis (Kratochviliana)*
Chrysocharis (Kratochviliana) protolithocolletidis Yoshimoto, 1973b, p. 1324.
Holotype male, C.N.C. no. 12944; Aweme, Manitoba, 25.IV.1929, ex *Protolithocolletis lathyri* Braun, R.M. White. Parts missing: left front leg beyond 3rd tarsal segment, right hind leg beyond coxa.

pseudotsugatae Peck *Pediobius*
Pediobius pseudotsugatae Peck, 1985, pp. 669-670.
Holotype female, C.N.C. no. 15518; Vernon, British Columbia, 28.V.1962, ex *Orgyia pseudotsugata* [*Orgyria pseudotsugatae*], F.I.S.

reticulatus Yoshimoto *Achrysocharoides*
Achrysocharoides reticulatus Yoshimoto, 1977a, p. 929.
Holotype female, C.N.C. no. 14084; Bells Corners, [Ontario], 12.V.1965, ex *Lithocolletis* sp. [ex *Phyllonorycter* sp.] on red oak [*Quercus rubra* L.], Freeman. Parts missing: left hind leg beyond 3rd tarsal segment.

robusta Yoshimoto *Chrysocharis (Kratochviliana)*
Chrysocharis (Kratochviliana) robusta Yoshimoto, 1973b, pp. 1318-1319.
Holotype female, C.N.C. no. 12939; Banff, Alberta, VII.1949, ex *Recurvaria milleri* Busck [ex *Coleotechnites (= Recurvaria) milleri* Busck], J.H. McLeod. Allotype male in C.N.C.

stipitis Yoshimoto *Chrysocharis (Kratochviliana)*
Chrysocharis (Kratochviliana) stipitis Yoshimoto, 1973b, pp. 1320-1321.
Holotype female, C.N.C. no. 12941; Lake Huron, [Ontario], 27.III.1961, ex *Nepticula lindquisti* Freeman, [F.I.S.]. Allotype male in C.N.C.

strobilicola Peck *Pediobius*
Pediobius strobilicola Peck, 1985, pp. 658-659.
Holotype female, C.N.C. no. 15887; Olustee, Baker County, Florida, 31.I.1979, [31.XII.1979], ex *Dioryctria amatella [pupa of Dioryctria amatella,* reared as second generation upon *Trichoplusia ni*], R.A. Belmont. Allotype male in C.N.C.

subcircularis Yoshimoto *Chrysocharis (Chrysocharis)*
Chrysocharis (Chrysocharis) subcircularis Yoshimoto, 1973c, pp. 1387.
Holotype female, C.N.C. no. 12950; Dows [Lake], Ottawa, Ontario, 12.VII.1949, O. Peck. Parts missing: right antenna beyond 2nd segment, both left wings, left middle leg beyond coxa, left hind and right middle legs beyond femur, right hind leg, (note: the tarsal segments of one leg are glued to point), abdomen glued to point.

tetrapunctatus Yoshimoto *Achrysocharoides*
Achrysocharoides tetrapunctatus Yoshimoto, 1977, pp. 917-918.
Holotype female, C.N.C. no. 14083; Ottawa, Ontario, 8.III.1971, ex *Litho* [ex *Phyllonorycter* sp.].

tropicalis Yoshimoto *Mestocharis*
Mestocharis tropicalis Yoshimoto, 1976d, pp. 757-758.
Holotype female, C.N.C. no. 15021; Grossman Hammock, Homestead, Florida, 2.IV.1952, G.S. Walley. Parts missing: half of right front wing glued to point.

truncatipennis Yoshimoto *Chrysocharis (Chrysocharis)*
Chrysocharis (Chrysocharis) truncatipennis Yoshimoto, 1973c, pp. 1402-1403.
Holotype female, C.N.C. no. 12953; Vancouver, British Columbia, VII.1936, parasite of *Coptodisca arbutiella [Busck], W. Mathers. Parts missing: both antennae beyond 2nd segment, both left wings.*

viridis Provancher *Chrysocharis*
Chrysocharis viridis Provancher, 1887, p. 209.

Lectotype female, C.N.C. no. 57; [Ottawa, (Harrington)]. Parts missing: left antenna, right antenna beyond 2nd flagellomere. Lectotype designated by Burks, 1963, p. 1257.

walleyi Yoshimoto *Chrysocharis (Kratochviliana)*
Chrysocharis (Kratochviliana) walleyi Yoshimoto, 1973b, pp. 1323-1324.
Holotype female, C.N.C. no. 12943; Golden Lake, Ontario 10.IX.1943, [1.IX.1943], ex *Lithocolletis salicifoliella* Chambers on poplar, G.S. Walley. Allotype male in C.N.C.

yoshimotoi Doganlar *Chrysocharis (Nesomyia)*
Chrysocharis (Nesomyia) yoshimotoi Doganlar, 1980a, pp. 120-121.
Holotype female, C.N.C. no. 19032; Haney, British Columbia, 5.IX.1977, ex *Lithocolletis blancardella*, [ex *P. elmaella* on *Malus*], [M.] Doganlar. Parts missing: head (with right antenna apparently missing) glued to point, both left wings.

Euderinae

According to Yoshimoto (personal communication) Euderinae stands as a distinct subfamily of Eulophidae instead of falling as a tribe under the subfamily Entedontinae.

alaskensis Yoshimoto *Euderus*
Euderus (Euderus) alaskensis Yoshimoto, 1971a, p. 576.
Holotype female, C.N.C. no. 11599; King Salmon, Naknek R., Alaska, 19.VII.1952, [19.VI.1952], W.R. [M.] Mason.

campbelli Yoshimoto *Aoridus*
Aoridus campbelli Yoshimoto, 1971b, pp. 883-884.
Holotype female, C.N.C. no. 11630; Anchicaya, [300 m.], Colombia, 24-27.VII.1970, J.M. Campbell, Malaise trap. Parts missing: right antenna on slide, both right wings on slide, right front leg on slide, genitalia on slide.

canadensis Yoshimoto *Euderus*
Euderus (Secodelloidea) canadensis Yoshimoto, 1971a, pp. 548-550.
Holotype female, C.N.C. no. 11589; Yellowknife, Northwest Territories, 19.VIII.1949, E.F. [E.R.] Cashman. Parts missing: left antenna on slide, both right wings on slide, abdomen glued to point. Allotype male in C.N.C.

chillcotti Yoshimoto *Euderus*
Euderus (Euderus) chillcotti Yoshimoto, 1971a, pp. 565-566.
Holotype female, C.N.C. no. 11597; Penetang, Ontario, 1.VIII.1955, J.G. Chillcott. Parts missing: right antenna on slide, both left wings, left hind leg beyond coxa.

fuscedinellae Yoshimoto *Euderus*
Euderus (Euderus) fuscedinellae Yoshimoto, 1971a, p. 565.
Holotype female, C.N.C. no. 11596; Palm Springs, California, 7.XI.193?, Melander, [Norton, Kings Co., New Brunswick, 12.V.1969, ex *Coleophora fuscedinella* on white birch, F.I.S.]. I cannot account for the discrepency between the information given on the holotype label and that given in the original description.

glaucus Yoshimoto *Euderus*
Euderus (Euderus) glaucus Yoshimoto, 1971a, pp. 564-565.
Holotype female, C.N.C. no. 11595; Vineland Station, Ontario, 18.VIII.1939, ex immature larva of *Epiblema obfuscana* in Solidago stem, W.L. Putman. Parts missing: right antenna on slide, both left wings on slide.

masoni Yoshimoto *Euderus*
Euderus (Euderus) masoni Yoshimoto, 1971a, pp. 562-564.
Holotype female, C.N.C. no. 11594; Innisville, Ontario, 12.VII.1963, W.R.M. Mason, Malaise trap. Parts missing: right antenna on slide, both left wings on slide.

notus Yoshimoto *Astichus*
Astichus notus Yoshimoto, 1970c, pp. 656-658.
Holotype female, C.N.C. no. 11049; Gatineau Park, Quebec, 21.VIII.1966, [14.VI.1966], ex *Polyporus betulinus,* D.P. Pielou. Allotype male in C.N.C.

pecki Yoshimoto *Euderus*
Euderus (Euderus) pecki Yoshimoto, 1971a, pp. 561-562.
Holotype female, C.N.C. no. 11592; Cap Rouge, Quebec, 11.VII.1953, O. Peck. Parts missing: left antenna on slide, both left wings on slide.

polyporicola Hedquist *Astichus*
Astichus polyporicola Hedquist, 1969, p. 172.
Holotype female, C.N.C. no. 19029; Carp, Ontario, 20.V.1954, ex fungus of *Ganoderma applanatum,* E.C. Becker.

purpureus Yoshimoto *Euderus*
Euderus (Euderoides) purpureus Yoshimoto, 1971a, pp. 550-552.
Holotype female, C.N.C. no. 11590; Vineland, Ontario, 15.IX.1933, host *Laspeyresia molesta* Busck. [host *Grapholitha molesta* Busck]. Parts missing: right antenna on slide, both left wings on slide.

saperdae Miller *Euderus*
Euderus saperdae Miller, 1965c, pp. 1070-1072.
Holotype female, C.N.C. no. 8938; Gore Bay, Ontario, 26.III.1963, ex *Saperda* sp. [ex gall formed by *Saperda moesta* Lec. in poplar twigs], F.I.S.

solidaginis Yoshimoto *Euderus*
Euderus (Euderus) solidaginis Yoshimoto, 1971a, pp. 566-567.
Holotype female, C.N.C. no. 11598; Merivale, Ontario, 9.V.1943, ex *Sesioplex depressus* Vier. in goldenrod gall [ex *Campoplex depressus* (Viereck) in goldenrod], J. McD. and T.N.F. [J. McDunnough and T.N. Freeman]. Parts missing: both antennae with one on slide, both left wings on slide.

viridilineatus Yoshimoto *Euderus*
Euderus (Neoeuderus) viridilineatus Yoshimoto, 1971a, p. 553.
Holotype male, C.N.C. no. 11591; Ottawa, Ontario, 23.VIII.1959, J.R. Vockeroth. Parts missing: left antenna, all wings, left hind leg glued to point, right front leg beyond 1st tarsal segment, abdomen glued to point.

vockerothi Yoshimoto *Euderus*
Euderus (Euderus) vockerothi Yoshimoto, 1971a, p. 562.
Holotype female, C.N.C. no. 11593; Punta Gorda, Florida, 9.IV.1952, J.R. Vockeroth. Parts missing: left antenna on slide, both left wings on slide.

Eulophinae

alaskensis Yoshimoto *Dicladocerus*
Dicladocerus alaskensis Yoshimoto, 1976a, pp. 1178-1179.
Holotype female, C.N.C. no. 14002; Cold Bay, 163°W., [Naknek], Alaska, 13.VIII.1952, [3.VII.1952], W.R. [M.] Mason. Parts missing: left antenna on slide, both left wings on slide. Allotype male in C.N.C.

atus Schauff *Elachertus*
Elachertus atus Schauff, 1985b, pp. 856-857.
Holotype female, C.N.C. no. 19068; Niagara, Ontario, 18.II.1932, Crown Gall Goldenrod, W.E. Steenburgh. One male paratype in C.N.C.

australis Yoshimoto *Dicladocerus*
Dicladocerus australis Yoshimoto, 1976a, p. 1178.

Holotype female, C.N.C. no. 14003; L. Ouachita St. Park, Mountain Pine, Arkansas, May 1972, G. Heinrich, Malaise trap. Parts missing: right antenna on slide, both left wings on slide.

betulae Yoshimoto *Dicladocerus*

Dicladocerus betulae Yoshimoto, 1976a, pp. 1182-1183.

Holotype female, C.N.C. no. 14008; Whitefish Falls, Ontario, 13.VI.1963, ex *Recurvaria apicitripunctella*, F.I.S. Parts missing: both antennae one of which is glued to point, the other is on a slide, both left wings on slide. Allotype male in C.N.C.

canadensis Miller *Paraolinx*

Paraolinx canadensis Miller, 1964, pp. 1354-1356.

Holotype female, C.N.C. no. 8443; Meach Lake, [Chelsea], Quebec, 29.VI.1961, ex *Eragora apicitripunctella* Clem. [*Recurvaria apicitripunctella* Clem.], on *Tsuga canadensis* [(L.)], C.D. Miller. Parts missing: left antenna on slide, mandibles, labium and maxillae also on slide, right front leg beyond 2nd tarsal segment. Allotype male in C.N.C.

compressicornis Provancher *Coccophagus* / *conica (Provancher) Sympiesis*

Metacolus conicus Provancher, 1887, pp. 200-201.

Coccophagus compressicornis Provancher, 1887, p. 206.

Lectotype female, C.N.C. no. 104; [Ottawa (Harrignton)]. Parts missing: both antennae beyond 1st segment, right middle leg beyond 1st tarsal segment. Lectotype designated by Burks, 1963, p. 1257.

elongatus Yoshimoto *Pnigalio*

Pnigalio elongatus Yoshimoto, 1983a, pp. 979-984.

Holotype female, C.N.C. no. 17001; Thurso, Quebec, 20.VIII.1958, L.A. Kelton. Allotype male in C.N.C.

enargiae Miller *Sympiesis*

Sympiesis enargiae Miller, 1970, pp. 42-43.

Holotype female, C.N.C. no. 9515; Cedar Lake, Ontario, 16.VII.1961, ex *Enargia decolour* [*decolor* Grote], F.I.S.

epinotiae Yoshimoto *Dicladocerus*

Dicladocerus epinotiae Yoshimoto, 1976a, pp. 1181-1182.

Holotype female, C.N.C. no. 14007 [1400]; Rossport, [Pass Lake], Ontario, 5.X.1964, [2.X.1964], ex *Epinotia transmissana* [Walker] on white birch, [F.I.S.]. Parts missing: both antennae and both right wings with apical part of 1 antenna on point. Allotype male in C.N.C.

exoteliae Yoshimoto *Dicladocerus*

Dicladocerus exoteliae Yoshimoto, 1976a, p. 1181.

Holotype female, C.N.C. no. 14006; Kemptville, Ontario, 9.V.1952, ex mass reared *Exotelia pinifoliella* (Chamb). Parts missing: both antennae 1 of which is on slide, both left wings on slide, left front leg beyond 2nd tarsal segment. Allotype male in C.N.C.

japonicus Yoshimoto *Dicladocerus*

Dicladocerus japonicus Yoshimoto, 1976a, pp. 1187-1188.

Holotype female, C.N.C. no. 14012; [Komora, Nago Prefecture], Japan, 24.VI.1974, ex *Coleophora laricella* [ex *Coleophora longisignella* Moriuti on Japanese larch, *Larix leptolepis* Gordon]. Parts missing: left front wing on slide. Allotype male in C.N.C.

mellipes Provancher *Euplectrus*

Euplectrus mellipes Provancher, 1887, p. 207.

Lectotype female, C.N.C. no. 93; [Cap Rouge]. Parts missing: right antenna beyond 2nd segment. Lectotype designated by Burks, 1963, p. 1258.

nearcticus Yoshimoto *Dicladocerus*
Dicladocerus nearcticus Yoshimoto, 1976a, pp. 1184-1186.
Holotype female, C.N.C. no. 14010; Hope, Idaho, 1972, ex *Coleophora laricella* infesting larch branches [ex larch branches infested with *Coleophora laricella*], R.E. Denton.

nebulosa Provancher *Miotropis* / *Eulophus*
Miotropis nebulosa Provancher, 1887, p. 208.
Lectotype female, C.N.C. no. 97; [Ottawa, (Harrington)]. Parts missing: left antenna beyond 2nd flagellomere, right antenna beyond 2nd segment. Lectotype designated by Burks, 1963, p. 1259.

neolongulus Yoshimoto *Pnigalio*
Pnigalio neolongulus Yoshimoto, 1983a, p. 991.
Holotype female, C.N.C. no. 17002; Warkworth Cr., near Churchill, Manitoba, 29.VI.1952, J.G. Chillcott. Allotype male in C.N.C.

occidentalis Yoshimoto *Dicladocerus*
Dicladocerus occidentalis Yoshimoto, 1976a, pp. 1179-1180.
Holotype female, C.N.C. no. 14004; Fraser Canyon, British Columbia, 15.V.1953, [4.V.1959], em. 3.VI.1953 ex Ponderosa pine, J.H. McLeod. Allotype male in C.N.C.

pacificus Yoshimoto *Dicladocerus*
Dicladocerus pacificus Yoshimoto, 1976, pp. 1186-1187.
Holotype female, C.N.C. no. 14011; Shoreacres, British Columbia, 25.V.1973, em. 3.VI.1973, G. Miller, [Creston, British Columbia, 11.VI.1973, ex *Coleophora laricella* (Hubner), G. Miller, F.I.S.]. Allotype male in C.N.C.

prealatus Yoshimoto *Dicladocerus*
Dicladocerus prealatus Yoshimoto, 1976a, p. 1180.
Holotype female, C.N.C. no. 14005; Echo Lake, 10,600 ft., Mt. Evans, Colorado, 13.VII.1961, S.M. Clark. Parts missing: left antenna on slide, both left wings on slide.

rugatus Yoshimoto *Pnigalio*
Pnigalio rugatus Yoshimoto, 1983a, pp. 985-986.
Holotype female, C.N.C. no. 17459; Padre Dam, San Diego Co., California, 13.VI.1980, em. sawfly gall on *Salix* [em. from *Pontania resinicola* Marlatt gall on *Salix lasiolepis*], D. Perkins. Parts missing: left front leg beyond coxa glued to point (beneath insect), both hind legs beyond tibia glued to point. Allotype male in C.N.C.

terraenovae Yoshimoto *Dicladocerus*
Dicladocerus terraenovae Yoshimoto, 1976a, pp. 1189-1190.
Holotype female, C.N.C. no. 14013; 1.5 mi. W.[N.] of Lake Ambrose, Newfoundland, [11-15.VI.1974], em. 11.VII.1974 ex *Coleophora laricella* Hbn. on *Larix laricina*, F.I.S. Allotype male in C.N.C.

tricladus Provancher *Eulophus* / *Sympiesis*
Eulophus tricladus Provancher, 1887, p. 208.
Lectotype female, C.N.C. no. 100; [Ottawa, (Harrington)]. Parts missing: left antenna beyond 2nd segment, right antenna, left front leg beyond coxa, left hind leg beyond tibia. Lectotype designated by Burks, 1963, p. 1258.

vulgaris Yoshimoto *Dicladocerus*
Dicladocerus vulgaris Yoshimoto, 1976a, pp. 1183-1184.
Holotype female, C.N.C. no. 14009; Berthierville, Quebec, 7.VI.1950, host *Recurvaria piceaella* [Kearfoot], L. Daviault. Parts missing: left middle leg beyond coxa glued beneath point. Allotype male in C.N.C.

yuekseli Doganlar *Sympiesis*
Sympiesis yuekseli Doganlar, 1979b, pp. 495-497.

Holotype male, C.N.C. no. 19033; Burnaby, British Columbia, 16.III.1977, [16.II.1977], ex *Lithocolletis blancardella,* [laboratory reared from mines of *Phyllonorycter* n. sp.], [M.] Doganlar. Allotype female in C.N.C.

Tetrastichinae

According to Yoshimoto (personal communication) the tribe Tetrastichini has been elevated to the subfamily Tetrastichinae; Graham (1977) places the genus *Peckelachertus* under the subfamily Tetrastichinae.

diprioni Yoshimoto *Peckelachertus*

Peckelachertus diprioni Yoshimoto, 1970a, pp. 909-910.
Holotype female, C.N.C. no. 10971; Katevale, Quebec, 21.VI.1960, D. de Oliveria. Parts missing: head glued to point. Allotype male in C.N.C.

magnifica Yoshimoto *Henryana*

Henryana magnifica Yoshimoto, 1983b, pp. 91-92.
Holotype female, C.N.C. no. 17719; Nova Teutonia, 27°18′S., 52°23′W., 300-500 m., Brazil, X-XI.1972, Fritz Plaumann.

pompilicola Graham *Tetrastichus*

Tetrastichus pompilicola Graham, 1960. In Lindroth and Graham, 1960, pp. 94-97.
Holotype female, C.N.C. no. 19010; W. St. Modeste [Modest], Labrador, 18.VII.1951, C. [H.] Lindroth. Modeste is misspelled (Modest) in the original description.

trisulcatus Provancher *Tetrastichus*

Tetrastichus trisulcatus Provancher, 1887, p. 211.
Lectotype female, C.N.C. no. 56; [Cap Rouge, Ottawa, (Harrington)]. Lectotype designated by Burks, 1963, p. 1262.

EURYTOMIDAE

Stage and Snelling (1986) synonymize the subfamilies Aximinae and Eudecatominae under Eurytominae.

Eurytominae

altifossa Bugbee *Eurytoma*

Eurytoma altifossa Bugbee, 1967, pp. 487-488.
Holotype female, C.N.C. no. 9507; Aweme, Manitoba, 10.VI.1929, ex galls of *O. [Oxytropis] lamberti,* R.M. White.

angulifera Boucek *Masneroma*

Masneroma angulifera Boucek, 1983, pp. 191-193.
Holotype female, C.N.C. no. 19009; Hamilton, Ontario, 22-29.VI.1981, M. Sanborne, Malaise trap.

calycis Bugbee *Eurytoma*

Eurytoma calycis Bugbee, 1961, pp. 33-34.
Holotype female, C.N.C. no. 7583; Black Sturgeon Lake, [40 miles northwest of Nipigon], Ontario, em. 2.VII.1958, ex *Pinus banksiana* shoot as pupa, J.B. Thomas. Four female and 2 male paratypes in C.N.C.

conica Provancher *Eurytoma*

Eurytoma conica Provancher, 1887, p. 193.
Lectotype female, C.N.C. no. 99; [Ottawa, (Harrington)]. Parts missing: right antenna beyond 1st flagellomere, left hind leg. Lectotype designated by Burks, 1963, p. 1259.

contractura Bugbee *Eurytoma*
Eurytoma contractura Bugbee, 1967, pp. 471-472.
Holotype female, C.N.C. no. 9506; Marmora, Ontario, 4.V.1949, host *Melanagromyza schineeri* Gir. [(Giraud)], O. Peck. Allotype male and 4 female and 1 male paratypes in C.N.C.

diabolus Yoshimoto and Gibson *Aplatoides*
Aplatoides diabolus Yoshimoto and Gibson, 1979, pp. 421-424.
Holotype female, C.N.C. no. 15848; Jatai, Goias, Brazil, I.1977, F.M. Oliveira. Parts missing: both antennae and all wings on slide, both hind legs beyond coxa on slide, right middle leg beyond tibia.

flavicrus Bugbee *Eurytoma*
Eurytoma flavicrus Bugbee, 1967, pp. 469-470.
Holotype female, C.N.C. no. 9505; Clemson, South Carolina, 14.V.1951, ex gall of *Nyssa sylvatica,* W. Mason. Allotype male and 2 female and 1 male paratypes in C.N.C.

nigricoxa Provancher *Eurytoma*
Eurytoma nigricoxa Provancher, 1887, p. 193.
Lectotype female, C.N.C. no. 2513; [Ottawa, (Harrington)]. Parts missing: left antenna. Lectotype designated by Burks, 1963, p. 1259.

novascotiae Balduf *Decatoma / Sycophila*
Decatoma novascotiae Balduf, 1932, pp. 50-52.
Holotype female, C.N.C. no. 3102; Lequille, Nova Scotia, em. 2.IV.1911, [reared by Prof. G.E. Saunders from the galls of *Neuroterus batatus* (Fitch) on April 2, 1911, from the type locality], G.E. Saunders. Allotype male and 1 female and 1 male paratypes in C.N.C.

picea Bugbee *Eurytoma*
Eurytoma picea Bugbee, 1967, pp. 510-511.
Holotype female, C.N.C. no. 19028; forestry station, New Westminster, British Columbia, 9.V.1939, [host *Pissodes sitchensis* Hopkins on] *Picea sitchensis,* R.H. Longmore. Thirty-four paratypes (females and males) in C.N.C.

solenozopheriae Ashmead *Eurytoma*
Eurytoma solenozopheriae Ashmead, 1887, p. 196.
Neotype female, C.N.C. no. 9504; Marmora, Ontario, 1.V.1949, ex gall of *Hemadas nubilipennis,* O. Peck. Neoallotype male in C.N.C. Neotype designated by Bugbee 1967, p. 468. Twenty-one neoparatypes (females and males) in C.N.C.

MYMARIDAE

Eubroncinae

orientalis Yoshimoto, Kozlov and Trjapitzin *Eubroncus*
Eubroncus orientalis Yoshimoto, Kozlov and Trjapitzin, 1972, pp. 879-881.
Holotype male, C.N.C., no. 19026; Grombak Field Stn., Selangor, Malaya, [Malaysia], 3-19.VII.1970, Chua Tock Hing.

Mymarinae

canadensis Yoshimoto *Macalpinia*
Macalpinia canadensis Yoshimoto, 1975b, p. 528.
Holotype female, C.N.C. no. 13549; near Medicine Hat, [Alberta], May 1973, [J.F.] McAlpine and [H.] Teskey. Holotype in amber.

immaculatum Schauff *Acmopolynema*
Acmopolynema immaculatum Schauff, 1981, pp. 453-454.

Holotype female, C.N.C. no. 16148; Aldershot, Nova Scotia, 18.VIII.1950, on apple tree, A. Mcphee. Parts missing: left antenna on slide, both right wings on slide. Allotype male and 2 male paratypes in C.N.C.

Mymaromminae

nearctica Yoshimoto *Archaeromma*

Archaeromma nearctica Yoshimoto, 1975b, pp. 506-507.

Holotype female, C.N.C. no. 13544; near Medicine Hat, Alberta, 1966, [1968, CNC-76], [J.F.] McAlpine and [J.E.H.] Martin. Holotype in amber.

Triadomerinae

bulbosus Yoshimoto *Triadomerus*

Triadomerus bulbosus Yoshimoto, 1975b, pp. 508-510.

Holotype female, C.N.C. no. 13545; near Medicine Hat, [Alberta], P. Boston. Holotype in amber. Allotype male also in amber.

PTEROMALIDAE

Ceinae

ciliata Yoshimoto *Spalangiopelta*

Spalangiopelta ciliata Yoshimoto, 1977c, pp. 541-543.

Holotype female, C.N.C. no. 14079; Mer Bleue, Ontario, 29.VII.1975, L. Masner. One female paratype in C.N.C.

Diparinae

beckeri Yoshimoto *Lelaps*

Lelaps beckeri Yoshimoto, 1977b, pp. 1052-1054.

Holotype female, C.N.C. no. 15006; Williamsville, Missouri, VIII-IX.1969, [VII-IX.1969], J.T. Becker, Malaise trap. Parts missing: left antenna and both left wings. Allotype male and 1 female and 4 male paratypes in C.N.C.

bilineatus Yoshimoto *Trimicrops*

Trimicrops bilineatus Yoshimoto, 1977b, pp. 1037-1038.

Holotype female, C.N.C. no. 15002; Williamsville, Missouri, 12.VII.1955, E.C. Becker, Berlese sample, deciduous duff. Allotype male and 2 female and 4 male paratypes in C.N.C.

melinus Yoshimoto *Lelaps*

Lelaps melinus Yoshimoto, 1977b, pp. 1054-1055.

Holotype male, C.N.C. no. 15007; Bayou Chicot, Evangeline Parish, Louisiana, 11-18.VIII.1971, [11-14.VIII.1971], D. Shanek. Parts missing: left antenna on slide, both left wings on slide. One male paratype in C.N.C.

nearctica Yoshimoto *Netomocera*

Netomocera nearctica Yoshimoto, 1977b, pp. 1044-1048.

Holotype female, C.N.C. no. 15005; in meadow, Chatterton, 13 mi. North of Belleville, Ontario, 27.V.1968, C.D. Dondale. Parts missing: both antennae 1 of which is on slide, left front and both right wings with 1 front and right hind wing on slide, left middle leg beyond tibia. Allotype male in C.N.C.

pedunculata Yoshimoto *Dipara*

Dipara pedunculata Yoshimoto, 1977b, pp. 1040-1042.

Holotype female, C.N.C. no. 15004; 5 mi. W. of Hopkinsville, Kentucky, 22.IX.1967, J.M. Campbell, Berlese sample of deciduous duff. Allotype male in C.N.C.

striatus Yoshimoto *Lelaps*
Lelaps striatus Yoshimoto, 1977b, p. 1055.
Holotype male, C.N.C. no. 15008; Williamsville, Missouri, 29.VI-5.VII.1969, J.T. Becker, Malaise trap. Parts missing: about half of right antenna. Fifteen male paratypes in C.N.C.

trilineatus Yoshimoto *Trimicrops*
Trimicrops trilineatus Yoshimoto, 1977b, p. 1038.
Holotype female, C.N.C. no. 15003; Mammoth Cave National Park, Edmonson Co., Kentucky, 24.III.1973, W. Suter. Parts missing: left antenna on slide. Three female paratypes in C.N.C.

Perilampinae

iodes Darling *Euperilampus*
Euperilampus iodes Darling, 1983, pp. 17-18.
Holotype female, C.N.C. no. 17004; Nova Teutonia, 27° 11′S., 52°23′W., 300-500 m., [Santa Catarina], Brazil, II.1968, Fritz Plaumann. One female and 2 male paratypes in C.N.C.

laevis Provancher *Perilampus*
Perilampus laevis Provancher, 1887, p. 199.
Lectotype female, C.N.C. no. 92; [Ottawa, (Harrington)]. Parts missing: right antenna, both front legs and right middle leg beyond coxa (2 of which are glued to point), left middle leg beyond trochanter glued to point. Lectotype designated by Burks, 1963, p. 1260.

Pteromalinae

americana Miller *Perniphora*
Perniphora americana Miller, 1965a, pp. 79-81.
Holotype female, C.N.C. no. 8622; Stanley, New Brunswick, 23.VI.1939, J.S. Prebble. This type is not listed under C.N.C. no. 8622 in C.N.C. type book. Three female paratypes in C.N.C.

facialis Provancher *Charitopus* / *Lampoterma*
Charitopus facialis Provancher, 1887, p. 203.
Lectotype male, C.N.C. no. 98; [Ottawa, (Harrington)]. Parts missing: right hind leg beyond coxa. Lectotype designated by Burk, 1963, p. 1256.

finlaysoni Doganlar *Mesopolobus*
Mesopolobus finlaysoni Doganlar, 1979a, pp. 649-651.
Holotype female, C.N.C. no. 19018; Burnaby, British Columbia, 21.VII.1977, ex *Apanteles longicauda* ex *Hemerophila pariana* [*E. pariana* on *Malus* spp.], [M.] Doganlar. Allotype male and 3 female and 3 male paratypes in C.N.C.

gallicolus Doganlar *Pteromalus (Pteromalus)*
Pteromalus (Pteromalus) gallicolus Doganlar, 1980b, pp. 156-159.
Holotype female, C.N.C. no. 19020; Burnaby, British Columbia, 15.XII.1977, ex *Rubus parviflorus*, [laboratory reared from the gall of *Diastrophus kincaidii* Gill. ex *Rubus parviflorus* Nutt.], Doganlar. Allotype male and 5 female and 5 male paratypes in C.N.C.

jonesi Yoshimoto *Dorcatomophaga (Nearctomophaga)*
Dorcatomophaga (Nearctomophaga) jonesi Yoshimoto, 1976c, pp. 558-560.
Holotype female, C.N.C. no. 13780; 6 mi. NW. of Terre Haute, Vigo Co., Indiana, 22.I.1974, [ex hibernation nest of a meadow jumping mouse, *Zapus hudsonius* (Zim-

merman), from collapsed woodchuck, *Marmota monax* (Linnaeus), burrow], G.S. Jones. Parts missing: left antenna and wings on slide. One female paratype in C.N.C.

lipardis Viereck *Amblymerus / hemerocampae* Girault *Tritneptis*
Tritneptis hemerocampae Girault, 1908, pp. 92-94.
Amblymerus lipardis Viereck, 1924, p. 69.
Holotype male, C.N.C. no. 792; Agassiz, [Vancouver], British Columbia, 22.IX.1921, R. Glendenning. There is another label on this type that gives the following information: New Westminster, British Columbia, 21.IX.1921, ex *Stilpnotia salicis,* R. Glendenning. Parts missing: genitalia on slide. Allotype female in C.N.C.

longicaudae Doganlar *Mesopolobus*
Mesopolobus longicaudae Doganlar, 1979a, pp. 652-654.
Holotype female, C.N.C. no. 19022; Burnaby, British Columbia, 22.X.1977, ex *Triclistus emarginatus* [(Say)], ex *H. pariana* [*Eutromula pariana* (Cl.) on *Malus* spp.], [M.] Doganlar. Parts missing: left antenna, all wings with 1 front and 1 hind wing glued to point, left middle leg beyond coxa, right middle leg beyond tibia. Allotype male and 2 female and 2 male paratypes in C.N.C.

oezbeki Doganlar *Arthrolytus (Anadolytus)*
Arthrolytus (Anadolytus) oezbeki Doganlar, 1978, pp. 1112-1115.
Holotype female, C.N.C. no. 19025; Burnaby, British Columbia, 25.I.1978, *O. californicum, R. parviflorus,* [laboratory reared from the gall of *Diastrophus kincaidii* on *Rubus parviflorus*], [M.] Doganlar. Allotype male and 5 female and 5 male paratypes in C.N.C.

squama Huggert *Zdenekiana*
Zdenekiana squama Huggert, 1979, p. 1057.
Holotype female, C.N.C. no. 15865; Lac Brule, Quebec, 7.VIII.1976, O. Peck. Parts missing: left antenna on slide on pin, both left wings on slide on pin.

tortricis Brues *Nasonia / Psychophagus*
Nasonia tortricis Brues, 1910, pp. 259-260.
Holotype female, C.N.C. no. 1361; Baskatong, Quebec, 1909, ex [reared early in August by Arthur Gibson from pupae of the spruce budworm] *Tortrix fumiferana.* Parts missing: left hind wing. Allotype male in C.N.C.

TETRACAMPIDAE

Baeomorphinae

ovatata Yoshimoto *Baeomorpha*
Baeomorpha ovatata Yoshimoto, 1975b, pp. 522-524.
Holotype female, C.N.C. no. 13548: Cedar Lake, Manitoba, VII.1950, [VIII.1950, CNC-77a], W.J. Brown and R. Bird. Holotype in amber.

Tetracampinae

cubensis Yoshimoto *Epiclerus*
Epiclerus cubensis Yoshimoto, 1978b, pp. 1210-1211.
Holotype female, C.N.C. no. 15498; Soledad, Cuba, 25.II.1925, Geo. Salt. Parts missing: left antenna on slide, both left wings on slide.

nearcticus Yoshimoto *Epiclerus*
Epiclerus nearcticus Yoshimoto, 1978b, pp. 1207-1210.
Holotype female, C.N.C. no. 15497; McDonald Is., St. Lawrence Is. National Park, Ontario, 20.VII.1976, [20.VI.1976], G. Thompson. Three female paratypes in C.N.C.

TORYMIDAE

Megastigminae

caperatus Milliron *Megastigmus*
Megastigmus caperatus Milliron, 1949, pp. 306-308.
Holotype female, C.N.C. no. 5900; Port Hope, Ontario, 23.V.1895.

formosus Milliron *Megastigmus*
Megastigmus formosus Milliron, 1949, pp. 339-342.
Holotype female, C.N.C. no. 5901; Ottawa, Ontario, 21.VII.1938, A. Brooks. Four female paratypes in C.N.C.

grandiosus Yoshimoto *Megastigmus* / *albifrons* Walker *Megastigmus*
Megastigmus albifrons Walker, 1869, p. 314.
Megastigmus grandiosus Yoshimoto, 1979, pp. 201-203.
Holotype female, C.N.C. no. 15496 [15788]; Calpulalpam, Tlaxcala, [Mexico], 27.I.1976, [reared from seed of] *Pinus montezumae* [Lamb.], D. Cibriau [Davis Cibrian]. Parts missing: right hind wing. This type is listed under both of the above C.N.C. no's. Allotype male and 12 female and 13 male paratypes in C.N.C.

heterophyllae Milliron *Megastigmus tsugae*
Megastigmus tsugae var. *heterophyllae* Milliron, 1949, pp. 309-311.
Holotype female, C.N.C. no. 5902; Vancouver, British Columbia, 24.III.1938, *Tsuga heterophylla* seed, W. Mathers. Parts missing: left antenna. Allotype male and 1 male paratype in C.N.C.

specularis Walley *Megastigmus*
Megastigmus specularis Walley, 1932, pp. 187-188.
Holotype female, C.N.C. no. 3390; New Brunswick, reared at Ottawa 19.III.1928 ex seed of *Abies balsamea*, E.B. Watson. Allotype male and 56 female and 17 male paratypes in C.N.C.

Monodontomerinae

bimaculatus Provancher *Oligosthenus* / *stigma* (Fabricius) *Glyphomerus*
Ichneumon stigma Fabricius, 1793, p. 188
Oligosthenus bimaculatus Provancher, 1887, p. 196
Lectotype female, C.N.C. no. 101; [Ottawa, (Harrington)]. Parts missing: both antennae, left hind wing, left front leg beyond tibia, left middle and right front legs beyond femur, right middle leg beyond 1st tarsal segment, right hind leg beyond trochanter glued to point. Lectotype designated by Burks, 1963, p. 1259.

Toryminae

splendens Provancher *Syntomaspis* / *Allotorymus*
Syntomaspis splendens Provancher, 1887, pp. 196-197.
Lectotype female, C.N.C. no. 94; [Ottawa, (Harrington)]. Parts missing: apical half of left front wing, left hind wing, left hind leg, abdomen. Lectotype designated by Burks, 1963, p. 1262.

TRICHOGRAMMATIDAE

forsythi Yoshimoto *Pseudoxenufens*
Pseudoxenufens forsythi Yoshimoto, 1976b, pp. 419-421.
Holotype female, C.N.C. no. 13779; rain forest, Science Center, Rio Pallinque [Rio Pallenque], 200 m., Western Ecquador, [Western Ecuador], 20.VII.1974, [20.VIII.1974], ex abdomen of *Opisphanes cassina* Feld., Adrian Forsyth. Ecuador is misspelled (Ecquador) on the type label.

CYNIPOIDEA

CYNIPIDAE

Alloxystinae

anthracina Andrews *Alloxysta*
Alloxysta anthracina Andrews, 1978, pp. 54-55.
Holotype male, C.N.C. no. 19077; Mile 236, Richardson Highway, Alaska, 16.VI.1951, W.R.M. Mason. Parts missing: left front leg beyond 1st tarsal segment, left middle and left hind legs beyond femur. Six female and 2 male paratypes in C.N.C.

laevis Andrews *Phaenoglyphis*
Phaenoglyphis laevis Andrews, 1978, pp. 40-41.
Holotype female, C.N.C. no. 19021; Johnston Canyon, 4700 ft., Banff, Alberta, 18.VII.1962, [18.VIII.1962], K.C. Herrmann [K.C. Hermann]. One female paratype in C.N.C.

minuscula Andrews *Alloxysta*
Alloxysta minuscula Andrews, 1978, p. 66.
Holotype female, C.N.C. no. 19023; Ottawa, Ontario, in lab 1937, G.A. Hobbs. Seven male paratypes in C.N.C.

pecki Andrews *Phaenoglyphis*
Phaenoglyphis pecki Andrews, 1978, pp. 41-42.
Holotype female, C.N.C. no. 19027; Chapin Sanctuary, East Ridge, Tennessee, 7.V.1952, O. Peck. Parts missing: left antenna and left front wing on slide, left hind leg beyond tibia.

quebeci Andrews *Alloxysta*
Alloxysta quebeci Andrews, 1978, pp. 66-67.
Holotype female, C.N.C. no. 19030; Chimo, Quebec, 17-18.VIII.1959, W.R.M. Mason. Parts missing: right middle leg beyond 4th tarsal segment. Four female paratypes in C.N.C.

stenos Andrews *Phaenoglyphis*
Phaenoglyphis stenos Andrews, 1978, pp. 43-44.
Holotype female, C.N.C. no. 19031; Paxson Lodge, [Paxon Lodge], 4000 ft., Gulkana, Alaska, 4.VIII.1951, W.R.M. Mason. One female paratype in C.N.C.

Cynipinae

harringtoni Ashmead *Aulax* / *Aulacidea*
Aulax harringtoni Ashmead, 1887b, p. 146.
Holotype female, C.N.C. no. 444; [Canada, described from one specimen sent by Mr. W. Hague Harrington of Ottawa].

triforma Shorthouse and Ritchie *Diplolepis*
Diplolepis triforma Shorthouse and Ritchie, 1984, pp. 1628-1632.
Holotype female, C.N.C. no. 18033; South Bay Road, Sudbury, Ontario, Fall 1980, [on *Rosa acicularis* em. Spring 1981], lab reared, J.D. Shorthouse. Parts missing: right front leg beyond coxa. Allotype male in C.N.C.

Himalocynipinae

vigintilis Yoshimoto *Himalocynips*
Himalocynips vigintilis Yoshimoto, 1970d, pp. 1584-1585.
Holotype female, C.N.C. no. 11601; Kathmandu, Godavari, 6000 ft., Nepal, 24.VII.1967, [W.R.M. Mason], Canadian Nepal Expedition. Parts missing: left

antenna on slide, both left wings on slide, right front and right middle legs beyond coxa. One female paratype in C.N.C.

FIGITIDAE

Aspiceratinae

provancheri Ashmead *Callaspidia*

Callaspidia provancheri Ashmead 1887a. *In* Provancher, 1887, pp. 167-168.
Holotype female, C.N.C. no. 443; [Cap Rouge, Hull, Guignard]. Parts missing: left antenna beyond 3rd flagellomere, right antenna beyond 2nd flagellomere (part of 1 antenna glued beneath point).

IBALIIDAE

Ibaliinae

gigantea Yoshimoto *Ibalia*

Ibalia gigantea Yoshimoto, 1970b, pp. 1196-1198.
Holotype female, C.N.C. no. 10970; Ribbon Cr., Alberta, em. 10.V.1965, reared log *Picea glauca,* [IV.1966, D.S. Kusch], F.I.S. Allotype male in C.N.C.

Acknowledgements

I would like to thank Carl Yoshimoto, Gary Gibson and Gene Bisdee for their help and for carefully reviewing this paper.

References

Andrews, F.G. 1978. Taxonomy and host specificity of Nearctic Alloxystinae with a catalog of the world species (Hymenoptera: Cynipidae). Occasional Papers in Entomology, State of California Department of Food and Agriculture, Division of Plant Industry. Laboratory Service Number 25, 129 pp.

Ashmead, W.H. 1887a. Studies on the North American Chalcididae, with descriptions of new species, chiefly from Florida. Transactions of the American Entomological Society, 14: 183-203.

Ashmead, W.H. 1887b. On the cynipidous galls of Florida, with descriptions of new species and synopses of the described species of North America. Transactions of the American Entomological Society, 14: 125-158.

Balduf, W.V. 1932. Revision of the chalcid flies of the tribe Decatomini (Eurytomidae) in America North of Mexico. Proceedings of the United States National Museum, 79(28): 1-95.

Barron, J.R. 1970a. A new species of *Copidosoma* (Hymenoptera: Encyrtidae) parasitizing larvae of *Anacampsis innocuella* (Lepidoptera: Gelechiidae). Canadian Entomologist, 102: 1337-1339.

Barron, J.R. 1970b. A new species of *Psyllaephagus* (Hymenoptera: Encyrtidae) parasitizing *Aphalara steironemicola* (Homoptera: Psyllidae) on Steironema ciliatum. Canadian Entomologist, 102: 1509-1512.

Barron, J.R. and H.E. Bisdee. 1984. Hymenopterous parasites with lepidopterous and sawfly hosts on *Lonicera* (Honeysuckle) in the Ottawa area. Canadian Entomologist, 116: 1345-1356.

Boucek, Z. 1983. On Buresium, Masneroma (n. gen.) and some other *Eurytomidae* (Hymenoptera). Entomologica Scandinavica, 14: 186-194.

Brues, C.T. 1910. A new pteromalid parasitic on *Tortrix fumiferana*. Canadian Entomologist, 42: 259-260.

Bugbee, R.E. 1961. A new species of the genus *Eurytoma* (Hymenoptera: Eurytomidae) phytophagous in the buds of jack pine (*Pinus banksiana*). Canadian Entomologist, 93: 33-34.

Bugbee, R.E. 1967. Revision of chalcid wasps of genus *Eurytoma* in America North of Mexico. Proceedings of the United States National Museum, 118: 433-552.

Burks, B.D. 1963. The Provancher species of Chalcidoidea (Hymenoptera). Canadian Entomologist, 95:1254-1263.

Darling, D.C. 1983. A review of the New World species of *Euperilampus* (Hymenoptera; Chalcidoidea), with notes about host associations and phylogenetic relationships. Quaestiones Entomologicae, 19: 1-40.

Doganlar, M. 1978. A new species of *Pteromalinae* (Hymenoptera: Pteromalidae) from Western North America. Canadian Entomologist, 110: 1111-1115.

Doganlar, M. 1979a. Two new species of *Mesopolobus* Westwood (Hymenoptera: Pteromalidae) from Western Canada. Canadian Entomologist, 111: 649-659.

Doganlar, M. 1979b. A new species of *Sympiesis* (Hymenoptera: Chalcidoidea: Eulophidae) reared from *Phyllonorycter* (sp.) (Lepidoptera: Gracilariidae). Canadian Entomologist, 111: 495-498.

Doganlar, M. 1980a. Two new species of *Chrysocharis* Foerster and a new synonymy and record of *Sympiesis* Foerster (Hymenoptera: Chalcidoidea; Eulophidae) from Western Canada. Turkiye Bitki Koruma Dergisi, 4(2): 119-129.

Doganlar, M. 1980b. A new species of *Pteromalus swederus* (Hymenoptera; Petromalidae) from Western Canada. Turkiye Bitki Koruma Dergisi, 4(3): 155-160.

Fabricius, J.C. 1793. Entomologia systematica, 2: p. 188.

Girault, A.A. 1908. A peculiar case of parasitism with *Hemerocampa leucostigma* Smith and Abbot, with description of a new genus and species of Pteromalidae. Psyche, 15: 89-121.

Girault, A.A. 1915. New genera of chalcidoid Hymenoptera. Journal of the New York Entomological Society, 23: 165-173.

Graham, M.W.R. deV. 1977. Systematic position of *Peckelachertus* Yoshimoto (Hym., Eulophidae) and description of a new species from Britain. Systematic Entomology, 2: 45-47.

Hansson, C. 1986. A revision of the Nearctic species of the genus *Zaommomyia* Ashmead (Hymenoptera, Eulophidae). Proceedings of the Entomological Society of Washington, 88(2): 244-252.

Hedquist, K.-J. 1969. Notes on the genus *Astichus* Forst. and description of new species (Hym., Chalcidoidea, Eulophidae, Euderinae). Entomologisk Tidskrift, 90(3-4): 166-173.

Heraty, J.M. 1985. A revision of the Nearctic Eucharitinae (Hymenoptera: Chalcidoidea: Eucharitidae). Proceedings of the Entomological Society of Ontario, 116: 61-103.

Heraty, J.M. 1986. *Pseudochalcura* (Hymenoptera: Eucharitidae), a New World genus of chalcidoids parasitic on ants. Systematic Entomology, 11: 183-212.

Howard, L.O. 1881. Report on the parasites of the Coccidae in the collection of this department. Annual Report of the United States Department of Agriculture for 1880, pp. 350-373.

Huggert, L. 1979. A new species of the genus *Zdenekiana* Hugg. in Canada (Hymenoptera: Chalcidoidea: Pteromalidae). Canadian Entomologist, 111: 1057-1058.

Krombein, K.V., P.D. Hurd, Jr., D.R. Smith and B.D. Burks (Eds.), (1979). Catalog of Hymenoptera in America North of Mexico. V. 1, Symphyta and Apocrita (Parasitica). Smithsonian Institution Press, Washington, D.C.

Lindroth, C.H., and M.W.R. de V. Graham. 1960. A new *Tetrastichus* from Labrador (Hym. Chalc.), parasite of a pompilid wasp. Opuscula Entomologica, 25: 93-97.

Miller, C.D.F. 1958. A new species of *Copidosoma* closely related to C. *nanellae silvestri*. Pan-Pacific Entomologist, 34: 57-61.

Miller, C.D.F. 1961. A new genus and species of *chalcid* (Hymenoptera: Encyrtidae). Canadian Entomologist, 93: 494-496.

Miller, C.D.F. 1962. Some Nearctic species of the chalcid genus *Enaysma* Delucchi (Eulophidae: Entedontinae). Canadian Entomologist, 94: 1039-1052.

Miller, C.D.F. 1964. Some species of the New World genus *Paraolinx* Ashmead (Hymenoptera: Eulophidae). Canadian Entomologist, 96: 1352-1362.
Miller, C.D.F. 1965a. A new species of *Perniphora* Ruschka (Hymenoptera: Cleonymini). Canadian Entomologist, 97: 78-82.
Miller, C.D.F. 1965b. A Nearctic species of *Parablastothrix* Mercet (Hymenoptera: Encyrtidae). Canadian Entomologist, 97: 750-753.
Miller, C.D.F. 1965c. A new Nearctic species of *Euderus* Haliday (Hymenoptera: Eulophidae). Canadian Entomologist, 97: 1070-1072.
Miller, C.D. 1970. The Nearctic species of *Pnigalio* and *Sympiesis* (Hymenoptera: Eulophidae). Memoirs of the Entomological Society of Canada, No. 68, 121 pp.
Milliron, H.E. 1949. Taxonomic and biological investigations in the genus *Megastigmus*. American Midland Naturalist, 41: 257-420.
Noyes, J.S. 1980. A review of the genera of Neotropical Encyrtidae (Hymenoptera: Chalcidoidea). Bulletin of the British Museum Natural History Entomology Series, 41(3): 107-253.
Peck, O. 1985. The taxonomy of the Nearctic species of *Pediobius* (Hymenoptera: Eulophidae), especially Canadian and Alaskan forms. Canadian Entomologist, 117: 647-704.
Provancher, Abbé L. 1887. Additions et corrections à la faune Hyménoptérologique de la province de Québec. Fam. VIII. Chalcidides. C. Daveau, Québec, pp. 184-211.
Schauff, M.E. 1981. A review of Nearctic species of *Acmopolynema* Oglobin (Hymenoptera: Mymaridae). Proceedings of the Entomological Society of Washington, 83: 444-460.
Schauff, M.E. 1985a. The new world genus *Paracrias* Ashmead (Hymenoptera: Eulophidae). Proceedings of the Entomological Society of Washington, 87: 98-109.
Schauff, M.E. 1985b. Taxonomic study of the Nearctic species of *Elachertus spinola* (Hymenoptera: Eulophidae). Proceedings of the Entomological Society of Washington, 87: 843-858.
Shorthouse, J.D. and A.J. Ritchie. 1984. Description of biology of a new species of *Diplolepis* Fourcroy (Hymenoptera: Cynipidae) inducing galls on the stems of *Rosa acicularis*. Canadian Entomologist, 116: 1623-1636.
Stage, G.I. and R.R. Snelling. 1986. The subfamilies of Eurytomidae and systematics of the subfamily Heimbrinae (Hymenoptera: Chalcidoidea). Contributions in Science, Natural History Museum, Los Angeles County, no. 375, pp. 1-17.
Viereck, H.L. 1924. Descriptions of new reared Hymenoptera from Nova Scotia and British Columbia. Canadian Entomologist, 56: 64-69.
Walker, F. 1869. Notes on Chalcididae; and description of a new species of *Megastigmus*. Transactions of the Entomological Society of London, pp. 313-320.
Walley, G.S. 1932. Host records and new species of Canadian Hymenoptera. Canadian Entomologist, 64: 181-189.
Yoshimoto, C.M. 1970a. A new eulophid parasite (Hymenoptera: Chalcidoidea) from eggs of the nursery pine sawfly, *Diprion frutetorum* (Hymenoptera: Tenthredinoidea). Canadian Entomologist, 102: 908-910.
Yoshimoto, C.M. 1970b. A new ibaliid wasp from North America (Hymenoptera: Cynipoidea, Ibaliidae). Canadian Entomologist, 102: 1196-1198.
Yoshimoto, C.M. 1970c. A new species of *Astichus* (Hymenoptera: Eulophidae) associated with the birch bracket fungus *Polyporus betulinus* and woody fungus *Ganoderma applanatum* in Eastern Canada. Canadian Entomologist, 102: 656-659.
Yoshimoto, C.M. 1970d. A new subfamily of Cynipoidea (Hymenoptera) from Nepal. Canadian Entomologist, 102: 1583-1585.
Yoshimoto, C.M. 1971a. Revision of the genus *Euderus* of America North of Mexico (Hymenoptera: Eulophidae). Canadian Entomologist, 103: 541-578.
Yoshimoto, C.M. 1971b. A new genus of Euderinae from South America (Hymenoptera, Chalcidoidea: Eulophidae). Canadian Entomologist, 103: 882-886.
Yoshimoto, C.M. 1973a. A new Nearctic *Derostenus* (Hymenoptera: Eulophidae) parasitic

on Nepticula (Lepidoptera: Nepticulidae) in North America. Canadian Entomologist, 105: 1053-1057.
Yoshimoto, C.M. 1973b. Review of North American *Chrysocharis (Kratochviliana)* (Eulophidae: Chalcidoidea) North of Mexico, especially species attacking birch casebearer (Lepidoptera: Coleophoridae) and birch leafminer (Hymenoptera: Tenthredinidae). Canadian Entomologist, 105: 1309-1340.
Yoshimoto, C.M. 1973c. Revision of the genus *Chrysocharis* Forster (subgenus *Chrysocharis* s. str.) (Eulophidae: Chalcidoidea) of America North of Mexico. Canadian Entomologist, 105: 1377-1405.
Yoshimoto, C.M. 1975a. A new species of *Ooencyrtus* (Hymenoptera: Chalcidoidea, Encyrtidae) reared from the elm spanworm, *Ennomos subsignarius* (Lepidoptera: Geometridae). Canadian Entomologist, 107: 833-835.
Yoshimoto, C.M. 1975b. Cretaceous chalcidoid fossils from Canadian amber. Canadian Entomologist, 107: 499-528.
Yoshimoto, C.M. 1976a. Revision of the genus *Dicladocerus* (Eulophidae: Chalcidoidea) of America North of Mexico, with particular reference to species attacking larch casebearer (Lepidoptera: Coleophoridae). Canadian Entomologist, 108: 1173-1206.
Yoshimoto, C.M. 1976b. *Pseudoxenufens forsythi* a new genus and species of Trichogrammatidae (Hymenoptera: Chalcidoidea) from Western Ecuador. Canadian Entomologist, 108: 419-422.
Yoshimoto, C.M. 1976c. A new species of Pteromalinae (Pteromalidae: Chalcidoidea) from North America. Canadian Entomologist, 108: 557-560.
Yoshimoto, C.M. 1976d. Synopsis of the genus *Mestocharis* Forster in America North of Mexico (Chalcidoidea: Eulophidae). Canadian Entomologist, 108: 755-758.
Yoshimoto, C.M. 1977a. The North American species of the genus *Achrysocharoides* (Hymenoptera: Eulophidae). Canadian Entomologist, 109: 907-930.
Yoshimoto, C.M. 1977b. Revision of the Diparinae (Pteromalidae: Chalcidoidea) from America North of Mexico. Canadian Entomologist, 109: 1035-1056.
Yoshimoto, C.M. 1977c. A new species of *Spalangiopelta* Masi in North America (Chalcidoidea: Pteromalidae, Ceinae). Canadian Entomologist, 109: 541-544.
Yoshimoto, C.M. 1977d. A new species *Ooencyrtus leptoglossi (*Hymenoptera: Chalcidoidea, Encyrtidae) reared from eggs of *Leptoglossus corculus* (Hemiptera: Coreidae). Canadian Entomologist, 109: 1009-1012.
Yoshimoto, C.M. 1978a. Revision of the subgenus *Achrysocharella* Girault of America North of Mexico (Chalcidoidea, Eulophidae: *Chrysonotomyia* Ashmead). Canadian Entomologist, 110: 697-719.
Yoshimoto, C.M. 1978b. Two new species of *Epiclerus* from the New World (Hymenoptera: Chalcidoidea, Tetracampidae). Canadian Entomologist, 110: 1207-1211.
Yoshimoto, C.M. 1979. A new species of *Megastigmus* from Mexico (Chalcidoidea: Torymidae, Megastigminae). Canadian Entomologist, 111: 201-206.
Yoshimoto, C.M. 1980. Synopsis of *Chrysonotomyia* Ashmead S. Str. of America North of Mexico (Hymenoptera: Chalcidoidea, Eulophidae). Canadian Entomologist, 112: 1039-1048.
Yoshimoto, C.M. 1981. First record of *Thripoctenoides* from North America, with description of a new species (Hymenoptera: Eulophidae). Canadian Entomologist, 113: 723-725.
Yoshimoto, C.M. 1983a. Review of North American *Pnigalio* Schrank (Hymenoptera: Eulophidae). Canadian Entomologist, 115: 971-1000.
Yoshimoto, C.M. 1983b. A new genus of Tetrastichinae from the new world (Hymenoptera: Chalcidoidea: Eulophidae). Contributions of the American Entomological Institute, 20: 70-92.
Yoshimoto, C.M. and G.A.P. Gibson. 1979. A new genus of Eurytomidae (Chalcidoidea: Eurytomidae, Aximinae) from Brazil. Canadian Entomologist, 111: 421-424.
Yoshimoto, C.M., M.A. Kozlov and V.A. Trjapitzin. 1972. A new subfamily of Mymaridae (Hymenoptera, Chalcidoidea). Entomologicheskoe obozrenie, 51: 878-885.

(Received 15 May, 1987; accepted 19 September, 1987)

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ALTERNATIVE POLLINATORS FOR ONTARIO'S CROPS: PREFATORY REMARKS TO PAPERS PRESENTED AT A WORKSHOP HELD AT THE UNIVERSITY OF GUELPH, 12 APRIL, 1986.

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Proc. ent. Soc. Ont. 118:109-110 (1987)

Insect pollination of flowering plants is a key-stone process in the ecology of all terrestrial biomes of the world. The process links, inextricably, the vast majority of the world's biomass, insects and angiosperms in a co-evolutionary net that is well over 100 million years old (Crepet 1983). Thus, it is not surprising that the health of the world's biota can be linked with ease to pollination. That is not only true of the natural world (Kevan 1975), but also of the anthropocentric one in which pollination is crucial to much agricultural productivity (Free 1970; McGregor 1976; Kozin 1976; Pesson and Louveaux 1984). The value of pollination to Canadian agriculture has been estimated at about $1 billion (Winston and Scott 1984). Perturbations of pollination systems in agriculture by insecticides (NRCC 1981) and the elimination of pollinators' habitats are fairly well documented and undisputed (Kevan 1986). The seriousness of the effects, and their ramifications, are not well appreciated and frequently belittled or discounted.

Bees (Apoidea), and especially honey bees (*Apis mellifera* L.) are the most valuable pollinators to agriculture (Free 1970; McGregor 1976). Their demise, from pesticides, habitat reductions, or diseases, is evoking much concern. For numerous crops, now grown in large monocultural stands, wild bees are no longer present in sufficient numbers to bring about adequate pollination. Honey bees, because of their manageability and transportability, have become increasingly an integral and indispensible part of agriculture (Jay 1986). The burgeoning problems in Canadian beekeeping have been seriously exacerbated by the introduction of the tracheal mite, *Acarapis woodi*, to the U.S.A. (Porter 1985) and now apiculture is under the even more serious threat from *Varroa jacobsoni* knocking at the border (Connor 1987) and even from the Africanized bees which have already penetrated into Mexico (Moffett *et al.* 1987). The effects of those menaces will likely be more severe than all previous problems combined. In the area of pollination, Canadian agriculture may find itself in for a severe shock. Many crops which are totally or partially dependent on bees for pollination (e.g. apples, pears, cherries, and other fruits, some oil seed crops, forage crops, cucurbits, and vegetables) will probably have drastically reduced yields. The blow would be immediately felt, not only as a problem for beekeepers but also for agriculture as a whole where there would be a much wider economic effect to affect all Canadians. The beekeeeping industry in North America is fast changing and completely new apicultural techniques will be needed. In the area of pollination the gravity of the issues and the challenge of meeting them require imagination, forethought, and insight on the parts of scientists, beekeepers, growers, and the agricultural community as a whole.

One way in which problems in pollination have been overcome has been by the use of special pollinators. Various pollinators have been introduced into some parts of the world to meet specific pollination needs (e.g. *Bombus* into New Zealand for red clover (see Bohart 1962), *Elaeidobius kamerunicus* (Coleoptera: Curculionidae) into Malaysia for oil palm (Syed *et al.* 1982)) in other places pollinating species appear to have been introduced accidentally and have proven to be valuable (e.g. *Xylocopa* into Hawaii and passion fruit, *Megachile rotundata* into North America and alfalfa (see Bohart 1962)) and in other instances pollinators have spread with the expanding cultivation of the crop with which they are associated (e.g. *Peponapis pruinosa* and squashes, pumpkins, and melons in North America (Hurd *et al.* 1971).

The amount of effort which has been expended on the biology and management of pollinators, other than honey bees, pales by comparison with that on honey bees. With that in mind, together with concern for what the future appears to hold, a proposal was sub-

mitted to Dr. F. McEwen, Dean of the Ontario Agricultural College of the University of Guelph to organize and hold a workshop on **Alternative Pollinators for Ontario's Crops**. Through his generosity, funding was made available to allow for the participation of the experts, whose presentations comprise the following proceedings, and for the workshop to take place at the University of Guelph Arboretum on the 12 April, 1986.

The sequence in which the papers are presented here differs slightly from that of the workshop session. The first paper is an overview of the biology, use and management of various bee pollinators about which enough is known to make them immediately useful in Ontario. The papers which follow concern specific crops, such as orchard fruits (apples), small fruits (blueberries and cranberries), alfalfa, and gingseng in relation to their pollination requirements and pollinators in Ontario. The importance of bumble bees, for which interest has been expressed in Ontario, is shown in a paper which complements the first presentation. However, it is unfortunate that time and resources did not permit the workshop's exploring the potential value of other pollinators for the vegetable seed industry, hybrid seed production, pollination in greenhouses, and so on.

The enthusiasm of the participants and their interest (and that of others) in the publication of the papers presented at the workshop, together with the overall concern for the issues which arose there, indicate that another, longer, event of a similar nature is needed.

References

Bohart, G.E., 1962. Introduction of foreign pollinators, prospects and problems. Proceedings of the First International Symposium on Pollination, Copenhagen, August 1960. pp. 181-188.

Connor, L., 1987. A nightmare unfolds. Canadian Beekeeping, 13: 197.

Crepet, W.L., 1983. The role of insect pollination in the evolution of angiosperms. In: L. Real (ed.), Pollination Biology. Academic Press, Inc., New York. pp. 31-50.

Free, J.B., 1970. Insect pollination of crops. Academic Press, New York. 544 pp.

Hurd, P.D. Jr., E.G. Linsley, and T.W. Whitaker, 1971. Squash and gourd bees (*Peponapis, Xenoglossa*) and the origin of cultivated cucurbits. Evolution, 25: 218-234.

Jay, S.C., 1986. Spatial management of honeybees on crops. Annual Review of Entomology , 31: 49-66.

Kevan, P.G., 1975. Pollination and environmental conservation. Environmental Conservation, 2: 222-227.

Kevan, P.G., 1986. Pollinating and flower visiting insects and the management of beneficial and harmful insects and plants. In: Hussein, M.Y. and A.G. Ibrahim (Eds), Biological Control in the Tropics. Universiti Pertanian Malaysia, Serdang, Selangor, Malaysia. pp. 439-452.

Kozin, R.B., 1976. Pollination of entomophilous agricultural crops by bees. Amerind Publishing Co., P.V.T. Ltd., India. XXX pp.

McGregor, S.E., 1976. Insect pollination of cultivated crop plants. United States Department of Agriculture, Agriculture Handbook 496, Washington, D.C., 411 pp.

Moffett, J.O., D.L. Maki, T. Andre, and M.M. Fierro, 1987. The africanized bee in Chiapas, Mexico. American Bee Journal, 127: 517-519 and 525.

NRCC, 1981. Pesticide-pollinator interactions. National Research Council of Canada, NRCC Publication No. 18471, Ottawa. 190 pp.

Pesson, P. and J. Louveaux, 1984. Pollinisation et production vegetales. Institute National de la Recherche Agronomique, Paris. XXX pp.

Porter, B., 1985. Acarine disease and its implications for Canada. Canadian Beekeeping, 12: 57-59.

Syed, R.A., I.H. Law, and R.H.V. Corley, 1982. Insect pollination of oil palm: introduction, establishment and pollinating efficiency of *Elaeidobius kamerunicus* in Malaysia. Planter (Kuala Lumpur), 58: 547-561.

Winston, M.L. and C.D. Scott, 1984. The value of bee pollination to Canadian apiculture (sic. agriculture). Canadian Beekeeping, 11: 134.

USE OF NON-HONEY BEE SPECIES AS POLLINATORS OF CROPS*

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Contribution No. 1 to the workshop **'Alternative Pollinators for Ontario's Crops'** held at the University of Guelph, 12 April, 1986.

Proc. ent. Soc. Ont. 118:111-124 (1987)

Introduction

When most of us hear the word "bees", a mental picture of the common honey bee appears. One individual may think of the time when a swarm of "bees" settled in the back yard; another may recall the experience of pulling a stinger from a naked toe; others may think of buzzing "bees" on fruit trees; and still others may remember a prodigious colony that produced large quantities of beautiful clear honey. We all have our mental pictures of the omnipresent honey bee and each of us "sees" this "bee" a little differently.

The perception of "bees" within the scientific community also varies. A majority recognize the honey bees and bumble bees while some recognize three types of bees (honey bees, bumble bees, other bees). However, those who study these "other bees" realize that they actually represent more than 99% of all known bee species. Thus, the terms "non-honey bees", "wild bees", or "solitary bees", refer to an extremely large number of organisms whose species are more numerous than those of birds and mammals combined.

These 30,000 "non-honey bees" are as diverse in appearances and biologies as they are numerous. The smallest bees *(Perdita* and *Oreopasites)* are little more than 2 mm long whereas some of the largest forms approach 80 mm in length. Some species are, like honey bees, highly social but most are solitary. Some bees nest only in existing holes (even in old snail shells) whereas many others drill their own tunnels in soil or in wood. Some bees construct clusters of resinous or mud cells in open environments but representatives of most taxa nest solitarily and/or gregariously. Some bees are nocturnal, others fly only at dawn or dusk, but the vast majority fly during daylight hours. Some "wild" bees have wide distributions across continents but others are known from one location in a particular township. In addition, some bees produce one generation per annum, others produce both one and biannual generations, and other bees have multiple generations each year. Some forms visit only one or a few closely related plant hosts for pollen-nectar resources while others visit a wide variety of flower types to obtain these resources. And, some species are parasites of other bees but others are nest inquilines or nest robbers or usurpers.

These non-honey bees produce little or no commercial honey or wax products; many are difficult to distinguish; most have complicated biologies; nesting sites of many species are difficult to locate; and, the adult form of the vast majority of "wild" bees is short-lived. These factors, combined with their non-obtrusive appearance and spatical-temporal fluctuations, are the primary reasons why "non-honey bee" species are not well-known compared to honey bees or even bumble bees.

**A contribution from Utah Agriculture Experiment Station, (Journal paper no. 3464) and USDA-ARS, Bee Biology and Systematics Laboratory, Utah State University, Logan, UT.*

During the last 80 years, the informational gap between "wild" bees and the honey bee has narrowed especially in the area of basic research. But even before that time, "wild" bees were recognized as potential pollinators of agricultural crops and, around the turn of the last century, a few preliminary attempts were made in North America to increase wild bee populations that were known to visit particular crop species. The first formal effort to develop non-honey bee species as commercial pollinators began in the late 1940's when the U.S. Department of Agriculture established a Laboratory in Logan, Utah and initiated studies to increase seed yields of North American forage crops. During the intervening period, several species of bees have been developed as commercial pollinators of several crops and a larger number of candidate species are now being tested as primary or alternative pollinators of additional crop species.

The development of non-honey bee species as commercial pollinators of agricultural crops is, therefore, a relatively new science. Information already gained in developing these non-honey bee pollinators should now be used as a foundation on which additional pollinator species can be developed. It follows, therefore, that a profile of each commercialized non-honey bee pollinator should be established as a reference point from which new studies can more easily proceed. The following discussion, however, simply attempts to outline some of the information that would be included in a profile of these pollinator species.

Alkali Bee *(Nomia melanderi)*

As agriculture expanded in the western U.S. during the late 1940's, alfalfa was commonly planted as a first crop on these virgin but alkaline soils. Almost immediately thereafter, growers began to notice large numbers of bees with gold to turquoise colored abdominal bands visiting their alfalfa fields. When nesting sites of these bees were discovered in alkali flats adjacent to the new alfalfa plantings, state and federal entomologists began studies to determine the pollination efficacy of this bee and its potential for manageability (Bohart 1950, 1960; Stephen 1959, 1960c). Those studies demonstrated the alkali bee to be a very effective pollinator of alfalfa and efforts were then directed to manage alkali bee populations (Stephen 1959). Eventually, the nesting requirements of the alkali bee were deciphered (Stephen and Evans 1960; Stephen 1960a), artificial nesting sites (called bee beds) were constructed and tested successfully (Stephen 1960c), and, as a result, the species became a dominant pollinator of alfalfa seed crops grown in the Pacific Northwest especially during the 1960's and early 1970's.

Biology: The alkali bee is about 2/3 the size of honey bees and it nests in large, dense aggregations in the soil. Each female constructs her own nest and provisions her own cells. Nests vary little in their architecture with each having a main burrow leading from the entrance hole to a carved out chamber 12-60 cm below the soil surface. A cluster of 6-22 elongate cells are constructed below the chamber and each is oriented vertically. The carved out cell is lined with waterproofing material secreted from the Dufour's gland (Cane 1983) preparatory to the collection of pollen-nectar resources. The collected provisions are then molded into moistened loafs and each is positioned at an angle along the ventrolateral margin of the cell. The egg is laid on the slightly curved surface of these provisions and the cell is subsequently capped with a soil plug. The larva hatches from the egg in 3-6 days and it consumes the entire loaf of pollen-nectar provisions in the following two-week period as it develops through 5 stadia. The fully grown larva then voids its feces by smearing the material onto the cell walls, whereupon it enters a diapausing stage (called a prepupa). The larva pupates the following May-July and the adult quickly digs its way to the soil surface where mating occurs. The mated females then establish new nests usually in the same nesting site and the cycle is repeated.

Bionomics: Alkali bees visit a wide variety of flowering plants that include alfalfa, sweetclover, onion, and mint crops. Daily flight periods normally begin 2-3 hours after sunrise and end by 4-5 p.m. during mid-summer periods. They can visit and trip 12

alfalfa florets per minute and calculations have been made to demonstrate how valuable individual bees are in relation to seed yields. There are, however, so many variables in these types of calculations that they should be used to indicate a potential rather than presented as actual measurements. In fact, it is more important to understand that the alkali bee, unlike other alfalfa pollinators, flies through the canopy of an alfalfa plant as it visits flowers and thereby increases its pollination efficiency on that crop.

Natural nesting sites are usually found in alkali flats but nesting populations have been observed utilizing a wide variety of soil types. All successful nesting sites do, however, have a reservoir source of water that is subirrigated to the surface of the nest site. The balance between monovalent and divalent salts in alkaline soils allows sufficient quantities of water to move through the soil and assure retention of dampness to these soil surfaces even during the hottest daily periods when evaporation is maximal. Dissolved salts are thus continually carried to the surface of these sites where they recrystalize through the evaporative process. As these salts accumulate, the soil surface turns whitish and plant growth is diminished or it disappears altogether. These denuded but especially wetted surfaces are attractive to the alkali bees which then utilize these areas to establish very large, permanent nesting aggregations. Eventually, these sites become honeycombed with old vacated cells, parasites and diseases build up, surface salts are washed away by flooding, etc., and nesting populations migrate to newly formed sites.

The soil surfaces of all successful artificial nesting sites closely resemble those of natural nesting sites. As a consequence, methods by which natural sites are formed should be simulated in artificial sites. These are the reasons why each bee "bed" is lined with a 40 cm deep gravel layer that serves as a water reservoir. The gravel layer is then covered over with a meter-deep layer of soil mixed with a divalent salt. To seed these sites, trenches are dug across the surfaces of the bee bed preparatory to inserting soil cores removed from active nest sites and filled with overwintering alkali bee larvae. These implanted soil cores (called seed blocks of 30 cm^3) are covered over with soil after which a monovalent salt is mixed into the upper 2-3 cm surface layer of the bee bed (see Torchio 1966; Parker and Torchio, 1980, for detailed instructions). Hundreds of these artificial nesting sites have been constructed in the western United States and many remain active after 35 years of continual management.

More recent studies have been focused on methods to better protect established populations of alkali bees and their nesting sites. As a result, most of the organisms associated with this bee have been studied and control methods have been developed for some parasitic species. The most important nest associate of the alkali bee is the bomber fly (*Heterostylum robustum* Diptera: Bombyliidae) whose common name aptly describes the methods by which it deposits eggs in entrance burrows of various host species. Its biology was first studied by Bohart, et al. (1960) who found that the daily use of the common fly swatter was the best control method of this fly at any particular nest site. Other fly parasites [*Zodion obliquefasciatum* (Conopidae) studied in detail by Howell (1967), and *Euphytomima nomiivora* (Sarcophagidae) studied by Moradeshaghi and Bohart (1968)] are important parasites when they periodically appear in large numbers. Their periodicity has, however, delayed testing of control methods already devised. The black blister beetle, *Meloe nigra* (Meloidae) is a parasite of alkali bees in the state of Washington. Its biology has been studied by Mayer and Johansen (1978) who developed inexpensive, but successful, control methods for this beetle (Johansen, et al. 1978). Particular nest sites can also be attacked by various birds who feed on emerging adults or skunks that dig into the soil in search of bee larvae. Even rabbits, when sufficiently numerous, can be a problem when they congregate on artificial nest sites and lick all of the salts from these surfaces in just 2-3 evenings.

When artificial nesting sites were constructed in the San Joaquin Valley of California, it was necessary to develop additional management procedures to accommodate different agricultural practices typical of that area and to protect bees against overexposure to a hot, low desert climate. As a consequence, spray schedules were coordi-

nated between involved growers during active nesting periods; reservoir water in bee beds was frequently replenished because of the rapid evaporation rate of surface moisture; and, some bee beds were covered with shading materials to reduce excessive build up of surface temperatures during mid-day hours. These mostly unpublished results (Torchio 1966) demonstrated that one-generation bees transported from Idaho developed through 5 generations per annum when nesting populations were exposed to warmer climates. This allowed growers to produce alfalfa bloom for seed setting throughout summer months but, at the same time, it exposed alkali bee populations to a multitude of environmental hazards for extended periods of time. In addition, accommodations had to be made to assure the availability of bloom throughout the extended flight period of multi-generation bees (early May to mid-October). These, and other methods developed to manage alkali bees in warm climatic environments (Stephen 1965), demonstrated that this pollinator can be used successfully and commercially in low desert environments where pesticides are applied as frequently as anywhere in the world. These same studies also demonstrate that 3,000 pounds of clean alfalfa seed per acre can be produced consistently when alkali bees are used as the only pollinator of the crop.

Alfalfa Leafcutting Bee *(Megachile rotundata)*

This Eurasian bee was accidentally introduced onto the east coast of North America prior to the mid-1930's. Collecting records indicate that the species was first established near Washington, D.C. It then migrated rapidly across the continent where it reached the Pacific Northwest sometime prior to the mid-1950's. Soon afterwards, alfalfa seed growers in Utah and Idaho began noticing numbers of this leafcutter bee visiting alfalfa bloom in their fields. When state and federal entomologists began their field studies of the species, they found surprisingly large populations of this bee concentrated in and around alfalfa seed fields, especially in the Great Basin states. As a consequence, studies with the leafcutter bee progressed rapidly (Stephen and Torchio 1961) and, by the early 1960's, the first commercial populations of leafcutting bees were available as pollinators of alfalfa seed crops grown in Oregon, Washington, and Idaho (Stephen 1962). A viable industry centered in southwest Idaho was then established to supply "bees", nesting materials, and equipment for management of large bee populations. Demand for these bees increased rapidly over the next decade and the industry responded by expanding into Canada and the entire western United States. As a result, the alfalfa leafcutting bee replaced the alkali bee as the dominant pollinator species of alfalfa in the Pacific Northwest where it continues to maintain this status (Stephen 1981). In addition, successful use of leafcutting bees in North America has more recently interested seed growers in other areas of the world. As a result, alfalfa leafcutting bees have been reintroduced into Europe and to various countries around the world.

Biology: The alfalfa leafcutting bee is about half the size of the honey bee and its abdomen is striped with bands of light-colored hair. It is a member of a family (Megachilidae) that carries pollen on the venter of the abdomen in a specialized hair brush known as a scopa (both honey bees and alkali bees carry pollen on their hind legs). This species, like most megachilid bees, nests in existing holes in which leaf cells are constructed. Each cell is composed of a series of overlapping leaf pieces cut by the female and carried to the nest. When this bee nests in deeper holes such as those supplied by man, cells are constructed directly on top of each other in linear series. The cut leaf pieces are individually carried to and into the nest under the body with at least the middle legs wrapped around each leaf piece. These leaf pieces are purposely overlapped across the substrate in the nesting hole and the edges of each are chewed and tamped into place as the cell is formed. As these chewed areas of leaf pieces dry, they form strong bonding lines that interconnect the overlapped leaf pieces and, in this way, a bullet-shaped leaf cell is formed. The pollen-nectar provisions are then deposited in

each cell until a pasty admixture of pollen-nectar fills the lower sections of the cell. The nesting female then adds a layer of nectar on top of the provisions and she immediately thereafter deposits an egg on the surface of those provisions. She then closes the cell by cutting circular leaf pieces and attaching each across the top edge of the cell. The edges of these leaf pieces are also chewed and tamped into place as this closure is formed so that the completed cell cap is composed of variable numbers of overlapping leaf pieces stacked immediately on top of each other. Construction of a second cell is initiated immediately on top of the first-completed cell and this sequence of activities is repeated until the last-constructed cell is positioned near the entrance of the nest. At this juncture, the female plugs the nest with a series of overlapping, circular leaf-pieces that are stacked on top of each other until the outer face is flush with the surface of the nest substrate. More than 30 cells can be constructed in 2 or more nests during the 5 to 6 week flight period of each female.

The egg deposited on top of the provision hatches in less than a week and the larva consumes the cell provisions over a two-week period as it develops through five stadia. The larva begins to void its feces near the end of the feeding period and it then spins its cocoon during and for some time after defecation is completed. Like the alkali bee, it then enters the "prepupal" form and spends the winter in its cocoon. Rising temperatures of the following spring signal the end of the diapausing period and the larva molts into a pupa followed by a molt into the adult form. The adult remains in its cocoon for variable periods before it chews its way out of the cell and into the open where mating takes place almost immediately. After mating, the female establishes its nest in a suitable nesting hole so that the cycle can be repeated.

Bionomics: The alfalfa leafcutting bee, like the alkali bee, is protandrous; that is, males emerge first followed by the appearance of females. This usually occurs because larvae of the male sex break diapause at slightly lower temperatures than those required for those of the female sex. This system is enhanced when cells are constructed in linear series and when the males are positioned in the outer cells. As a consequence, rising spring temperatures reach these outer cells first so that males complete development and emerge prior to females. Because these rising temperatures are gradual and directional through any particular nesting substrate, emergence from linear cell series is also a sequential process.

At higher latitudes of this bee's distribution (i.e., Canada), lower summer temperature regimes normally prevent the development of more than one generation of bees per annum. In lower latitudes (i.e., Pacific Northwest and California) leafcutting bees commonly have two or more generations per annum (Stephen and Osgood 1965). The commercial advantages and/or disadvantages of producing one-generation or multi-generation bees can be argued from either prospective. And, an individual's attitudes can sometimes be reversed when it becomes necessary to change pesticide spray programs; when "new" pest species are discovered in managed bee populations; or, when weather conditions change abruptly. It should be remembered, however, that our understanding of diapause inducing mechanisms for the alfalfa leafcutting bee are incomplete at best. As a consequence, we presently have no way of really controlling numbers of bee generations produced even when populations are carefully managed. Thus, a strong effort should be made to better understand diapause induction before we thoroughly discuss the advantages and disadvantages of one- or multiple-generation bees.

Several types of nesting materials have appeared on the market during the two and a half decades that this leafcutter species has been managed commercially. Paper soda straws were first used as nest materials but they were soon replaced by drilled boards. More recently, laminated wood and plastic wafers have been marketed along with rolled cardboard material. The advantages and disadvantages of using each of these materials under different climatic conditions and in different types of management

programs have been reviewed by Bitner (1982) and Richards (1982). One subject area seldom discussed, however, is the apparent relationship between particular types of nests or nest materials and their potential for increased or decreased attacks by particular nest associates. Direct evidence to support field observations has not yet been obtained but some indirect evidence is scattered in the literature. In most cases, the physical structure of a particular nest type either facilitates entrance by the nest associate or it strongly reduces the probability of entrance by that organism.

There are at least 35 known nest associates of the alfalfa leafcutter bee. Some species occur only in particular localities whereas others have the same distribution as their leafcutter host. Some are scavangers but others are nest depredators and a few are parasites. The parasites carry the greatest potential for reducing leafcutter host populations and the most important parasites of leafcutter bees are wasps and one fungus. These wasps are, with one exception (Sapygidae), members of the superfamily Chalcidoidea and they are, therefore, commonly referred to as "chalcids". Four genera of chalcids *(Monodontomerus, Tetrastichus, Pteromalus, Melittobia)* are associated with the alfalfa leafcutting bee. Control methods developed for *Monodontomerus* and *Sapyga* involve the trapping of emerging adults with the use of black light during incubation periods of the host species (Johansen, et al. 1973; Torchio, 1972, 1974). Carbaryl and DEET have also been used to control *Tetrastichus, Melittobia,* and *Pteromalus* (Brindley 1976; Parker 1978; Asensio 1982).

Chalk brood *(Ascosphaera)* is a fungus that was first recognized as a parasite of honey bees. A closely related species attacks solitary bees including the alfalfa leafcutter. Spores of this fungus *(A. aggregata)* are inadvertently deposited in cell provisions and they are consumed by the young feeding larva (McManus and Youssef 1984) . These spores germinate anaerobically in the gut and the hyphae eventually fill the inner space of the larva (Youssef *et al.* 1984). Death of the larva usually occurs during cocoon spinning and the host can either swell slightly and darken to a graphite-black color or it hardens and turns a grayish color. The darkened larva is colored by a layering of black spore balls aligned immediately below the translucent cuticle of the dead bee, and it is this color that is observed. The grayish color appears when spore balls are not formed and only the mass of hyphae below the larval cuticle is viewable. This disease has spread rapidly since it was first recognized as a potentially destructive organism of leafcutter bees in 1974. It is now one of the most important parasites of the leafcutter bee in the United States and studies are in progress to determine efficient methods to control this organism (Youssef *et al.* 1985). Field trials have recently shown that Captan effectively controls this disease (Parker 1984, 1985a; Youssef and McManus 1985).

Blue Orchard Bee *(Osmia lignaria propinqua)*

The blue orchard bee is distributed across the continental United States and southern Canada. It is one of a number of closely related holarctic species of which the female sex has a pair of horn-like prongs extending forward from the lower section of the face above the mandibles. Taxonomists recognize two subspecies that are morphologically distinguishable and without overlapping distributions (allopatric) (Rust 1974). The eastern form *(Osmia lignaria lignaria)* extends from the eastern slopes of the Rocky Mountains to the Atlantic Ocean whereas the western form *(Osmia lignaria propinqua)* is found from the western slopes of the Rocky Mountains to the Pacific Ocean. This species is placed in the same subfamily as the alfalfa leafcutting bee (Megachilinae) but in a separate tribe (Osmiini). The osmiine bees, unlike other Megachilinae, collect mud, or mud mixed with macerated leaf material, or only macerated leaf material to construct their cells and they are, therefore, called "mason" bees. Most of the osmiine bees, including *Osmia lignaria*, construct nests in existing holes.

In 1970, a survey was begun at the USDA Laboratory in Utah to determine if native bees could be developed as alternative pollinators of orchard crop species. The study was initiated at a time when honey bee colonies in the United States were declining in

number as the acreage planted to orchard crops was increasing dramatically. It was apparent that if this trend continued uninterruptedly for another 20 years, the U.S. could have experienced a pollination crisis for many of its cross-pollinated crops and especially those which bloom early in the year (orchard crops). Our intent, therefore, was to first determine if any one or combination of native bee species showed promise as pollinators of *Prunus* and *Malus* crops and, if so, could those species be managed as commercial pollinators. Results of the survey clearly demonstrated that one native bee species *(Osmia lignaria)* was omnipresent wherever collections were made on flowers of *Malus* and *Prunus* . As a consequence, we initiated an intensive study of this potential apple pollinator beginning in 1972 and these studies have continued to the present time. Some of the results obtained during this long-termed program are used below in an attempt to establish a profile of *Osmia lignaria propinqua* from which comparisons can be made with other pollinator species.

Biology: This bee, like the alfalfa leafcutter species, is protandrous and, as a result, patrolling males are available to mate with females as they emerge from their nests. Each female mates more than once during the first day of adult flight but she is ignored by the patrolling males within several hours after flight is initiated. Apparently, the emerging female releases a short-lived pheromone that solicits the mating response by males. By the second flight day, however, the mated female has normally established a solitary nest in an existing hole at which time she locates a mud source and collects this material for construction of the first cell partition. The mud is gathered with the mandibles but it is carried to the nest as a glob under the head and behind the mandibles. The mandibles are then used to form a thin, concave mud partition that covers the diameter of the nesting hole at or near its basal limits. After the mud partition is completed, the female provisions the cell with pollen wetted with nectar until a somewhat dryish appearing pollen loaf covers all or most of the mud partition and the surface of the nest substrate in front of the partition. As the pollen loaf is enlarged, it narrows anteriorly, thus allowing the female access to deposit her remaining pollen-nectar loads across the dorsal surface of the cell provisions. This is accomplished when the foraging female returns to her nest and begins to chew the surface of her provisions with rapid, pinching actions of her mandibles. As this chewing process continues, nectar is regurgitated from the honey stomach and deposited onto the surface of the cell provisions. The female then backs out of the nest, turns, and crawls backwards into the nest until her pollen-ladened abdominal scopa is positioned over the surface of the partially formed pollen loaf. Pollen is removed from the scopa with rapid scraping actions of the legs and it is thus deposited directly onto the nectar-wetted surface of the provisions. The female then leaves the nest to collect additional pollen-nectar resources.

The last foraging trip to collect provisions for a cell is normally signalled when the female returns to the nest without pollen but with a large quantity of nectar. The nectar is deposited on the surface of the loaf-like cell provisions near its anterior margin until that area of the provision's surface is saturated with nectar. The female then backs out of the nest, turns, backs into the nest and positions the tip of its abdomen above and slightly in front of the nectar droplet. Then, a pumping action of the abdomen begins as the tip of the abdomen opens and the stinger is exerted. The egg is then slowly discharged through the abdominal opening and, because of its curvature, it angles downward until its free tip (posterior) contacts the droplet of nectar on the provision's surface. At that point, the female bee lifts its abdomen upward and, at the same time, takes one or two steps forward in the nest. These movements allow the anterior section of the now attached egg to be pulled free from the tip of the abdomen. As a consequence, the deposited egg is angled upward from the provision's surface and its unattached anterior tip faces the nest entrance. This is possible only because the posterior tip of the egg is firmly anchored onto the cell. After the egg is deposited, the female immediately constructs a second and identical mud partition immediately in front of the cell provi-

sions. Then a second cell is provisioned in front of the first constructed cell until a linear series of as many as 14 cells are completed. At that juncture, the female constructs a mud plug that is 5 mm thick with its outer surface flush with the surrounding substrate.

As in most other bees, the embryo rotates 180 degrees on its long axis during late embryogenesis (Torchio 1984 a). The larva hatches from the egg in 6-7 days after the cell is sealed and it immediately begins to feed on cell provisions. The feeding period is longer than that of the alfalfa leafcutting bee because the 5th instar larva feeds for extended periods. Soon after molting into the 5th stadium, the larva begins to defecate as it consumes the remaining provisions. Cocoon spinning is initiated near the end of the feeding period and defecation is completed before the outer cocoon layer is completely spun. Then a second complete cocoon layer is spun directly over the inner surface of the outer layer and third and fourth layers are facultatively added. The larva enters a short "rest" period after cocoon spinning is completed and it then transforms into a pupa which colors over time followed by a final molt into the adult form. The adult remains in its cocoon over the winter and it emerges the following spring to repeat the cycle.

Bionomics: Studies designed to field-trap populations of *Osmia lignaria propinqua* were initiated in 1972 at the Laboratory in Utah and they have continued to the present. Results obtained from this long-term study have demonstrated that wood is the most attractive nest material and the most efficient hole size is 15 cm long by 7 mm in diameter. If each drilled hole is separated from adjacent holes by a centimeter or more, the attractiveness of that nest unit is also increased. This species is, however, gregarious and bees tend to establish new nests adjacent to active nests or recently completed nests. Thus, if the first bees to emerge accept non-wood products in which to nest at a particular location on a particular year, nesting results obtained at that site would show that a competing nest material is at least as attractive as wood materials. Nevertheless, a multi-year trapping program of the same site would reveal that wooden nests are most attractive overall (unpublished data).

Wood products, although attractive to bees, are heavy to transport and they are expensive per unit nest hole constructed. Several other products have been tested both at this Laboratory and at other locations and some materials are now available commercially. Unfortunately, no one nest material has been tested across the climatic distribution of this bee to determine its general suitability under extreme conditions. Sufficient testing has, however, been completed whereby we now know that the level of attractiveness of any nesting material used as field traps will be equally attractive to nesting bees in commercial orchard environments (unpublished data).

In our early orchard studies, it was necessary to dissect field-trapped materials to establish exact numbers of bees available for release into orchards and the number of females represented in those populations. As a consequence, cocoons were removed from their cells in the fall and placed individually into gelatin capsules. These capsules were placed in a cold temperature cabinet over the winter and then incubated during the "popcorn stage" of apple bud development. As individuals emerged from cocoons, they were returned to the cold temperature cabinet until emergence was completed. Each bee was then de-encapsulated within a walk-in cold temperature cabinet and placed into specially designed wood boxes having holes cut on two sides. When de-encapsulation was completed, the boxes were moved to the apple orchard from which bees were allowed to escape and establish nests in materials supplied. This mass release method served our purposes in determining dispersal patterns of bees through the orchard, numbers of bees that nested within experimental orchards, and the potential for increasing population sizes in commercial orchard environments. As a result of these experiments, however, we learned that more than one-half of the mass-released female population dispersed beyond the limits of the orchard before nesting was established (Torchio 1982).

In subsequent studies, filled paper soda straw nests were X-rayed in the fall and placed in cold temperature cabinets where they remained until the following spring. These materials were then removed from the storage cabinet approximately two weeks before apple bloom and each straw nest was inserted into wood or styrene nest traps. These "filled" nest traps were then placed into the same experimental apple orchards and observed until nesting was completed. The results of those studies showed that many fewer bees dispersed away from the orchard prior to nesting and most released bees nested in and adjacent to emerged nest holes (Torchio 1984b).

More recent research has been directed towards pollination studies where large populations of the blue orchard bee have been used as the only pollinator species in isolated apple orchards. Results obtained from these studies have shown that maximum pollination can be achieved with as few as 250 female bees released per acre. These same studies have also demonstrated that numbers of seeded carpels and seeds/fruit increase in all apple varieties exposed to pollination by the blue orchard bee. At the same time, three- and four-fold increases of bee populations nesting in orchard environments can be realized (Torchio 1985).

These results can be attributed to a number of biological features expressed by blue orchard bees. For example, this bee species initiates daily flight at 13-15C which happens to be the lower temperature limits at which apple pollen germinates (Torchio 1985). Thus, bees that fly at even lower temperatures may not contribute to effective pollination even though pollen is transferred between flowers and varieties. In addition, blue orchard bees collect pollen directly from flowers and it is stored on the abdominal scopa in a dry state. This allows the viability of pollen on the scopa to remain high until it is wetted and added onto cell provisions. When either sex of the blue orchard bee visits an apple flower, it lands directly on the sexual column to collect its resources, thus assuring a higher probability for the transfer of viable pollen between flowers. Without even considering the scopa, both sexes of the blue orchard bee are very hairy across the entire venter of their bodies and this feature only increases the potential of the species to effectively pollinate various orchard crops. Careful observations of flight patterns to and from the nest, combined with various pollen analyses of bees and their provisions, strongly suggest that the blue orchard bee does not follow strong orientation markers while foraging. As a consequence, this bee visits numbers of trees across rows in one foraging trip and it may visit different sections of an orchard on each foraging trip. This species also continues to fly during cloudy and windy conditions and entire daily flight periods are restricted to an orchard as long as sufficient quantities of pollen-nectar resources remain. These features, when combined, greatly improve the pollinating effectiveness of any pollinator species under consideration.

Some nest associates of the blue orchard bee are members of the same genera *(Sapyga, Monodontomerus, Ascosphaera)* but they are different species from those organisms found in nests of the alfalfa leafcutting bee. Other associates are members of the same beetle family (Meloidae) but are represented by different genera *(Tricrania* in *Osmia* nests, *Nemognatha* in *Megachile* nests). And, there are specific nest associates for each of these two host species. The more important parasites of the blue orchard bee found to date are *Monodontomerus* and *Stelis.* Black light has been successfully tested against this particular *Monodontomerus* and it is used during periods when host bees are spinning larval cocoons and are most vulnerable to reparasitism (unpublished).

Stelis montana is a bee parasite that lays its egg on nearly completed host provisions. After the host cell is sealed, the *Stelis* larva kills its host immature and proceeds to consume the cell's provisions. The larval biology of the parasite is similar to that of its host but this bee overwinters as a prepupa within its strong cocoon. This, in turn, delays emergence of *Stelis* so that control of the parasite can be effected by developing an efficient phase-out program of contaminated nest traps placed in commercial orchard environments (unpublished).

"Orange Orchard Bee" *(Osmia cornuta)*

This species is native to Europe and it is a close relative of *Osmia lignaria*. As a consequence, it too has a pair of prongs extending forward from the lower part of the head. The female is slightly larger than the female of *O. lignaria* and it is easily distinguished from it and most North American species of bees by having the abdomen coated with a beautiful pile of bright orange hair. Work on this species began in 1974 when a cooperative program was established between this Laboratory and Spain (Instituto Nacional de Investigaciones Agrarias) in an effort to locate candidate pollinator species for several native European crop species grown in the United States.

This cooperative program began with a field-trapping study of northern Spain which was used as a method to survey those bee taxa that nest in existing holes. When numbers of *Osmia cornuta* were discovered nesting in these trap nests, we decided to expand the trapping program to obtain larger numbers of bees required for field studies. Soon afterwards, small populations of *O. cornuta* were transported to the USDA Laboratory in Utah where its nesting biology of *O. cornuta* was studied in a greenhouse environment. As we expected, the biology of *O. cornuta* proved to be nearly identical to that of its sister species, *O. lignaria,* and these results justified a designed field study to compare the nesting success of both species introduced into the same orchard at the same time.

Results of that study have recently been published (Torchio and Asensio 1985) and the data clearly demonstrate that both *Osmia* species respond similarly when they are released in commercial orchard environments. Subsequent studies have, however, revealed that the immature stages of *O. cornuta* immatures require warmer temperatures for longer periods of time to complete their development. Additionally, *O. cornuta* successfully overwinters at warmer temperatures than its sister species, *O. lignaria,* and for shorter periods. This information, once confirmed by objective comparative studies, suggested to us that *O. cornuta* may be a better adapted pollinator species for orchard crops grown in warmer climates than apple (i.e., almond). As a consequence, *O. cornuta* was introduced into California almond orchards where populations wintered successfully in those environments, adults emerged in synchrony with almond bloom, and successful nesting was documented (Torchio, et al. in press). These studies have stimulated related work in southern Spain where *O. cornuta* is now established in some commercial almond orchards.

Horned-Faced Bee *(Osmia cornifrons)*

This species is native to Japan where it has long been established as a commercial pollinator of apple and plum (Maeta and Kitamura 1965 a,b, 1974). It is also related to *Osmia lignaria* as indicated by its common name which refers to the pair of prongs extending from the front of its face. Its biology, studied in both Japan and in our greenhouses, is nearly indentical to that of *O. cornuta* and *O. lignaria*. The species was first introduced into Utah during the 1960's (Rust 1974) but the severe winter climate did not permit for successful overwintering of field populations. Other studies (unpublished) did, however, demonstrate that small populations released in orchard environments near Logan, Utah did nest successfully and their progeny wintered very well in temperature cabinets set at 2-4 degrees above freezing.

These populations were subsequently sent to Dr. Batra of the United States Department of Agriculture, Agricultural Research Service, Agriculture Research Center at Beltsville, Md. who established field populations in a winter climate that was similar to that of Japan. After the original population of *O. cornuta* was established in the Beltsville area, Batra obtained additional bees from Japan and distributed small foundress populations throughout the eastern United States and southern Canada. Some of those introductions were successful and, as a result, the horn-faced bee is now permanently established in North America. However, no effort has yet been made to develop this bee as a commercially managed species of pollinator for orchard crops in North America.

Other Candidate Species

Other bee species have been studied in varying degrees of detail to determine their pollination potentials for particular crop species. Although space does not permit a full discussion of each of these candidate pollinators, it seems worthwhile to list some of the better studied species and offer a short commentary on each:

Osmia coerulescens: This species is native to Europe where it occurs abundantly throughout France and Spain. It was apparently introduced accidentally into the United States some time ago and it is semi-abundant in localized areas East of the Rocky Mountains. It also occurs west of that mountain range but never in abundant numbers. When large numbers of this bee species were obtained from trap nest materials placed in northern Spain during our collaborative studies in that country, populations were transported to this Laboratory and released into a greenhouse planted to red clover *(Trifolium pratense)*. These bees nested successfully in the greenhouse and females readily visited the long corolla-tubed red clover flowers to obtain pollen-nectar resources. As a consequence, field studies were completed that demonstrated this bee to be an effective pollinator of red clover in western North America (Parker 1981). Those results agreed with those obtained by Tasei (1972, 1976) in France.

Osmia sanrafaelae: This species is restricted primarily to the San Rafael Desert in southern Utah where it occurs in abundance. Parker (1985b) recently reported results obtained in field-cage studies where a small population was increased by 11 fold in an environment where alfalfa was the only available source of pollen and nectar. Bees nested in man-made laminated wood traps and they expressed a number of biological features that suggest their amenability for incorporation into established management programs of other non-honey bee species. Open field tests for *O. sanrafaelae* have not been completed to date.

Eumegachile pugnata: This species is distributed across the continental U.S. and southern Canada and it visits flowers primarily in the family Compositae. It nests in existing holes and its biology has most recently been studied by Frohlich and Parker (1983). They (Parker and Frohlich 1983, 1985) have also tested this species as a pollinator of commercial sunflower and demonstrated the feasibility of managing populations and increasing population sizes in commercial environments or by field trapping methods.

Less intensive studies have been made on a number of other bee species that show promise as pollinators of crops. For example, *Osmia bruneri*, a native species to western North America shows promise as a red clover pollinator; *Chalicodoma mucorea* (from Egypt) shows potential as an alfalfa pollinator in hotter climates; *Anthophora parietina* in Poland has been used as a pollinator of hairy vetch; *Peponapis* and *Xenoglossa* are New World Taxa that pollinate native and cultivated squash; and, there is a large group of species that show promise as pollinators of greenhouse crops (unpublished).

The bumble bees *(Bombus)* and carpenter bees (especially *Xylocopa*) are large-sized bees that are important pollinators of many native plants. Their potential use as crop pollinators has been thoroughly discussed in the literature but few attempts have been made to utilize these bees on a large scale. Until recently, small colony size has limited most attempts to establish sufficient numbers of bumble bees required to pollinate the large acreages of monocultured crops that typify North American agriculture. Recently, however, techniques have been developed that demonstrate how bumble bees can be induced to lay eggs year-round (Roseler 1985) and this new development may stimulate additional studies aimed at establishing bumble bees as commercial pollinators of crops.

References

Asensio, E. 1982. Leafcutter bee management in Spain: Problems of parasitism. Proceedings of the First International Symposium on Alfalfa Leafcutting Bee Management. University of Saskatchewan, Saskatoon, Canada, pp. 71-79.

Bitner, R.M. 1982. Current management practices with the leafcutter bee in Idaho, U.S.A. Proceedings of the First International Symposium on Alfalfa Leafcutting Bee Management. University of Saskatoon, Canada, pp. 161-164.

Bohart, G.E. 1950. The alkali bee *Nomia melanderi,* a native pollinator of alfalfa. Proceedings of the 12th Alfalfa Importer Conference, Lethbridge, Alberta: 32-35.

Bohart, G.E. 1960. Insect pollination of forage legumes. Bee World, 41: 57-64, 85-97.

Bohart, G.E., W.P. Stephen, and R.K. Eppley. 1960. The biology of *Heterostylum robustum* (Diptera: Bombyliidae), a parasite of the alkali bee. Annals of the Entomological Society of America, 53: 425-435.

Brindley, W. 1976. Carbaryl control of chalcidoid parasites from alfalfa leafcutting bees. Journal of Economic Entomology, 69: 225-228.

Cane, J.H. 1983. Chemical evolution and chemosystematics of the Dufour's gland secretions of the lactone-producing bees (Hymenoptera: Colletidae, Halictidae, and Oxaeidae). Evolution, 37: 657-674.

Frohlich, D.R., and F.D. Parker. 1983. Nest building behavior and development of the sunflower leafcutter bee: *Eumegachile (Sayapis) pugnata* (Say) (Hymenoptera: Megachilidae). Psyche, 90: 193-209.

Howell, J.F. 1967. The biology of *Zodion obliquefasciatum,* a parasite of the alkali bee, *Nomia melanderi.* Washington Agriculture Experiment Station Technical Bulletin, 51: 31 pp.

Johansen, C.A., J. Eves, and C. Baird. 1973. Control of alfalfa leafcutting bee enemies. Washington State University Cooperative Extension Service Publication EM 2631 (Rev.): 10 p.

Johansen, C.A., D.F. Mayer, and J.D. Eves. 1978. Biology and management of the alkali bee, *Nomia melanderi* Cockerell (Hymenoptera: Halictidae). Melanderia, 28: 25-46.

Maeta, Y., and T. Kitamura. 1965a. Studies on the apple pollination of *Osmia* I. Ideal and present conditions in utilizing *Osmia* pollinators of apples in Japan. Tohoku Konkyû 1964, 1, 2: 45-52.

Maeta, Y., and T. Kimura. 1965b. Studies on the apple pollination by *Osmia* II. Characteristics and underlying problems in utilizing Osmia. Kontyû, 33: 17-34.

Maeta, Y. and T. Kimura. 1974. How to manage the Mame-kobachi, *Osmia cornifrons* Radoszkowski for pollination of the fruit crops. Ask Co., Ltd. 16 p.

Mayer, D.F., and C.A. Johansen. 1978. Bionomics of *Meloe niger* Kirby (Coleoptera: Meloidae) a predator of the alkali bee, *Nomia melanderi* Cockerell (Hymenoptera: Halitidae). Melanderia, 28: 1-22.

McManus, W.R. and N.N. Youseff, 1984. Life cycle of the chalkbrood fungus, *Ascosphaera aggregata* in the alfalfa leafcutting bee, *Megachile rotundata,* and its associated symptomatology. Mycologia, 76: 830-840.

Moradeshaghi, M.D., and G.E. Bohart. 1968. The biology of *Euphtomima nomiivora,* a parasite of the alkali bee, *Nomia melanderi.* Journal of the Kansas Entomological Society, 41: 456-473.

Parker, F.D. 1978. Alfalfa leafcutter bee-reducing parasitism of loose cells during incubation (Hymenoptera: Megachilidae). Pan-Pacific Entomologist, 55: 90-94.

Parker, F.D. 1981. A candidate red clover pollinator, *Osmia coerulescens* (L.). Journal of Apicultural Research, 20: 62-65.

Parker, F.D. 1984. The effect of fungicide treatments on incidence of chalkbrood disease in nests of the alfalfa leafcutting bee. Journal of Economic Entomology, 77: 113-117.

Parker, F.D. 1985a. Effective fungicide treatment for controlling chalkbrood disease (Ascomycetes: Ascosphaeraceae) of the alfalfa leafcutting bee (Hymenoptera: Megachilidae) in the field. Journal of Economic Entomology, 78: 35-40.

Parker, F.D. 1985b. A candidate legume pollinator, *Osmia sanrafaelae* Parker (Hymenoptera: Megachilidae). Journal of Apicultural Research, 24: 132-136.

Parker, F.D., and D.R. Frohlich. 1983. Hybrid sunflower pollination by a manageable composite specialist: The sunflower leafcutter bee (Hymenoptera: Megachilidae). Environmental Entomology, 12: 576-581.

Parker, F.D., and D.R. Frohlich. 1985. Studies on management of the sunflower leafcutter bee, *Eumegachile pugnata* (Say) (Hymenoptera: Megachilidae). Journal of Apicultural Research, 24: 125-131.

Parker, F.D., and P.F. Torchio. 1980. Management of wild bees. *In:* Beekeeping in the United States, United States Department of Agriculture Handbook, 335: pp. 144-160.

Richards, K.W. 1982. Inputs, expectations, and management of the alfalfa leafcutter bee, *Megachile rotundata.* Proceedings of the First International Symposium on Alfalfa leafcutting bee management. University of Saskatchewan, Saskatoon, Canada, pp. 113-135.

Roseler, Peter-Frank. 1985. A technique for year-round rearing of *Bombus terrestris* (Apidae, Bombini) colonies in captivity. Apidologie, 16: 165-170.

Rust, R.W. 1974. The systematics and biology of the genus *Osmia,* subgenera *Osmia, Chalcosmia,* and *Cephalosmia* (Hymenoptera: Megachilidae). Wasmann Journal of Biology, 32: 1-93.

Stephen, W.P., 1959. Maintaining alkali bees for seed production. Oregon State College Agriculture Experiment Station Bulletin 568, 23 pp.

Stephen, W.P., 1960a. Studies in the alkali bee (*Nomia melanderi* Cockerell). II: Preliminary investigations on the effect of soluble salts on alkali bee nesting sites. Oregon State College Agriculture Experiment Station Technical Bulletin, 52: 15-26.

Stephen, W.P. 1960b. Artificial bee beds for the propagation of the alkali bee, *Nomia melanderi.* Journal of Economic Entomology, 53: 1025-1030.

Stephen, W.P. 1960c. Studies in the alkali bee (*Nomia melanderi* Cockerell). III. Management and renovation of native soils for alkali bee inhabitation. Oregon State College Agriculture Experiment Station Technical Bulletin, 52: 27-39.

Stephen, W.P. 1962. Propagation of the leaf cutter bee, *Megachile rotundata,* for alfalfa seed production. Oregon State University Agriculture Experiment Station Bulletin 586.

Stephen, W.P. 1965. Temperature effects on the development and multiple generations in the alkali bee, *Nomia melanderi* Cockerell. Entomologia Experimentalis et Applicata, 8: 228-240.

Stephen, W.P. 1981. The design and function of field domiciles and incubators for leafcutting bee management (*Megachile rotundata* (Fabricius)). Oregon State University Agriculture Experiment Station Bulletin 654, 13 pp.

Stephen, W.P. and D.B. Evans, 1960. Studies in the alkali bee (*Nomia melanderi* Cockerell). I: Soil physical requirements for bee nesting. Oregon State College Agriculture Experiment Station Technical Bulletin 52: 3-14.

Stephen, W.P. and C.E. Osgood, 1965. The induction of emergence in the leaf cutter bee, *Megachile rotundata,* an important pollinator of alfalfa. Journal of Economic Entomology, 58: 284-286.

Stephen, W.P. and P.F. Torchio, 1961. Biological notes on the leaf cutter bee, *Megachile (Eutricharaea) rotundata* (Fabricius). Pan-Pacific Entomologist, 37: 85-93.

Tasei, J.N. 1972. Observations preliminaires sur la biologie d'*Osmia (Chalcosmia) coerulescens* L., pollinisatrice de la luzerne. Apidologie, 3: 149-165.

Tasei, J.N. 1976. Recolte des pollens et approvisionnement du nid chez *Osmia coerulescens* L., Apidologie, 7: 277-300.

Torchio, P.F. 1966. A survey of alfalfa pollinators and pollination in the San Joaquin Valley of California with emphasis on establishment of the alkali bee. Unpublished, M.S. Thesis, Oregon State University. 106 pp.

Torchio, P.F. 1972. *Sapyga pumila* Cresson, a parasite of *Megachile rotundata* (F.). I: Biology and description of immature stages. II. Methods for control. Melanderia, 10: 1-30.

Torchio, P.F. 1974. Biology and control of *Sapyga pumila,* a parasite of the alfalfa leafcutting bee. Utah State University Agriculture Experiment Station Research Report, 16: 13 p.

Torchio, P.F. 1982. Field experiements with the pollinator species, *Osmia lignaria propingua* Cresson in apple orchards: II, 1976 studies. Journal of the Kansas Entomological Society, 55: 759-778.

Torchio, P.F. 1984a. The nesting biology of *Hylaeus bisinuatus* Forster and development of its immature forms. Journal of the Kansas Entomological Society, 57: 276-297.

Torchio, P.F. 1984b. Field experiments with the pollinator species, *Osmia lignaria propingua* Cresson in apple orchards: III, 1977 studies. Journal of the Kansas Entomological Society, 57: 517-521.

Torchio, P.F. 1985. Field experiments with pollinator species, *Osmia lignaria propinqua* Cresson, in apple orchards: V (1979-1980), methods of introducing bees, nesting success, seed counts, fruit yields. Journal of the Kansas Entomological Society, 58: 448-464.

Torchio, P.F., and E. Asensio. 1985. The introduction of the European bee, *Osmia cornuta* Latr., into the U.S. as a potential pollinator of orchard crops, and a comparison of its manageability with *Osmia lignaria propingua* Cresson. Journal of the Kansas Entomological Society, 58: 42-52.

Torchio, P.F., E. Asensio, and R.W. Thorp. Introduction of the European bee, *Osmia cornuta,* into California almond orchards. Journal of Economic Entomology, (in press).

Youssef, N.N. and W.R. McManus, 1985. Captan: a promising fungicide for management of chalkbrood diseases in the alfalfa leafcutting bee. Journal of Economic Entomology, 78: 428-431.

Youssef, N.N., W.R. McManus, and P.F. Torchio, 1985. Cross-infectivity potential of *Ascosphaera* spp. (Ascomycetes: *Ascosphaera*) on the bee *Osmia lignaria propinqua* Cresson (Megachilidae: *Osmia*). Journal of Economic Entomology, 78: 227-231.

Youssef, N.N., C.F. Roush, and W.R. McManus, 1984. In vivo development and pathogenicity of *Ascosphaera proliperda* (Ascosphaeraceae) to the alfalfa leafcutting bee, *Megachile rotundata.* Journal of Invertebrate Pathology, 43: 11-20.

THE IMPORTANCE OF NATIVE POLLINATORS IN CULTIVATED ORCHARDS: THEIR ABUNDANCE AND ACTIVITIES IN RELATION TO WEATHER CONDITIONS

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Contribution No. 2 to the workshop **'Alternative Pollinators for Ontario Crops'** held at the University of Guelph, 12 April, 1986.

Abstract *Proc. ent. Soc. Ont.* 118:125-141 (1987)

The importance, efficiency, and activity of native and domestic insect pollinators were studied for 3 consecutive years, during the blossom period in a semi-dwarf apple orchard of the Niagara Peninsula. Insect numbers and activity were correlated with apple cultivar (Empire, MacIntosh, Golden Delicious, Red Delicious) located on the east and west slopes of the orchard, and with temperature, humidity, and light intensity fluctuations. Blossom development was also monitored. The efficiency of the pollinators was determined by analysis of the pollen carried on their bodies; and their effectiveness was determined by measuring fruit set, seed set, and the effective pollination period.

Apis mellifera L. was the most frequent pollinator for all years, but was less efficient as it carried less pollen and less fruit pollen than the Andrenidae. The physical factors, especially temperature, were mainly responsible for the variation in the numbers of honeybees. Factors such as cultivar, east and west slopes, and year were more significant in explaining the variation in the number of native pollinators than were temperature, humidity, and light (light being the most important). The Andrenidae are better pollinators than the honeybees, they carry more pollen and more fruit pollen, they are present during peak blossom, their range of activity is slightly narrower than that of the honeybees but their numbers do not fluctuate with changing weather conditions. The Diptera although numerically ranked second in importance in 1978 and 1979 were less effective than the Hymenoptera as they carried little pollen on their bodies.

The 1979 season was long and cool, there were significantly less honeybees than in the other years and significantly more native pollinators. Fruit set for all three years was not significantly different. Thus native pollinators become important in pollination during blossom seasons with adverse weather conditions, these insects compensated for the reduced activity of the honeybees, an observation that has been underestimated in orchard management.

Introduction

Most fruit blossoms are self-incompatible and therefore require cross-pollination. The amount of cross-pollination greatly depends on the numbers and types of insect pollinators present. Their activity and effectiveness are greatly dependent upon the physical environment (Kevan and Baker 1983). Strong winds, overcast skies, temperature fluctuations have all been reported to affect foraging. The general effects of weather on populations of flower-visiting insects have almost never been studied.

The importance of honeybees as pollinators has long been established (Free 1960b, Jaycox 1964, Kendall and Smith 1975, Langridge and Jenkins 1970, Morse 1976), and most surveys have shown that they form a high percentage of the insects visiting fruit blossoms (Bornus *et al.* 1977, Free 1960a, Kendall 1971). Honeybees are usually brought into

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apple orchards in hives for the blossom period to secure adequate pollination (Free 1970, McGregor 1976, NRCC 1981). The population density of flying insects in an orchard has up to now been determined using suction traps (Lewis and Smith 1969; Taylor 1951, 1963) or by very short observation periods. These traps may give a good estimate of the aerial fauna, but the insects caught by this method are not necessarily actual pollinators. Very little has been done to determine the importance of the various native populations as they relate to the entire pollination process in cultivated areas.

During periods of unfavorable weather, many native or wild insects are more readily observed and can be seen on blossoms of fruit trees. These insects are also present while hive bees are foraging but because of their generally smaller size they tend to go unnoticed. These native insects seem to be less affected by weather fluctuations than their domesticated counterparts and, consequently, their role in pollination should not be ignored or underestimated (Bohart 1952, Brittain 1933, Chansigaud 1972, Free 1960a, Lewis and Smith 1969).

The objectives of this study were to determine the importance and efficiency of the various groups of native pollinators versus domesticated honeybees in a cultivated orchard and to determine the effect of the different abiotic factors on their activity.

Materials and Methods

Observations were carried out in a semi-dwarf apple orchard at the Agriculture Canada Jordan Experimental Farm, Jordan Station, Ontario, during 3 consecutive blossom periods (1978-1980). The layout of the orchard is given in Figure 1. Four cultivars were present: MacIntosh, Empire, Red Delicious, and Golden Delicious. Trees were planted to allow maximum cultivar distribution thus ensuring proper cross-pollination. Due to the small tree size, i.e. semi-dwarf about 1 to 3 meters, it was possible to observe the entire tree without choosing a select few branches. In an attempt to reproduce cultivated orchard conditions but still maximize visitations by native populations, pesticides were not sprayed in the orchard. Also two hives were brought in for the blossom period (see layout Figure 1).

Daily observations of pollinators during the entire blossom period were carried out from sunrise to sunset. Because the general aerial fauna of an orchard is quite different from the pollinating insect fauna (Lewis and Smith 1969), and because many insects merely sit on the petals or approach the nectaries from the side without getting covered in pollen (Free 1960b), observations and collections were made only of insects actually visiting and touching the reproductive parts (anthers and stigma) of the flowers.

For each visit, a record of the numbers and types of pollinators, of the specific cultivar, and of weather conditions (temperature, relative humidity, and light intensity) was obtained from approximately 0600 to 2100 hours for each blossom day. A visit consisted of a 5-min observation period of each tree (referred to as simply a "visit" from now on), and a total of 16 trees was used. Each tree was visited approximately every 2.5 hours throughout the day. Because identification of insects to species while in flight is impossible, insects visiting the blossoms were subdivided into 20 easily recognizable groups (Figure 2). The number of opened blossoms on each sample tree were counted daily. Blossom development was correlated with the population composition and density, and yearly comparisons were made.

As many insects as possible were collected during field observations for identification and pollen analysis. They were collected in individual killing jars to eliminate pollen contamination. To determine efficiency of each main group of pollinator, a representative sample was used in pollen analysis. Pollen was brushed off the insects with a fine jet of ethanol and brushing with a fine brush (Kendall and Solomon 1973), counted, and fruit and non-fruit pollen differentiated. Differences in pollen and nectar gatherers were also considered (Boyle and Philogène 1983).

The effectiveness of the pollinators was evaluated by measuring fruit set and seed set (see methods in Boyle and Philogène 1983; Williams 1970) for each cultivar for each year.

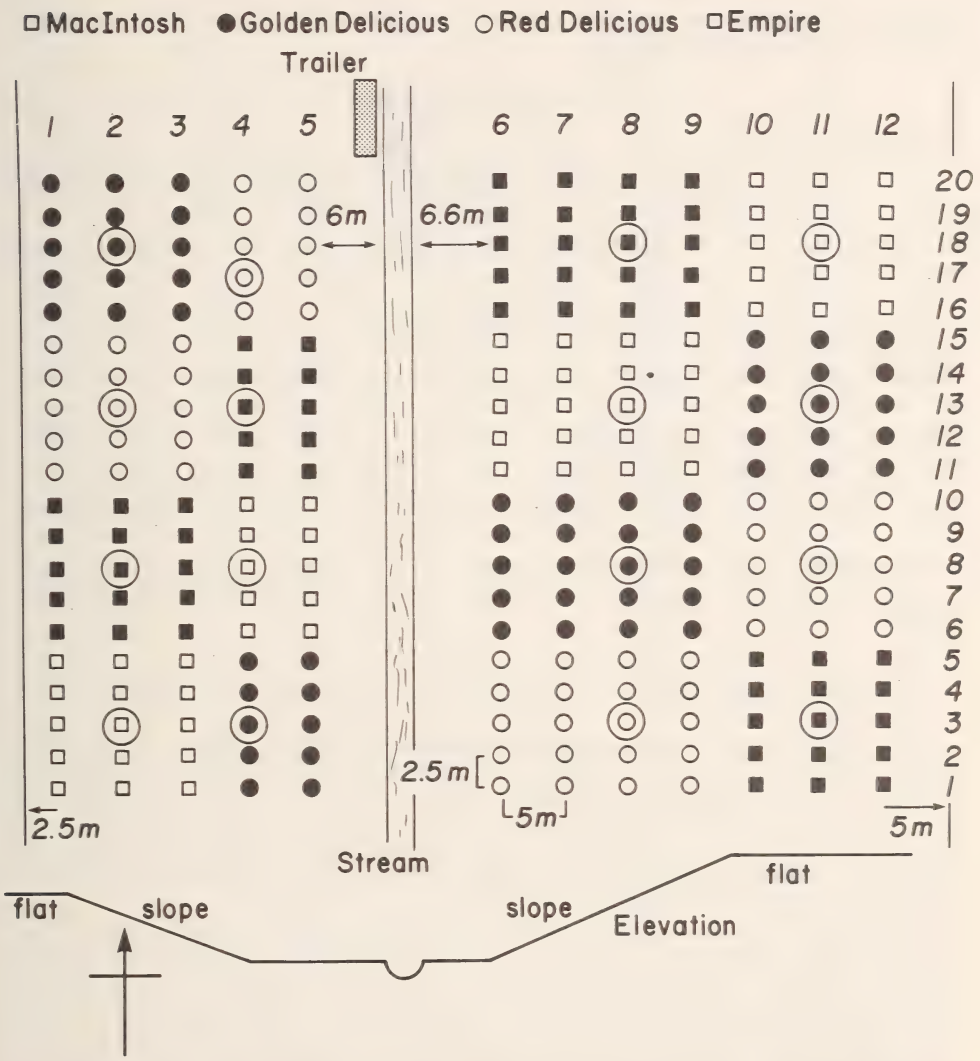

FIGURE 1. Lay-out of the apple orchard used in this study. Location: Jordan experimental station, Niagara Peninsula, Ontario. Root stock: M.26.

The effective pollination period, which is an estimate of the number of days the stigma is receptive to pollen after the flower opens, was determined for the 4 cultivars. This was done by hand pollinating each cultivar with the appropriate compatible pollen at various times after flower opening. Subsequently, initial and final fruit set and seed set were measured (see methods in Boyle-Makowski and Philogène 1985).

Temperature (°C), relative humidity (%), and light energy (Wm^{-2}) were recorded continuously. Thermocouples for temperature monitoring were placed on trees in each of the sample rows and positioned at the blossom level. The thermocouples were connected to a Data Acquisition System and miniprocessor (Esterline Angus, Pd 2064) programmed to print out temperatures every 30 min. RH was recorded with a thermo-hygrograph placed in a Stevensons Screen in the middle of the orchard. Total light

energy was monitored using a meter master Solarimeter (Tip Zonen CM6) and digital multimeter (Phillips PM 2421).

Results and Discussion

Population Composition

A total of 11,401 insects were observed throughout the three years. Altogether 106 species belonging to 77 genera and to 40 families were identified from the 758 insects caught (Boyle and Philogène 1983).

Apis mellifera L. were the most numerous of all visitors. The numbers observed increased greatly from one year to the next, with 162 in 1978, over three thousand in 1979, and more than four thousand in 1980. The Bombinae, often thought to be more important pollinators than the honeybees, were extremely rare in all years. In accordance with Heinrich (1979), *Apis* and *Bonbus* seem to compete for similar resources, and thus fewer *Bombus* are present when *Apis* are abundant. The Andrenidae and the Halictidae, which are the main Hymenoptera groups following *A. mellifera*, had the greatest diversity of species in 1979, but greater numbers were observed in 1980 than in previous years. Most other groups of Hymenoptera had fewer numbers but a greater species diversity in 1979.

Among the Diptera, the Syrphidae and the Anthomyiidae were of importance. The greatest diversity and numbers of Syrphidae were observed in 1980. The Anthomyiidae were very abundant, especially in 1979. Most other groups of Diptera were more abundant and diverse in 1979 than in other years.

The Coleoptera, Lepidoptera and Hemiptera were also very few but showed a greater diversity in 1979.

Yearly Variations in Population Composition

In the 1978 season there were only 167 observation periods, compared with 1653 in 1979 and 916 in 1980.

Apis mellifera increased in relative importance from 1978 to 1980, from 50% to 80% of the total pollinator population (Figure 2). The 1979 season was very long (Figure 3) mainly because of adverse weather. Towards the middle of the season there were five very cool days which retarded blossom development considerably. A much greater diversity of species was recorded because of this extended period. Discounting the honeybees, the Diptera were the main groups present. In 1980 the other Hymenoptera were more prevalent than the Diptera.

In 1978, there were fewer honeybees than in the other years making up only 50% of the pollinating insects (Figure 4), thus the native pollinators were equally important during this blossom season that was extremely short and warm. Honeybees were less active in 1979 than in 1980. The other Hymenoptera and the Diptera were more active in 1979 than in 1980. The greater number of species of native pollinators in 1979 seemed to compensate for the adverse weather conditions and the decreased honeybee activity.

Seasonal Distribution

Flowers that open at different times are exposed to different insect pollinators (Lewis and Smith 1969). Only the insects active during the critical receptive period (effective pollination period or E.P.P.) of the flowers will contribute to their pollination. MacIntosh and Empire were receptive to pollen for two days following flower opening (Figure 5). Red Delicious did not set final fruit but, from the initial fruit set, was also receptive for the first two days. Golden Delicious was receptive to pollen from day 2 to the fourth day following flower opening. Although these observations apply to 1980 only, it can be extrapolated that the insects present or peaking from the beginning to peak blossom are of greater significance in pollination than the insects peaking towards the end of the blossom season.

The numbers present in each group throughout each blossom season are represented in Figure 3. In 1978, most groups present peaked with peak blossom of Red and Golden Delicious: honeybees, Andrenidae, Formicidae, Syrphidae, Anthomyiidae. In 1979, two peaks of activity occurred, a slightly smaller one at the beginning and the other towards

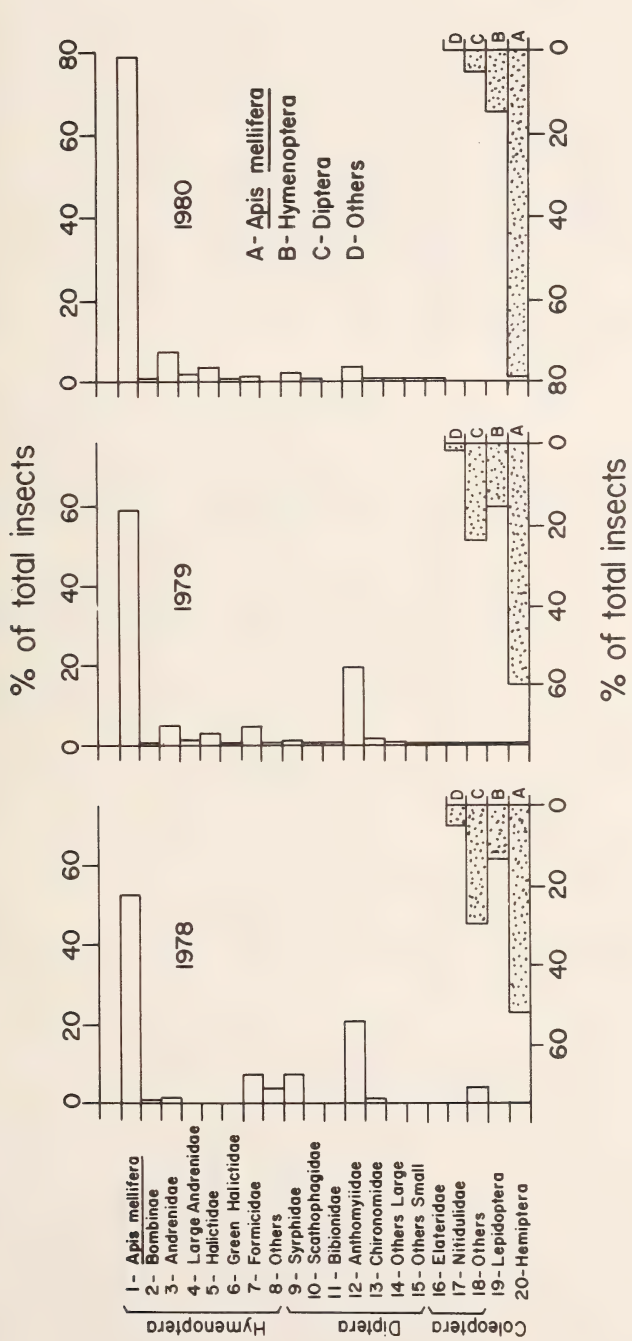

FIGURE 2. The yearly distribution of the 20 groups of pollinators expressed as the percentage of the total number of insects observed, then summarized as the four main groups.

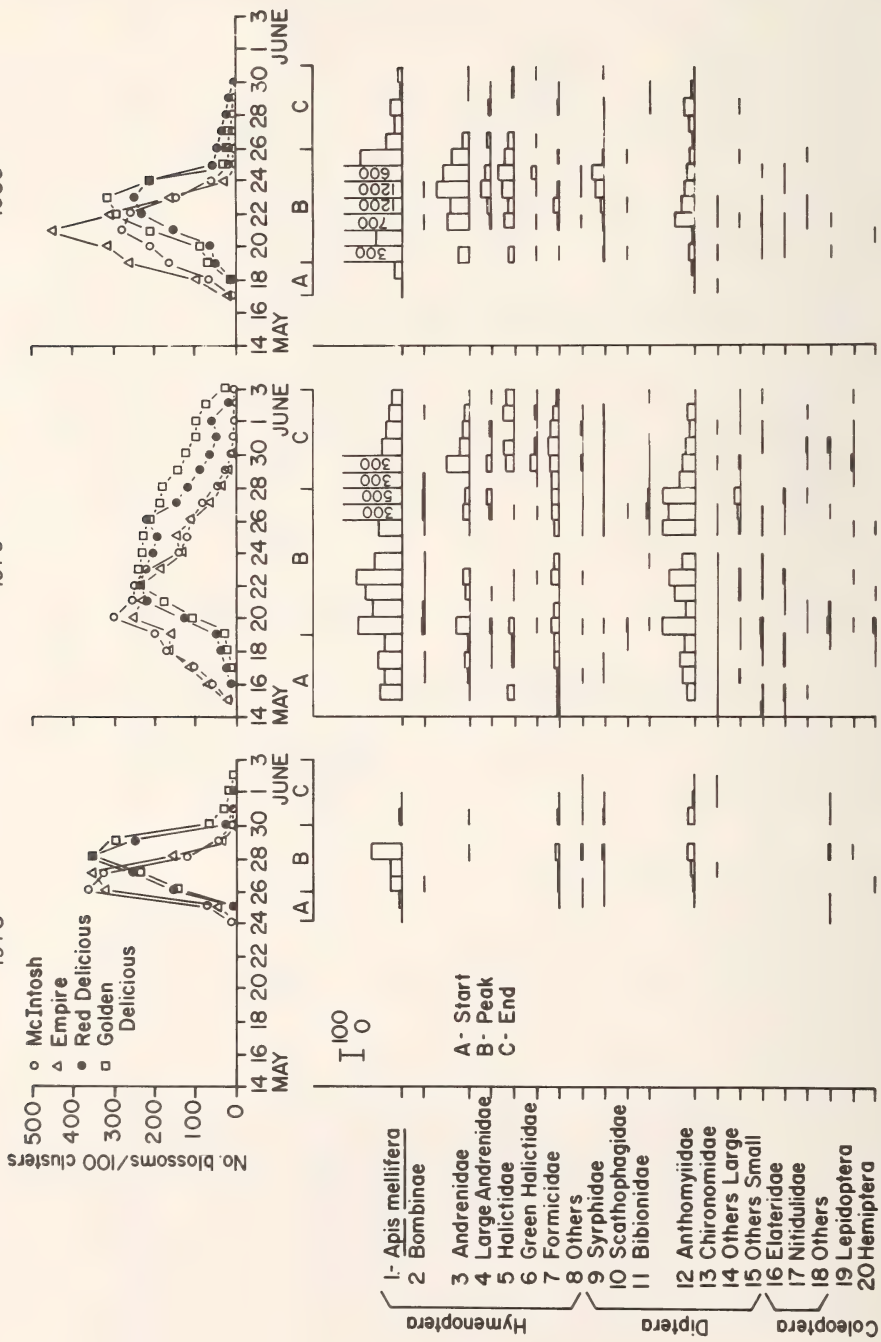

FIGURE 3. Bloom development and seasonal distribution of the total number of insects of each group of pollinator observed each day for 1978, 1979, and 1980.

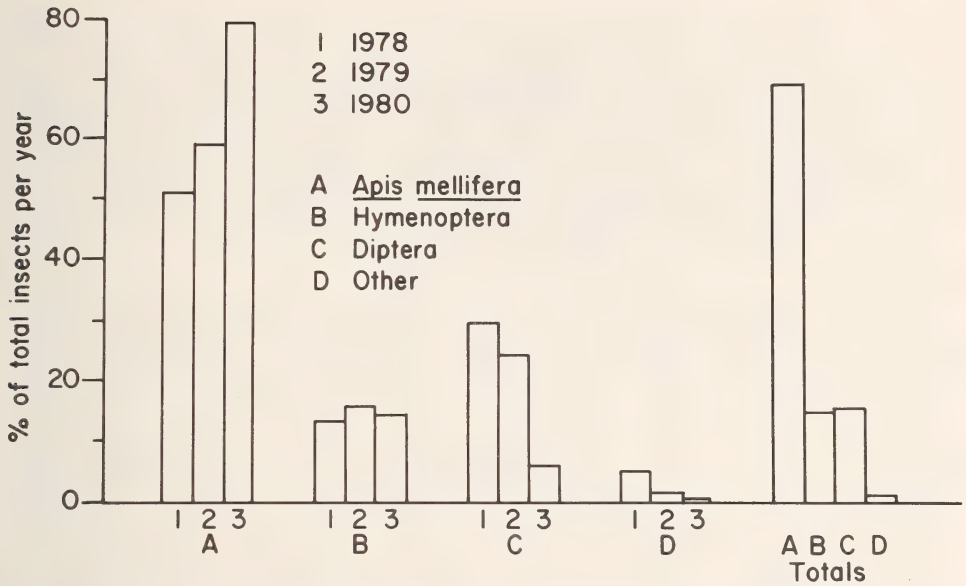

FIGURE 4. Comparisons between years of the four main groups of pollinators and the relative importance of these groups for all years combined.

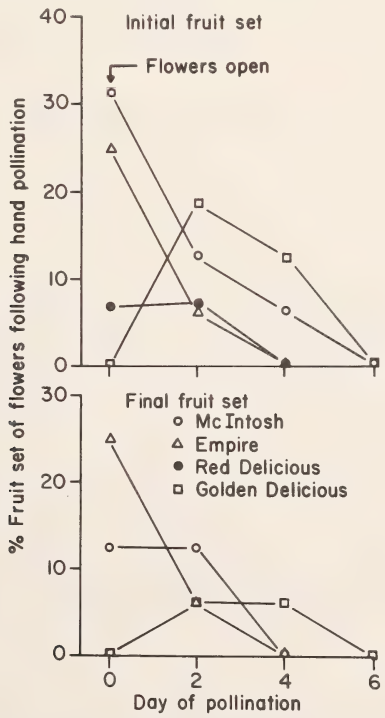

FIGURE 5. Initial and final fruit set following hand pollination for each of the four cultivars for 1980. Day of pollination represents number of days after blossoms opened that hand pollination was done.

the finish of the peak blossom period (between B and C in Figure 3). The second peak is due to the slight second peak in blossoms and improved weather conditions. The Andrenidae, the Formicidae, the Anthomyiidae, and the Chironomidae were present from the start. The honeybees and the Halictidae were present a few days later once Red and Golden Delicious had started blossoming. The Bombinae, the large Andrenidae, and the 'green' Halictidae were present once MacIntosh and Empire started to peak. The Syrphidae and the Bibionidae were present mainly at the end thus contributing little to pollination. In 1980, most groups peaked with peak blossom of Red and Golden Delicious as in 1978. The honeybees and the Anthomyiidae were present throughout.

Pollen Analysis

The amount of pollen on the body of an insect is a good indication of its efficiency in pollination (Kendall and Solomon 1973). The Hymenoptera, which possess morphological structures for pollen collection, had significantly more pollen on their bodies than the Diptera (Table 1). For the first six groups of Hymenoptera (*Apis mellifera*, Bombinae, Andrenidae, large Andrenidae, Halictidae, and 'green' Halictidae) pollen and nectar gatherers were separated on the basis of the presence or absence of pollen loads on their hind legs. Nectar and pollen gathering Hymenoptera were compared; it was found that only the large Andrenidae and the Halictidae had significantly less pollen on the nectar gatherers than the pollen gatherers. Nectar-gathering large Andrenidae and Halictidae would therefore be less efficient in pollination. Pollen gatherers have been reported as being more valuable as pollinators since they must necessarily touch the anthers and the stigma, whereas many nectar gatherers can approach the nectaries from the side without contracting pollen (Brittain 1933; Free 1960a, 1960b, 1967; Roberts 1945). Of the Hymenoptera, the Andrenidae and the pollen-gathering large Andrenidae had the most fruit pollen on their bodies, followed in decreasing order by *Apis mellifera*, the nectar-gathering large Andrenidae, the Bombinae, the 'green' Halictidae, and the pollen and nectar-gathering Halictidae,

Kendall and Solomon (1973) reported that larger solitary bees and bumblebees had great amounts of pollen. In this study, the larger solitary bees had the most pollen. The bumblebees however had less, this may be due to too small a sample size since bumblebees were rare and only three were used for pollen analysis. Kendall (1971, 1973) reported that most solitary bees tested carried larger quantities of fruit pollen than honeybees, this was also found in this study. This supports the suggestion that greater amounts of fruit pollen on an insect indicate a better pollinator as they remain constant to fruit blossoms. Among the Diptera, the Syrphidae had the greatest amount of pollen.

The honeybees were the most numerous of all pollinators but were less efficient than the Andrenidae, and their activity fluctuated greatly during adverse conditions. The Anthomyiidae, which ranked second numerically and were widely distributed in 1978 and 1979, even during unfavorable conditions, had nevertheless very few pollen grains and therefore contributed very little to pollination. On the other hand the Syrphidae, which had the greatest amount of pollen among the Diptera, were mainly active towards the end of the season or during seasons with better weather conditions; they were less effective pollinators than the Hymenoptera. The Andrenidae, the large Andrenidae and the Halictidae compensated for the poor performance of the honeybees in 1979; these groups had high quantities of pollen and were present during the receptive period of the blossoms. The Andrenidae and large Andrenidae have greater percentages of fruit pollen than the other groups and thus are more constant to fruit pollen and are thus better pollinators than the others.

Fruit Set and Seed Set

'Tree', 'Row', and 'Year' were factors considered responsible for the variation in fruit set, and in the number of seeds per apple. The four different cultivars (Figure 1) were classified as 'Tree'. 'Row' was separated into east- and west-facing slopes. The three seasons were grouped as 'Year'.

TABLE I. Quantity of pollen grains washed from the bodies of the various groups of Hymenoptera and Diptera.

Group	Number of insects	Total no. pollen grains*		No. fruit pollen grains*		**	% fruit pollen
Apis mellifera	11	9020	(1.9)	8266	(1.9)	ab	92
Bombinae	3	5617	(4.3)	5288	(4.3)	abc	94
Andrenidae	50	9230	(2.6)	8517	(2.8)	a	93
Large Andrenidae							
pollen gatherers	13	38610	(2.1)	36074	(2.1)	a	94
nectar gatherers	10	7415	(2.2)	6747	(2.3)	ab	91
Halictidae							
pollen gatherers	30	3558	(2.3)	1488	(13.4)	c	79
nectar gatherers	11	388	(6.1)	186	(11.6)	de	75
'Green' Halictidae	16	2640	(3.2)	2205	(3.4)	bc	78
Formicidae	7	30	(2.4)	16	(4.2)	fg	86
'Other' Formicidae	7	131	(5.0)	105	(4.4)	def	82
Syrphidae	29	806	(7.0)	296	(13.7)	d	61
Scathophagidae	3	168	(2.1)	130	(2.4)	def	79
Bibionidae	5	41	(11.1)	41	(11.1)	ef	80
Anthomyiidae	12	32	(4.2)	16	(6.8)	fg	68
Chironomidae	2	0	(0)	0	(0)	g	0
Large 'Other' Diptera	10	108	(6.8)	73	(5.5)	def	64
Small 'Other' Diptera	8	2	(3.9)	1	(2.3)	g	13

* Means expressed as the geometric mean. Standard deviations in brackets.

** Values followed by the same letter are not significantly different by Duncan's Multiple Range Test (P = 0.05).

TABLE II. Significance of the discrete variables responsible for the fluctuations in fruit set and seed set. Test conducted on logarithmic values. (df: degrees of freedom; S.S.: sum of squares; see Snedecor and Cochran 1967; this also applies to Table 4).

	Analysis of Variance			
Variables	**df**	**S.S.**	**F**	**Sign. F (P)**
Fruit Set				
Tree	3	1.319	9.601	0.000
Row	1	0.066	1.444	0.241
Year (78-80)	2	0.147	1.601	0.222
Seed Set				
Tree	3	1.329	23.171	0.000
Row	1	0.012	0.626	0.429
Year (79-80)	1	0.080	4.203	0.041

With interactions between the three variables taken into consideration, only 'Tree', that is cultivar was significant in explaining the variations in fruit set (Table II). There were significantly more fruit that set on Golden Delicious than on any of the other cultivars (Table III).

The number of seeds per fruit was determined for a sample of 25 apples from each observation tree in 1979 and 1980. With interactions among the three variables taken into account, 'Tree' and to a lesser extent 'Year', were significant in explaining the variation in the number of seeds per apple (Table II). There were significantly more seed per apple of Golden Delicious than of the other cultivars, and there were significantly more seed per apple in 1980 than in 1979 (Table III).

TABLE III. Significance of cultivar on fruit set and seed set, and of year on seed set. (Test conducted on logarithmic values. Values followed by the same letter are not significantly different by Duncan's multiple range test (P = 0.05). This also applies to Table 6).

	Geometric mean	
Variables	**Fruit Set**	**Seed Set**
Tree		
MacIntosh	8.5 ab	7.4 a
Empire	13.2 b	6.9 b
Red Delicious	10.4 a	5.9 b
Golden Delicious	23.5 c	7.7 c
Year		
1979		6.8 a
1980		7.1 b

Pollinator Activity

The data were first examined qualitatively, to determine the range of activity of the different groups of insects, and then analyzed statistically to elucidate which factors were most important in influencing the level of pollinating activity of each group of pollinators. These factors were divided into 2 categories: discrete and continuous variables. The discrete variables were approximately or fully constant within 1 day, i.e. static, well delimited factors; these consisted of the number of blossoms per tree, the type of cultivar, the different rows, and the year. The continuous variables or covariates changed markedly within 1 day and were time, temperature, humidity and light. For the statistical analysis, many of the variables were reorganized as explained below.

Much unavoidable variation was inherent in the data because of the differences in the number of blossoms present between years, trees and cultivars. As expected, there were more insects present on trees that had more blossoms. This was verified via a stepwise multiple regression and 'F' test from which it was determined that the number of blossoms ranked first among the biotic factors influencing pollinator activity and was highly significant for the 3 main groups of pollinators. Therefore, for meaningful comparisons among the other variables, the number of insects present for each group per visit was transformed to the number of insects present per 100 blossoms.

'Tree', 'Row', and 'Year' have already been explained. 'Time' was divided on an hourly basis between 0600 and 2100 hours.

The 20 groups of insects (as defined in Figure 2) were reclassified into 4 groups: (I) *Apis mellifera* (honeybees); (II) all other Hymenoptera; (III) all Diptera; and (IV) others (Coleoptera, Lepidoptera, and Hemiptera). Because the fourth group consisted of only 1% of the total pollinator population, it was excluded from statistical analysis.

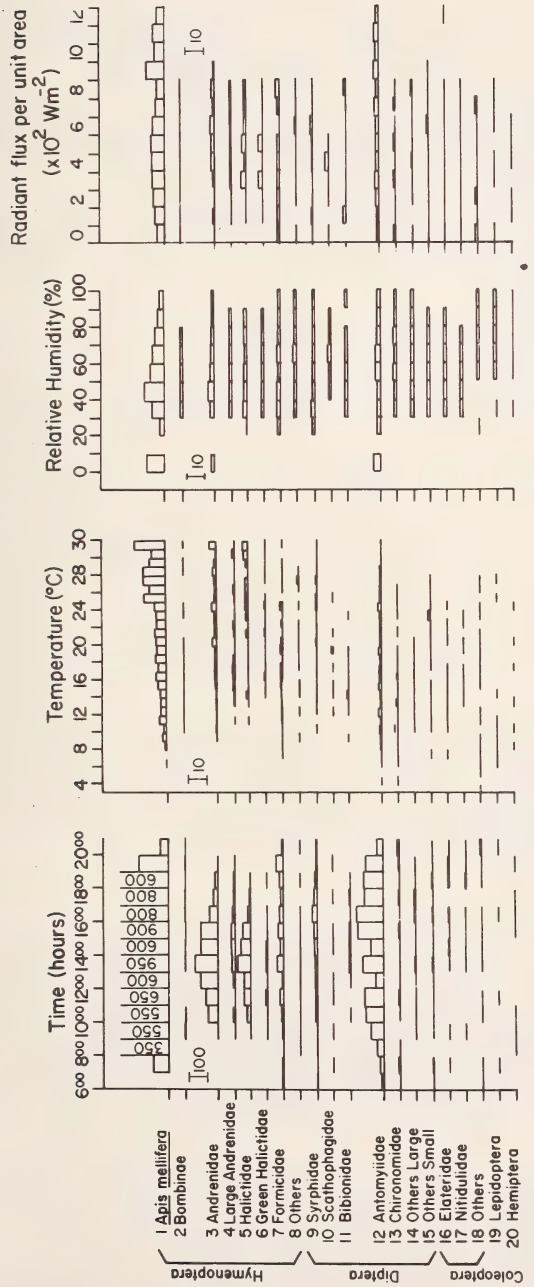

FIGURE 6. Column 1: Distribution of the total number of insects of each group of pollinator observed over the three years for each hour of the day from 6:00 to 21:00 hours, Columns 2 to 4: Distribution of the mean number of insects of each group of pollinator observed per visit for the three years over the range of physical factors measured, temperature, relative humidity, and radiant flux.

Qualitative Analysis

(1) Daily variations. The distribution of the various groups of pollinators differed according to the time of day (Figure 6). *Apis mellifera*, Andrenidae, Halictidae, Formicidae, Syrphidae, and Anthomyiidae were the most commonly observed insects. Although *A. mellifera*, Formicidae, Syrphidae, and Anthomyiidae were present throughout the period of observation, Andrenidae and Halictidae were mostly active from 1000 to 1600 hours, corresponding to the greater availability of pollen and nectar (Butler 1945, Free 1960a, Langridge 1969, Percival 1955). Hymenoptera with the exception of *A. mellifera* and Formicidae did not appear before 0900, whereas most Diptera, Coleoptera, and other groups were active throughout the observation time, often peaking later in the day.

(2) Influence of Weather Conditions. Weather conditions have been reported to account for daily fluctuations in the number of pollinators (Free 1960a,b; Lewis and Smith 1969). Variations in range and distribution of the 20 different groups of insects observed with respect to temperature, humidity, and light are presented in Figure 6 and are summarized below.

Most honeybees observed were present at temperatures of 10°C and above, and throughout the range of humidity measured in the orchard, but primarily around 50% RH, and were uniformly distributed over the entire range of light measured in the orchard (not detectable (nd) to 1200 Wm^{-2}). The Andrenidae followed the same distribution thresholds, and were present between nd and 900 Wm^{-2}. The large Andrenidae and the Halictidae displayed a narrower range of activity, preferring temperatures above 12°C, humidities between 30 and 90% RH, and light intensities of 100-800 Wm^{-2}. The Formicidae were present between 8 and 32°C, at 20-100% RH, and under light range of nd to 900 Wm^{-2}, with a slight preference for higher intensities. The Syrphidae were present above 11°C, between 20 and 100% RH, and light intensities of nd to 800 Wm^{-2}. The Anthomyiidae were the most widely distributed group, being present throughout the entire recorded ranges of temperature (5-32°C), humidity (0-100%), and light (nd to 1200 Wm^{-2}). Other groups were generally sparsely represented as illustrated in Figure 6, sharing no particular temperature range, occurring essentially at 30-100% RH, and light intensities nd to 800 Wm^{-2}.

Honeybees seemed to be the only group greatly affected by temperature changes, their number increasing markedly with higher temperatures. The other groups were constant throughout their ranges of temperature. Honeybees again were the only group affected by the changes in humidity as they peaked around 45% RH. All groups were uniformly distributed throughout the ranges of light readings. All groups had definite threshold temperatures, humidities, and light intensities for their activity.

Statistical Analysis

With all variables being considered, the standard ANOVA (Table IV) shows that weather conditions were mostly responsible for the variation in the number of honeybees, whereas the static factors (Tree, Row, Year) had a greater influence on the variation in the numbers of native pollinators, i.e. the other Hymenoptera and the Diptera. This is consistent with previously reported findings that the activity of honeybees is affected more by weather conditions than is that of native pollinators (Bohart 1952, Chansigaud 1972, Free 1960b, Kevan and Baker 1983, Lewis and Smith 1969). The effect of the different variables will be examined separately.

(1) *Covariates or Continuous Variables.*

Temperature, humidity, light, and time were analyzed using a stepwise multiple regression, which accounts for interactions among variables and ranks them to indicate which is responsible for the greatest variation in the number of insects.

Temperature was the most significant factor for the honeybees, followed by humidity, whereas only light was significant for the other Hymenoptera, and for the Diptera none of the continuous variables had a significant influence on activity (Table V-1).

The analysis was done a second time based exclusively on insects present on the blos-

TABLE IV. Significance of the discrete variables responsible for the fluctuations in the numbers of insects, using a standard ANOVA accounting for the interactions of the continuous variables. This test was conducted on the logarithmic values of the number of insects per 100 blossoms per visit.

Source	df	S.S.	F	Sign. F (P)
		A. mellifera		
Continuous variables	4	20.711	69.094	0.000
Temperature	1	2.661	35.506	0.000
Time	1	0.768	10.250	0.001
Humidity	1	3.920	52.309	0.000
Light	1	0.220	2.939	0.087
Discrete variables	8	5.899	9.840	0.000
Tree	3	2.999	13.338	0.000
Row	1	0.004	0.050	0.823
Year	2	2.323	15.499	0.000
		Other Hymenoptera		
Continuous variables	4	3.492	12.432	0.000
Temperature	1	0.102	1.459	0.227
Time	1	0.255	3.628	0.057
Humidity	1	.021	0.295	0.587
Light	1	2.190	31.186	0.000
Discrete variables	8	18.558	33.035	0.000
Tree	3	1.285	6.101	0.000
Row	1	0.285	4.056	0.044
Year	2	1.865	13.280	0.000
		Diptera		
Continuous variables	4	1.440	4.329	0.002
Temperature	1	0.368	4.425	0.036
Time	1	0.091	1.098	0.295
Humidity	1	0.114	1.369	0.242
Light	1	0.372	4.468	0.035
Discrete variables	8	29.720	44.679	0.000
Tree	3	4.769	19.119	0.000
Row	1	0.327	3.938	0.047
Year	2	5.626	33.832	0.000

soms, i.e. the insects had reached their threshold temperature and were active (Table V-2). Humidity became the most significant variable for the other Hymenoptera and became the only significant factor for the Diptera. The change from inability to fly to ability to fly occurs abruptly at a threshold temperature (Taylor 1963), but once attained, the other physical factors become important to the fluctuations in the numbers of active insects as seen in this second analysis.

(2) *Static or Discrete Variables.*

Variation and cultivar: The type of cultivar was significant for all pollinators. Empire and Red Delicious were more attractive to honeybees than the other cultivars (Table VI). MacIntosh and Red Delicious were more attractive to the other Hymenoptera, and MacIntosh, Empire, and Red Delicious were equally attractive to the Diptera. There were significantly fewer insects per 100 blossoms on Golden Delicious than on the other cultivars for all three groups of pollinators. However, there were significantly more fruit that

TABLE V. Significance of the continuous variables with respect to fluctuations in the numbers of the 3 main groups of pollinators. A stepwise multiple regression was carried out twice: (1) on all observations, i.e. including those where no insects were present on the blossoms; (2) only on observations when insects were present on the blossoms. (B: coefficients in regression equation; see Snedecor and Cochran 1967).

	(1) All observations			(2) Only when active		
Variables	**B**	**F**	**Sign. F (P)**	**B**	**F**	**Sign. F (P)**
			A. mellifera			
Temperature	0.0080	33.528	0.000	−0.0091	75.172	0.000
Humidity	−0.0032	49.337	0.000	−0.0200	27.920	0.000
Time	−0.0044	9.671	0.002	0.0107	13.967	0.000
Light	0.0036	2.783	0.150	0.0165	13.709	0.000
(constant)	0.1651			0.5791		
			Other Hymenoptera			
Light	0.0113	27.946	0.000	0.0521	37.070	0.000
Time	−0.0025	3.243	0.070	−0.0173	4.328	0.035
Temperature	−0.0016	1.310	0.250	−0.0021	1.261	0.250
Humidity	−0.0002	0.265	0.250	0.0009	0.027	0.250
(constant)	0.0029			−0.0911		
			Diptera			
Light	0.0047	3.775	0.062	0.0211	11.278	0.001
Temperature	−0.0029	3.746	0.060	−0.0065	2.861	0.150
Humidity	0.0005	1.152	0.250	0.0052	1.119	0.250
Time	−0.0015	0.926	0.250	−0.0002	0.031	0.250
(constant)	0.0746			−0.2369		

set on Golden Delicious than on any of the others (see above and Table IV). Golden Delicious has been reported to be an extremely fertile cultivar (Milutinovic and Milutinovic 1970) and therefore seems to require fewer pollinator visits. In addition, if the insects prefer the other cultivars, when they do visit Golden Delicious they will transfer a greater amount of compatible pollen. The effective pollination period for this cultivar was longer than for the others (see above and Figure 5); therefore there was a better chance of its being adequately pollinated (Stott 1972, Williams 1970).

Variation and slope: Analysis of the number of insects present per 100 blossoms per visit (5-min observation period) between rows, indicated that there was no significant differences in number of honeybees between east- and west-facing slopes (Table VI). There were, however, significantly more other Hymenoptera and Diptera on the east slope (west-facing). This slope is illuminated over a longer period of time towards the end of the day (refer to Figure 1). The importance of light to the other Hymenoptera was shown to be significant in the previous section.

Yearly variations: Yearly variations in population composition from a qualitative viewpoint were reported earlier. Variations in the number of insects per 100 blossoms per visit for each of the 3 years are presented in Table VI. The 1978 season was shorter than that of the other years and weather conditions were the most favorable. The number of insects per visit was similar for each pollinator group in 1978.

The 1979 season was long and cool. The 1980 season was intermediate in length and weather conditions between 1978 and 1979. Honeybee activity was reduced in 1979, however, the other Hymenoptera and the Diptera were more active in 1979 than in 1980. There was no difference in fruit set between years (see above and Table II). Therefore, the native pollinator activity compensated for decreased honeybee activity in 1979.

TABLE VI. Significance of cultivar (Tree), east and west slopes (Row), and year on the variation of the number of insects per 100 blossoms per visit. Numbers followed by the same letter in any row are not significantly different from each other.

	Geometric mean		
Variables	**Honeybees**	**Other Hymenoptera**	**Diptera**
Tree			
MacIntosh	1.109 ab	0.994 a	0.891 a
Empire	1.187 bc	0.947 ab	0.880 a
Red Delicious	1.248 c	1.019 a	0.849 a
Golden Delicious	1.037 a	0.918 b	0.724 b
Row			
East	1.150 a	0.997 a	0.856 a
West	1.137 a	0.945 b	0.808 b
Year			
1978	1.269 a	1.219 a	1.199 a
1979	1.127 b	0.987 b	0.854 b
1980	1.150 ab	0.901 c	0.741 c

Conclusion

The importance of native populations of pollinators in cultivated orchards has not been determined nor the general effects of weather on their activity (Kevan and Baker 1983). Research has concentrated on a single species but not on the entire pollination assemblage. This present study elucidates which groups of insects are most effective in pollination and which factors are responsible for the fluctuations of pollinator numbers in a cultivated orchard.

The honeybees were the most numerous of all pollinators, but were less efficient than the Andrenidae and large Andrenidae. The number of honeybees fluctuated greatly with weather conditions especially temperature. Cultivar, slope and year were more important in explaining variations in the numbers of native pollinators, i.e. other Hymenoptera and Diptera, visiting flowers than were temperature, humidity, and light (light being the most important). Native pollinators have definite temperature, humidity, and light intensity thresholds for their activity but this remains constant, once the insects are active, throughout the ranges of these observed factors. More specifically, the Andrenidae and large Andrenidae representing mainly: *Andrena miserabilis* Cresson, *A. nasonii* Robertson, *A. sigmundi* Cockerell, *A. carlini* Cockerell, and of a slightly less importance the Halictidae and 'green' Halictidae representing mainly: *Dialictus inconspicuus* (Smith), *Augochlorella striata* Provancher (Boyle and Philogène 1983), were better pollinators than the honeybees. They carried more pollen and more fruit pollen than *Apis*, they were present during peak blossom, their range of activity was slightly narrower than that of honeybees but their numbers did not fluctuate with changing weather conditions. The Andrenidae *(A. miserabilis, A. nasonii, A. sigmundi)*are active at temperatures above 10°C, the large Andrenidae and the Halictidae *(A. carlini, D. inconspicuus)* are active at temperatures above 12°C, and *Augochlorella striata* is active above 14°C. They are mostly present between 20-90% RH and 100-900 Wm^{-2}.

The 1979 season was long and cool, there were significantly less honeybees than in the other years and significantly more native pollinators. Fruit set for all three years was not significantly different. Thus native pollinators become important in pollination during blossom seasons with adverse weather conditions, these insects compensated for the

reduced activity of the honeybees, an observation that has been underestimated in orchard management. Conservation of native pollinators is essential for adequate crop pollination and is of increasing concern to many researchers (Kevan and Baker 1983, NRCC 1981). Because these native pollinators remain in close proximity to the orchard, care should be taken in timing pesticide applications during conditions when insect activity is low (below 10°C, or at light intensities below 100 Wm^{-2}).

Acknowledgements

I am grateful to Dr. P. Kevan for organizing and bringing together those concerned with the fate of native pollinators, and for the opportunity of presenting an overall view of my studies even if segments have been published previously.

This project was supported by an Agriculture Canada extramural grant. Thanks are given to the Vineland Research Station for use of the facilities and to Drs. B.J.R. Philogène, J.T. Arnason, A. Hagley, and R. Trottier for their advice and criticisms.

References

Bohart, G.E. 1952. Pollination by native insects. pp. 107-121 *in* USDA Yearbook. Washington, DC.

Bornus, L.B., B. Jablonski, S. Krol, K. Kuna, W. Bystydzienski, M. Opala, M. Ceglowski, H. Rechnio, W. Michalski, and J. Stepor, 1977. An attempt to estimate the optimal number of honeybees for a good pollination of apple orchard. Fruit Science Reports, 4(1):51-52.

Boyle, R.M.D., and B.J.R. Philogène. 1983. The native pollinators of an apple orchard: variations and significance. Journal of Horticultural Science, 58:355-363.

Boyle-Makowski, R.M.D., and B.J.R. Philogène. 1985. Pollinator activity and abiotic factors in an apple orchard. Canadian Entomologist, 117:1509-1521.

Brittain, W.H. 1933. Apple pollination studies in the Annapolis Valley, N.S., Canada, 1928-1932. Bulletin, Department of Agriculture, Canada (New Series), No. 162.

Butler, C.G. 1945. The influence of various physical and biological factors of the environment on honeybee activity. An examination of the relationship between activity and nectar concentration and abundance. Journal of Experimental Biology, 21:5-12.

Chansigaud, T. 1972. Distribution of the flights of wild bees in some orchards near Paris in 1969 and 1970. Apidologie 3:263-273.

Free, J.B. 1960a. The pollination of fruit trees. Bee World, 41:141-169.

Free, J.B. 1960b. The behaviour of honeybees visiting the flowers of fruit trees. Journal of Animal Ecology, 29:385-395.

Free, J.B. 1967. Factors determining the collection of pollen by honeybee foragers. Animal Behaviour, 15:134-144.

Free, J.B. 1970. Insect pollination of crops. Academic Press, New York. 544 pp.

Heinrich, B. 1979. Bumblebee economics. Harvard University Press, US.

Jaycox, E.R. 1964. Pollination of fruit trees by honey bees. American Bee Journal, 104:338-339.

Kendall, D.A. 1971. Effectiveness of pollinating insects. Report, Long Ashton Research Station for 1970, pp. 99-100.

Kendall, D.A. 1973. The viability and compatibility of pollen on insects visiting apple blossoms. Journal of Applied Ecology, 10:847-853.

Kendall, D.A., and B.D. Smith. 1975. The foraging behaviour of honey bees on ornamental *Malus* spp. used as pollinizers in apple orchards. Journal of Applied Ecology, 12:465-471.

Kendall, D.A., and M.E. Solomon. 1973. Quantities of pollen in the bodies of insects visiting apple blossom. Journal of Applied Ecology, 10:627-634.

Kevan, P.G., and H.G. Baker. 1983. Insects as flower visitors and pollinators. Annual Review of Entomology, 28:407-453.

Landridge, D.F. 1969. Effects of temperature, humidity, and caging on the concentration of fruit pollen in the air. Apples, peaches, cherries. Australian Journal of Experimental Agriculture and Animal Husbandry, 9 (40):549-552.
Landridge, D.F., and P.T. Jenkins. 1970. The role of honey bees in pollination of apples. Australian Journal of Experimental Agriculture and Animal Husbandry, 10:366-368.
Lewis, T., and B.D. Smith. 1969. The insect faunas of pear and apple orchards and the effect of windbreaks on their distribution. Annals of Applied Biology, 64:11-20.
McGregor, S.E. 1976. Insect pollination of cultivated crop plants. Agricultural Handbook 496. ARS-USDA, Washington, DC. 411 pp.
Milutinovic, M., and V. Milutinovic. 1970. Effect of pollinator on Golden Delicious apples. Contemporary Agriculture 18:47-54.
Morse, R.A. 1976. Efficient use of honey bees in the orchard. Proceedings of the Annual Meeting of New York State Horticultural Society, 121:61-64.
NRCC. 1981. Pesticide-pollinator interactions. NRCC No. 18471. 190 pp.
Percival, M.S. 1955. The presentation of pollen in certain Angiosperms and its collection by *Apis mellifera*. New Phytology, 54:353-368.
Roberts, R.H. 1945. Blossom structure and setting of Delicious and other apple varieties. Proceedings of the American Society for Horticultural Science, 46:87-90.
Snedecor, G.W., and W.G. Cochran. 1967. Statistical Methods. 6th edition, Iowa State University Press, Ames, IA. 485 pp.
Stott, K.G. 1972. Pollen germination and pollen-tube characteristics in a range of apple cultivars. Journal of Horticultural Science, 47:191-198.
Taylor, L.R. 1951. An improved suction trap for insects. Annals of Applied Biology, 38:582-591.
Taylor, L.R. 1963. Analysis of the effect of temperature on insects in flight. Journal of Animal Ecology, 32:99-117.
Williams, R.R. 1970. An analysis of fruit-set determinants in 1969. pp. 11-22 *in* Williams, R.R., and D. Wilson (Eds.), Towards regulated cropping. Grower Books, London.

CONTROL OF FRUIT SET IN 'DELICIOUS' APPLE

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Contribution No. 3 to the workshop **'Alternative Pollinators for Ontario Crops'** held at the University of Guelph, 12 April, 1986.

Proc. ent. Soc. Ont. 118:143-147 (1987)

'Delicious' is the most important apple cultivar grown in the United States, accounting for over 35% of total production. It is self-unfruitful, and therefore requires cross-pollination. In the late 1970's, fruit growers in the mid-western U.S.A. became concerned about the failure of 'Delicious' to bear heavy crops of fruit. This led to several studies to establish what factors limit set. In this paper we summarize the results of studies designed to determine the effects of some environmental, physiological, and entomological factors associated with 'Delicious' yield.

The problem of poor yield of 'Delicious' is not new (see Dennis 1979). The cultivar was recognized as a "shy bearer" as early as 1928 (Howlett 1928). Five-year average per acre yields in Michigan were less than half of those for 'McIntosh' in 1964-68 and 1971-75 (Ricks and Karony 1977), and cumulative total yields for 'Delicious', 'Jonathan', and 'McIntosh' over a 22-year were 142, 153, and 178 lb/in^2 (704, 774, and 915 g/cm2) final trunk cross-section, respectively, in a replicated experiment in Michigan (Dennis 1979).

What limits yield? Many possibilities have been suggested, including weather conditions during and after bloom, susceptibility to frost injury, and the effects of flower structure on pollen transfer by bees (see Dennis 1979). Gardner *et al.* (1949) presented data for 'Delicious' fruit set in relation to temperature and solar radiation at approximately 40 sites in the U.S.A. and Canada. They concluded that these two parameters accounted for the differences in fruit set observed from site to site. However, subsequent statistical analysis of their data indicated that correlation coefficients were low and non-significant (Dennis 1979). Data from a subsequent cooperative experiment (Dennis 1981a) confirmed that temperatures from 3 weeks prior to bloom until 3 weeks after petal fall had little bearing upon set (Table I). Although fruit set was significantly correlated with solar radiation prior to and during bloom, the data were too scant to allow firm conclusions to be drawn.

Recent work in England and New York have suggested that temperatures in late winter may affect set (Beattie and Folley 1977; Jackson and Hamer 1980; Lakso 1984). A formula developed by using mean daily maximum temperatures for February, March, and April, with adjustments for additional parameters, predicts yields of 'Cox's Orange Pippin' in England (Jackson and Hamer 1980) and of total yields of all cultivars in New York State (Lakso 1984) with surprising accuracy. The higher the temperatures, the lower the yield. No satisfactory explanation has been offered for this correlation, although some believe that high temperatures may stimulate respiration, thereby reducing the supply of substrates needed for fruit setting.

Several physiological factors can affect fruit set. 'Delicious' trees propagated on MAC (Michigan Apple Clone) 9 and certain other size-controlling rootstocks set a much higher percentage of their flowers than do those propagated on more vigorous stocks (Table II). The strain of 'Delicious' is also important; more than 100 mutants now

TABLE I. Correlation coefficients (r) for fruits per 100 flower clusters vs. heat units as accumulated growing degree days, base 5.6°C (GGD), and solar radiation (g-cal) during various periods relative to bloom from 1978 to 1980. Sixty-four to 73 paired observations were available for GGD, 14 to 23 for g-cal. Asterisks indicate r values significantly different from 0 at $p<0.05$ (*) or 0.01 (**). First flower – "king" flowers open; petal fall – petal fall on "king" flowers (Dennis, 1981a).

Period of accumulation	Correlation coefficients (r)	
	Heat Units (GGD)	Solar radiation (g-cal)
3 weeks prior to first flower	+0.150	+0.783**
5 days beginning with first flower	−0.110	+0.532**
Mean per day from first flower to petal fall	−0.079	+0.319
First week after petal fall	−0.090	+0.392
Second week after petal fall	−0.108	+0.147
Third week after petal fall	−0.157	+0.133
First and second weeks after petal fall	−0.113	+0.353
First through third weeks after petal fall	−0.154	+0.381

TABLE II. Effect of Michigan Apple Clone (MAC) rootstocks upon tree size, flowering and fruit set of 'Delicious' apple at East Lansing, MI (Dennis 1981b).

Rootstock [1]	Trunk circumference in 1987 (cm.)	Buds flowering (per cent) in:		Fruits set per 100 flower clusters in:	
		1978	1980	1978	1980
9	26	87	91	27	14
24	42	51	60	10	2

[1]Difference between rootstocks are significant at the 5% level for all parameters.

exist. Twenty-eight of the most promising strains were planted in Washington, Oregon, British Columbia, Idaho, Indiana, and Michigan in 1980 in a cooperative experiment. Marked differences are evident among strains in both precocity and fruit setting ability, at least in their early years (unpublished).

Pomologists have been searching for years for "magic bullets" in the form of chemicals which can increase set of tree fruits. Some have been effective experimentally, but most have proven ineffective for commercial use. Sprays of the ethylene synthesis inhibitor aminoethoxyvinylglycine (AVG) consistently increase apple fruit set when applied at or shortly after bloom (Williams 1980; Greene 1980; Dennis *et al.* 1983). In a typical experiment, branches of 'Delicious' sprayed with 200 ppm AVG set 26% of their flowers, whereas untreated flowers set only 16% (Table III). Unfortunately, the cost of this chemical, which is produced by a species of *Rhizopus,* is prohibitively expensive. Hopefully, other effective chemicals will be found which will be less costly to produce.

We have seen that 'Delicious' fruit set can be influenced by weather conditions, chemical treatment, rootstock and strain. But are there other problems which specifically limit pollen transfer? In 1947, R.H. Roberts of the University of Wisconsin

TABLE III. Effects of sprays of aminoethoxyvinyglycine (AVG) on fruit set (fruits per 100 flower clusters) of 3 apple cultivars, East Lansing, MI, 1980 (Rahemi 1982).

	Cultivar:		
Treatment	**McIntosh**	**Delicious**	**G. Delicious**
None	33	35	26
AVG, 200 ppm[1]	118	63	58

[1]Treatment effect significant at 5% level in all 3 cultivars.

proposed that the structure of the 'Delicious' flower made it susceptible to "side-working" – extraction of nectar by bees through "basal gaps" between the stamen filaments. The bees could thus obtain nectar without crawling over the top of the flower, and cross-pollination did not occur. Robinson (1979) and Robinson and Fell (1981) extended Roberts' observations, showing that all strains of 'Delicious' examined possessed basal gaps, and that flowers which were side-worked did not set fruit.

Starting with these observations as a base, DeGrandi-Hoffman (1983) developed a computer model for pollination of 'Delicious', including factors for temperature, solar radiation, wind speed, availability of compatible pollen, etc. Her data cast doubt on the role of basal gaps as a factor limiting set. Various apple cultivars bloom at different times; 'McIntosh', for example, begins blooming before 'Delicious', and its flowers have few basal gaps. As 'Delicious' trees in the same orchard begin to flower, time is required for the bees to learn that they can obtain nectar more easily by 'side-working'. By the time they have become adept at that, most of the flowers have already been cross-pollinated (DeGrandi-Hoffman *et al.* 1985).

The pollen grains of apple cultivars can be distinguished from one another by exine patterns as viewed under scanning electron microscopy (SEM). Using this technique, DeGrandi-Hoffman, *et al.* (1984a,b) noted that the stigmata of all flowers examined bore copious amounts of compatible pollen within a few days of anthesis. A second, more surprising discovery was that fruit set appeared to be independent of distance from the pollinizer. For example, in one Michigan orchard 16.4% of the flowers set fruit on 'Delicious' trees adjacent to the 'McIntosh' pollinizer vs. 16.7% on trees 4 rows removed from the pollinizer (DeGrandi-Hoffman *et al.* 1984a,b).

Further experiments demonstrated that all honey bees examined by SEM bore pollen not only of several apple cultivars, but of other species as well (DeGrandi-Hoffman *et al.* 1984a,b), and that viable pollen could be transferred from one bee to another within the hive (DeGrandi-Hoffman *et al* 1986). From these and other observations the inference was drawn that most cross-pollination occurred not by direct bee visitation (tree-to-tree), but by exchange of pollen within the hive by bees which were working different cultivars (bee-to-bee).

The computer model developed by those workers predicts the time at which sufficient pollination has occurred for a commercially acceptable crop. This may allow fruit growers to: a) remove bees before set is excessive, this reducing the need for chemical or hand removal of immature fruits ("thinning"), and/or b) estimate whether fruit thinning will be necessary at all. The model is currently being tested by covering branches with netting at various times during bloom to prevent bee visitation, then evaluating the crop load in comparison with control limbs.

Given the importance of the 'Delicious' apple to North American fruit growers, heavy and regular bearing are essential for high returns. The experiments summarized herein do not support some of the commonly-held views as to why 'Delicious' is a "shy bearer". First, our data indicate no clear relationshiop between fruit set and temperatures during, or immediately before or after bloom. Although the

cultivar is notoriously susceptible to frost injury, non-lethal temperatures do not appear to be a critical factor in fruit set. This does not rule out the possibility that late winter temperatures may affect set, as shown for 'Cox's Orange Pippin' in England. Some evidence was obtained that high solar radiation before and during bloom might be associated with good set; that might be expected, given the importance of carbohydrates in fruit setting.

Our data suggest that some of the concepts of pollination may also need revision. In years when weather conditions limit bee flight, fruit set of 'Delicious' may indeed be better adjacent to pollinizers, but when conditions are favorable pollen transfer does not appear to be a limiting factor so long as the minimum ratio of pollinizers to main cultivar is sufficient at 1:3 (DeGrandi-Hoffman 1983). The above is a logical extension of our observation that most pollen transfer occurs within the hive. Orchardists may find it more convenient to plant solid blocks of one cultivar and place honey bee colonies between blocks. That would greatly facilitate operations which differ from cultivar to cultivar, such as thinning and harvesting.

Literature Cited

Beattie, B.B. and R.R.W. Folley, 1977. Production variability in apple crops. Scientia Horticulturae, 6:271-279.

DeGrandi-Hoffman, G. 1983. The construction, validation, and behavior of a pollination and fruit set model for 'Delicious' apples. Ph.D. Thesis, Michigan State University.

DeGrandi-Hoffman, G., R.A. Hoopingarner and K.K. Baker. 1984a. Identification and distribution of cross-pollinating honey bees (Hymenoptera: Apidae) in apple orchards. Environmental Entomology, 13:757-764.

DeGrandi-Hoffman, G., R.A. Hoopingarner and K.K. Baker. 1984b. Pollen transfer in apple orchards. Tree-to-tree or bee-to-bee? Bee World, 63(3):126-133.

DeGrandi-Hoffman, G., R.A. Hoopingarner and K.K. Baker. 1985. The influence of honey bee "sideworking" behavior on cross-pollination and fruit set in apples. HortScience, 20:397-399.

DeGrandi-Hoffman, G., R.A. Hoopingarner, K.K. Baker and K. Klomparens. 1986. The influence of honey bee (Hymenoptera: Apidae) in-hive pollen transfer on cross-pollination and fruit set in apple. Enviromental Entomology, 15:723-725.

Dennis, F.G., Jr. 1979. Factors affecting yield in apple, with emphasis on 'Delicious'. Horticultural Reviews, 1:395-422.

Dennis, F.G., Jr. 1981a. Limiting factors in fruit set of 'Delicious' apple. Acta Horticulturae, 120:119-124.

Dennis, F.G., Jr. 1981b. Performance of 'Red Prince Delicious' on eight Michigan Apple Clone (MAC) rootstocks in Michigan, 1978-1980. Compact Fruit Tree, 14:55-57.

Dennis, F.G., Jr., D.D. Archbold and C.O. Vecino. 1983. Effects of inhibitors of ethylene synthesis or action, GA 4 + 7. and BA on fruit set of apple, sour cherry, and plum. Journal of the American Society for Horticultural Science, 108:570-573.

Gardner, V.R., T.A. Merrell and W. Toenjes. 1949. Fruit setting in the Delicious apple as influenced by certain post-blossoming enviromental factors. Michigan State Agricultural Experimental Station Special Bulletin, 358 pp.

Greene, D.W. 1980. Effect of silver nitrate, aminoethoxyvinylglycine and gibberellins A_{4+7} plus 6-benzylaminopurine on fruit set and development of 'Delicious' apples. Journal of the American Society for Horticultural Science, 105:717-720.

Howlett, F.S. 1928. Fruit setting in the Delicious apple. Proceedings of the American Society for Horticultural Science, 25:143-148.

Jackson, J.E. and P.J.C. Hamer. 1980. The causes of year-to-year variation in the average yield of Cox's Orange Pippin apple in England. Journal of Horticultural Science, 55:149-156.

Lakso, A.N. 1984. Weather patterns and apple yields. Great Lakes Fruit Growers News, (Sparta, MI), April, pp. 20-21.

Rahemi, M. 1982. Role of ethylene in fruit set of apple. Ph.D. Thesis, Michigan State Univ. 153 pp.

Ricks, D. and S. Karony. 1977. Michigan apple production trends and future predictions. Agricultural Economics Staff Paper 77-24 (April 14, 1977). Michigan State University Department of Agricultural Economics, East Lansing, Michigan. 21 pp.

Roberts, R.H 1947. Notes on the setting of Delicious, 1946. Proceedings of the American Society for Horticulture Science, 50:85-94.

Robinson, W.S. 1979. Effect of apple cultivar on foraging behavior and pollen transfer by honey bees. Journal of the American Society for Horticultural Science, 104:596-598.

Robinson, W.S. and R.D. Fell. 1981. Effect of honey bee foraging behavior on 'Delicious' apple set. HortScience, 16:326-328.

Williams, M.W. 1980. Retention of fruit firmness and increase in vegetative growth and fruit set of apples with aminoethoxyvinylglycine. HortScience, 15:76-77.

POLLINATORS AND POLLINATION REQUIREMENTS OF LOWBUSH BLUEBERRY *(VACCINIUM ANGUSTIFOLIUM* AIT. AND *V. MYRTILLOIDES* MICHX.) AND CRANBERRY *(V. MACROCARPON* AIT.) IN ONTARIO WITH NOTES ON HIGHBUSH BLUEBERRY *(V. CORYMBOSUM* L.) AND LIGNONBERRY *(V. VITIS-IDEAE* L.).

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Proc. ent. Soc. Ont. 118:149-154 (1987)

Introduction

Both the lowbush blueberry (*Vaccinium angustifolium* Ait. and *V. myrtilloides* Michx.) and cranberry (*V. macrocarpon* Ait.) are generally considered to be self-sterile. Information on highbush blueberry (*V. corymbosum* L.) is less definitive and that on lignonberry (*V. vitis-ideae* L.) is scant. All four species are dependent on insects to meet their pollination requirements (see below). The value of honey bees (*Apis mellifera* L.) as pollinators of these crops is variable, depending on variety, conditions, and the presence of other pollinators. The flowers of all, which do not seem to be "preferred" honey bee forage, produce relatively small amounts of nectar and pollen (Shaw *et al.* 1956, Marucci 1967, Shimanuki *et al.* 1967, and below). Yet these plants are attractive to a number of native pollinators, some of which may be managable alternatives to honey bees.

Lowbush Blueberry

Lowbush blueberry plants are perennials, usually less than 30 cm high, which grow best on acidic soils. They propogate from seeds dispersed by animals or rhizomotously from clonal patches. They are grown only for their small, blue, sweet, round berries. Almost all the fruit harvested in Ontario comes from unmanaged and uncultivated plants in the bush and is used for fresh consumption. In other parts of Canada, especially Nova Scotia, New Brunswick, and Quebec, wild lowbush blueberries are commercially managed and are an important, if minor export crop.

The white to pink petals of the flower are fused to form an urceolate, sympetalous corolla which hangs with the opening downwards before and during pollination (Free 1970; McGregor 1976). After pollination, the corolla drops and the floral remains, including the developing ovary, turn skyward (Oldershaw 1970). There are eight to ten stamens around a single longer style. The stamens remain well within the flower but the tip of the stigma may protrude beyond the petals. Pollen is released through tubes on the anthers, which are termed poricidal, and nectar is produced at the base of the corolla. The berry is mature 2-3 months after pollination (McGregor 1976). Berries may contain as many as 65 small seeds.

Blueberry flowers are "buzz" pollinated (Buchmann 1983), that is, because their pollen is contained in the poricidal anthers, they require some vibration by bees for the pollen to be released. Honey bees do not buzz-pollinate (Buchmann 1983), and do not collect pollen from blueberry. Because of the flowers' structure, if bees do not actively collect the pollen they are less likely to become dusted with pollen, and so, are less likely to be effective pol-

linators. That suggests that there is a problem intrinsic to pollination of blueberries by honey bees.

However, because honey bees have proven to be useful pollinators (because high densities can be artificially maintained on crops), they have been widely accepted for pollination of blueberries and less and less attention has been paid to wild bees. It is important to note that many blueberry growers still rely on the large assemblage of wild pollinators known to be associated with the plants (Boulanger *et al.* 1967; Helms 1970; Finnamore and Neary 1978), but insecticide applications have upset the system by decimating populations of wild bees on blueberry fields (Kevan and Collins 1974; Kevan 1975; Kevan and LaBerge 1979) and required growers to import honey bees for pollination.

In general, bumble bees (*Bombus* spp.) are considered to be the most efficient pollinators of blueberry (*ca.* three times more so than honey bees, see Shaw *et al.* 1939) but no serious attempts have been made to manage these bees. Even less work has been done with appropriate solitary bees. Practically nothing is known about the foraging efficiency, behaviour, or importance of blueberry nectar and pollen to the biology of most solitary bees associated with blueberries. A notable exception is the work of Schrader and LaBerge (1978) on *Andrena (Melandrena) regularis* and *A. (M.) carlini* in New Brunswick. Osgood (1972) has documented the soil characteristics of nesting solitary bees associated with lowbush blueberries in Maine, which are similar to those we found from preliminary research near Kirkland Lake, Ontario where the soils of the blueberry fields are sandy, well drained and acidic.

There are other reasons why honey bees may not be effective as pollinators of lowbush blueberries in Ontario. The commercial fields in Ontario are located in the north (i.e. Kirkland Lake area) where their development is relatively recent (see Kevan *et al.* 1986). Year round beekeeping there is considered to be not commercially viable because of the long winters and oftentimes sparse availability of forage. In the summer, some commercial beekeepers move bees to the area, but only where and when there are exceptional populations of nectariferous plants (i.e. not in the vicinity of blueberry fields in bloom). Therefore, in northern Ontario, there are clear reasons to explore the potential for using alternative, native pollinators and encouraging their populations to increase with appropriate management techniques, such as habitat amelioration for nesting sites and other plants at which the bees will forage when blueberries are not in bloom. Preliminary observations from around Kirkland Lake suggest that various ground nesting bees (Andrenidae and Halictidae) may be highly efficient pollinators, as has been suggested for the maritime provinces. However, research is needed to determine methods of encouraging their numbers to meet pollination needs. Andrenids and halictids that we have identified from the flowers of blueberry in northern Ontario include the following: *Andrena (Melandrena) vicina* Smith, *Andrena (Trachandrena) forbesii* Robertson, *Andrena (Trachandrena) sigmundii* Cockerell, *Andrena (Conandrena) bradleyi* Viereck, *Andrena (Thysandrena) w-scripta* Viereck, *Halictus rubicundus* (Christ), *Lasioglossum acuminatum* McG, *Evylaeus rufitarsis* (Lett.), *Evylaeus comagenensis* Kril. We have also recorded *Bombus terricola* Kirby, *B. frigidus couperi* Cresson, *B. vagans* Smith, *Psithyrus ashtoni* Cresson (Apidea) and *Colletes validus* Cresson (Colletidae) as visitors to blueberry flowers near Kirkland Lake.

Until more is known about the biology and assemblage of bees native to the region, honey bees must continue to be used to supplement native pollinators in commercial blueberry fields (Kevan *et al.* 1986).

Cranberry

The cranberry is a low growing, creeping perennial that roots from runners to form a mat (McGregor 1976). Fruiting branches are up to 46 cm high, and year old branches produce fruit. It is grown in moist marshes or bogs which are either natural or artificial (McGregor 1976).

The flowers are white to slightly pink in colour and 0.6-0.8 cm in diameter. The flower hangs downwards with the petals curled back leaving the sporophylls exposed. The stigma

protrudes past the anthers, which are poricidal like those of blueberry. Cranberry flowers must be insect pollinated to set fruit. The pollen of cranberry is dry and will "rain" down on flower visitors (Free 1970; McGregor 1976). Apparently the flower does not need to be buzzed (although it often is by bumblebees) despite the similar construction of its anthers to those of blueberries. The berries mature about three months after pollination.

Honey bees are used to pollinate commercial fields of cranberries. Two and a half strong colonies of honey bees per hectare are recommended to ensure adequate pollination (Stewart 1970; Stewart and Marucci 1970; McGregor 1976). It has been recommended that colonies be left on the marsh for at least four days (Moeller 1979). However, there are varying reports of their actual value as pollinators. Some reports state that honey bees are essential to cranberry pollination. Swenson (1958) even goes so far as to say "no [honey] bees", means "no berries". Other reports indicate that honey bees are of no obvious value (references in Kevan *et al.* 1983). It appears that small to moderately sized marshes, such as are in production in Ontario of a few hectares may not require supplemental pollination and that native pollinators usually provide adequate pollination. Hutson (1925, 1927) expressed the view that honey bees should be used as insurance in those years in which populations of native pollinators are low, as is also suggested by Kevan *et al.* (1983) for the small marshes in the Muskoka area of Ontario. On large marshes, populations of native pollinators may be low and restrict their activities to the margins where adequate habitat for nesting is nearby.

Kevan *et al.* (1983) found bumble bees (*Bombus vagans* and *Bombus terricola*) to be the most important pollinator of cranberry on commercial marshes near Bala, Ontario. Experiments in those marshes showed that cranberries which were openly available for pollination by bumble bees had increased yields, larger fruit and more seeds per berry than did cranberries to which only smaller insects had access (Kevan, unpublished). The results of past research point out the value of bumble bees in cranberry pollination. Therefore, their numbers and use should be encouraged by habitat amelioration for nesting sites and other plants that sustain bumblebees. Solitary bees were few on the marshes near Bala and it was concluded that their value was small (Kevan *et al.* 1983). Large numbers of syrphids (*Toxomerus* spp.) were also observed on the flowers and it appears that they may be more important than their small size suggests (Kevan *et al.* 1983; Kevan unpublished). In general, the diversity of insect pollinators on cranberry is low (Kevan *et al.* 1983; Roberts 1979; MacKenzie and Winston 1984).

Highbush Blueberry

Highbush blueberry (*Vaccinium corymbosum*) is grown on a few farms in southern Ontario, especially along the north shore of Lake Erie and in the Niagara area. The plants are taller than those of the lowbush blueberries and grow to about 1 meter or more. They are usually planted in rows. The flowers are similar in structure and colour to those of lowbush blueberries.

The literature on pollination is confusing because some authors have used the term self-fruitful to mean fruitful by cross-pollinations within a single variety, but others have used the term to mean within the same individual plant. The issue of self-fruitfulness is still not resolved and Shutack and Marucci (1966), in summarizing the conflicting information on cross and self-pollination, conclude that "Solid block plantings of all standard varieties are yielding satisfactory crops, but it is doubtful that they are producing to their full potential".

Although highbush blueberry plants may be self-fertile, they certainly require insect pollinators for pollination and fruit-set, as was discovered very early (Coville 1910). Some varieties, especially those with long, narrow, corollas are better pollinated by bumblebees than by honey bees, but other varieties seem to be well serviced by the latter (see Shutak and Marucci 1966). Different varieties of highbush blueberries have flowers which differ in their attractiveness to pollinators (Dorr and Martin 1966) and experiments with honey bees have indicated that the sugar content of the nectar is important (Rajotte and Roberts

1979). The demise of native pollinators for highbush blueberries, caused by extensive use of insecticides and habitat destruction, has caused concern and necessitated the use of honey bees (Rajotte and Roberts 1979). On brief excursions to small fields of flowering highbush blueberries in the Niagara area in 1986 and 1987, we have found remarkably few native pollinators. It is clear that more documentation on pollination and pollinators of highbush blueberry is needed as a basis for guidelines for the management of plants to yield to their potential and to make their culture economically attractive.

Lignonberry

The lignonberry or mountain cranberry, *Vaccinium vitis-ideae*, is similar in its growth habit and floral characteristics to the lowbush blueberries, except that the flowers are more open than those of the blueberries. It is not harvested commercially in North America, where it is widespread in the boreal regions. In northern Europe, especially Scandinavia, the berries are of sufficient economic importance as a harvestable wild fruit that a little work on their pollination has been done. Ångeby (1979) explains the value of native pollinators, such as bumble bees and solitary bees to the crop, but advocates the use of honey bees to increase yields of berries on newly cut-over forest, where the plants grow vigorously but where populations of native pollinators are low, and for assuring pollination in years when there are few native pollinators.

Lignonberries are now imported from Scandinavia into Canada and are available as preserves in grocery shops and in gourmet restaurants. Their potential as an economically harvestable wild berry has not been explored. Perhaps the plants could be encouraged by similar management practices as are used for lowbush blueberries.

Conclusions

Honey bees are not the ideal pollinator of any of the ericaceous fruit crops. Bumble bees appear to be more efficient pollinators of all, but much research is needed for their management (Plowright and Lavery 1987). Solitary bees are also a plausible alternative for blueberry pollination, but basic research into their general biology and foraging behaviour is needed before firm recommendations can be made.

References

Ångeby, O. 1979. *Apis mellifera* as pollinators of *Vaccinium myrtillus* and *Vaccinium vitis ideae*. Proceedings of the IV International Symposium on Pollination, Oct. 11-13, 1978. Maryland Agriculture Experiment Station Miscellaneous Publication, 1: 165-169.

Boulanger, L.W., G.W. Wood, E.A. Osgood, and C.O. Dirks, 1967. Native bees associated with lowbush blueberry in Maine and eastern Canada. Technical Bulletin of the Maine Agriculture Station, No. 26 and Canada Agriculture Research Station, Fredericton, New Brunswick. xxx pp.

Buchmann, S.L. 1983. Buzz pollination in angiosperms. pp. 73-113 *In:* C.E. Jones and R.J. Little (Eds.) Handbook of Experimental Pollination Biology, Scientific and Academic Editions, Van Nostrand, New York.

Coville, F.V. 1910. Experiments in blueberry culture. United States Department of Agriculture Bulletin, No. 193.

Dorr, J. and E.C. Martin, 1966. Pollination studies on the highbush blueberry *Vaccinium corymbosum* L. Quarterly Bulletin of the Michigan Agricultural Experiment Station, 48:437-488.

Finnamore, B. and M.E. Neary, 1978. Blueberry pollinators of Nove Scotia, with a check list of the blueberry pollinators of eastern Canada and northeastern United States. Annales de la Societe Entomologique du Quebec, 23: 168-181.

Free, J.B. 1970. Insect Pollination of Crops. Academic Press, London and New York. 544 pp.

Helms, C.W. 1970. Bees and blueberries. Canadian Journal of Zoology, 48:185.

Hutson, R. 1925. The honeybee as an agent in the pollination of pears, apples and cranberries. Journal of Economic Entomology, 18: 387-390.

Hutson, R. 1927. The use of honeybees as pollinating agents on cranberry bogs. Proceedings of the American Cranberry Growers' Association Convention, 57th Annual Convention, pp. 10-11.

Kevan, P.G. 1975. Forest applications of the insecticide fenitrothion and its effects on wild bee pollinators (Hymenoptera:Apoidea) of lowbush blueberries (*Vaccinium* spp.) in southern New Brunswick, Canada. Biological Conservation, 7:301-309.

Kevan, P.G. and M. Collins, 1974. Bees, blueberries, birds and budworms. Osprey (Newsletter of the Newfoundland Natural History Society), 5:54-72.

Kevan, P.G. and W.E. LaBerge, 1979. Demise and recovery of native pollinator populations through pesticide use and some economic implications. Proceedings of the IV International Symposium on Pollination, Oct. 11-13, 1978. Maryland Agriculture Experiment Station Special Miscellaneous Publication, 1: 489-508.

Kevan, P.G., R.M. Gadawski, S.D. Kevan and S.E. Gadawski, 1983. Pollination of cranberries, *Vaccinium macrocarpon*, on cultivated marshes in Ontario. Proceedings of the Entomological Society of Ontario, 114:45-53.

Kevan, P.G., N.A. Mohr and G. Gambles, 1986. Bees for blueberries in northern Ontario. The Sting (Newsletter of the Ontarion Beekeepers' Association), 3(4): 17-18.

MacKenzie, K.E. and M.L. Winston, 1984. Diversity and abundance of native pollinators on berry crops and natural vegetation in the lower Fraser Valley, British Columbia. Canadian Entomologist, 116:965-974.

Marucci, P.E. 1967. Cranberry pollination. American Bee Journal,. 107:212-213.

McGregor, S.E. 1976. Insect pollination of cultivated crop plants. USDA Agric. Handbook No. 496.

Moeller, F.E. 1979. How long must honeybees be present to effectively set a crop of cranberries? Proceedings of the IV International Symposium on Pollination, Oct. 11-13, 1978. Maryland Agriculture Experiment Station Special Miscellaneous Publication, 1:171-173.

Oldershaw, D. 1970. The pollination of high bush blueberries. *In:* The Indispensible Pollinators. Arkansas Agriculture Extension Service Miscellaneous Publication, 127:107-232.

Osgood, E.A. 1972. Soil characteristics of nesting sites of solitary bees associated with low-bush blueberries in Maine. Maine Life Sciences and Agriculture Experimental Station Technical Bulletin, No. 59. 8 pp.

Plowright, R.C. and T.M. Laverty 1987. Bumblebees and crop pollination in Ontario. Proceedings of the Entomological Society of Ontario, 118: 155-160.

Rajotte, E.G. and R.B. Roberts, 1979. Nectar sugar dynamics of highbush blueberrry cultivars (*Vaccinium corymbosum* L.). Proceedings of the IV International Symposium on Pollination, Oct. 11-13, 1978. Maryland Agriculture Experiment Station Special Miscellaneous Publication, 1:157-164.

Roberts, R.B. 1979. Energetics of cranberry pollination. Proceedings of the IV International Symposium on Pollination. Oct. 11-13, 1978. Maryland Agriculture Experiment Station Special Miscellaneous Publication, 1:431-440.

Schrader, M.N. and W.E. LaBerge, 1978. The nest biology of the bees *Andrena (Melandrena) regularis* Malloch and *Andrena (Melandrena) carlini* Cockerell (Hymenoptera: Andrenidae). Biological Notes of the Illinois Natural History Survey, No. 108.

Shaw, F.R., J.S. Bailey, and A.I. Bourne, 1939. The comparative value of honeybees in the pollination of cultivated blueberries. Journal of Economic Entomology, 32:872-874.

Shaw, F.R., W.M. Shaw and J. Weidhaus, 1956. Observations on the sugar concentration of cranberry nectars. Gleanings in Bee Culture, 84:150-151.

Shutak, V.G. and P.E. Marucci, 1968. Plant and fruit development. Chapter 8 of P. Eck and N.F. Childers (eds), Blueberry Culture, Rutgers University Press, New Brunswick, New Jersey. pp. 179-198. 378 pp.

Shimanuki, H., T. Lehnert and M. Strickler, 1967. Differential collection of cranberry pollination by honeybees. Journal of Economic Entomology, 60:1031-1033.

Stewart, J.D. 1970. Cranberry pollination in New Jersey. *In:* The Indispensible Pollinators. Arkansas Agriculture Extension Service Miscellaneous Publication, 127:181-184.

Stewart, J.D. and P.E. Marucci, 1970. Honey bees for cranberry pollination. New Jersey Agriculture Experimental Station Circular, 588-A, 4pp.

Swenson, A.A. 1958. Bees and cranberries – a winning combination. American Bee Journal, 98:64.

BUMBLE BEES AND CROP POLLINATION IN ONTARIO

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Contribution No. 5 to the Workshop **'Alternate Pollinators for Ontario Crops'** held at the University of Guelph, 12 April, 1986.

Proc. ent. Soc. Ont. 118:155-160 (1987)

Introduction

In this paper we discuss the role of bumble bees as pollinators of agricultural crops in Ontario. After a brief description of their life cycle, we list the conditions under which bumble bees can supplement or (on certain crops) replace honey bees as pollinating agents. We then compare and contrast the two main techniques that have been proposed to augment natural populations of bumble bees: habitat modification and artificially rearing colonies. We conclude that, except in special circumstances, rearing colonies artificially is prohibitively expensive. We stress the need for basic research on habitat modification, especially that involving the provision of an unbroken sequence of food sources for bumble bee colonies throughout their development.

Bumble bees are one of the most common native pollinators in Ontario. They occur in all parts of the province, from the Great Lakes to Hudson's Bay. There are 16 species represented in Ontario. Bumble bees are important pollinators of many native plants and a wide variety of crops including red clover, alfalfa, blueberries, fruit trees, and several vegetables. The bees annually produce colonies which reach a peak size, depending on species and conditions, of 50-100 individuals in mid- to late-summer.

Life Cycle

The life cycle of a bumble bee colony begins with a mated queen which has overwintered in an underground hibernation chamber, hollowed out in the soil or in the debris of a rotted tree stump. Such an overwintered queen, emerging to the warmth of an early spring day, is the link between generations. After emergence, she divides her time between feeding from flowers and searching for a suitable nest site, usually an old mouse or vole nest. Having selected her nest and carried out necessary housekeeping duties, such as arranging the nest material, she then gathers a quantity of pollen from spring flowers. She eats some and the rest she fashions into a compact lump on the floor of the nest cavity.

Next, the queen spends hours incubating the pollen lump, metabolizing sugars contained in the nectar that she has imbibed, while rhythmically pulsing her abdomen to generate body heat. This activity dries out the nest material immediately surrounding the cavity. Also, the queen begins to produce thin slivers of wax from between the segments on the underside of her abdomen. She uses this wax to construct egg cells (usually between 6 and 15 in number) on the surface of the pollen lump. Into each cell the queen lays a single egg (in most cases, although some species are exceptional in that their queens lay several eggs per cell in the first brood). The eggs, which will eventually give rise to the first brood of worker bees, hatch after about 5 days, during which time the queen continues to incubate them. At the same time, she uses the wax that she secretes to fashion a honeypot for the storage of food reserves.

The first brood larvae are fed with both honey and pollen, which the queen collects from flowers during periodic foraging excursions. The larvae generally take about a week

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to reach final size, after which they spin silken cocoons in preparation for pupation. The queen then builds more wax egg cells, this time on the top surfaces of the first brood cocoons. These new cells contain the second brood eggs, which may number 40 or more. Most species lay several eggs per cell in the second, and subsequent, broods.

Following a further period of incubation, lasting 10 days or so, the adult workers of the first brood, which are female like their mother but much smaller in size, begin to emerge from their cocoons. At this point, the bumble bee nest becomes a true insect society: soon the workers take over all the duties of the hive except for egg-laying, which remains (at least until the social order breaks down late in colony development) the sole prerogative of the queen.

After several successive broods of workers, the colony begins to rear males and young queens. After this no more workers are produced. The males leave the colony, never to return, but the young queens remain within the nest except when making one or more short excursions to find a mate. Eventually, having gorged themselves on honey and pollen to use to build up their fat bodies, the mated young queens leave the colony and search for a suitable site in which to dig a hibernaculum. Meanwhile the colony, its resources spent and its few remaining inhabitants old and worn, gradually declines and eventually perishes.

For more details, excellent accounts are given in Sladen (1912), Plath (1934), Free and Butler (1959), Alford (1975), and Heinrich (1979).

The role of the bumble bees in crop pollination

In general, bumble bees assume an important role as pollinators under conditions in which honey bees do not do a very good job (see below). These are probably the only circumstances where it might be economical to increase numbers of bumble bees in the field.

Bumble bees are well known for their ability to forage at lower temperatures than can honey bees (Heinrich 1979). Therefore, they tend to become important in areas, or at times of the year, where honey bee activity is reduced - for example, in northern regions or during wet, rainy years. Bumble bees pollinate a wide variety of crops that are commercially pollinated by honey bees. These include apples, peaches, and other fruit trees. For such crops, it may be worthwhile to have adequate bumble bee populations to serve as a backup in case of inclement weather or the outbreak of honey bee diseases.

Bumble bees are intrinsically more efficient than honey bees at pollinating some crops. For example, because honey bees have relatively short tongues (*ca.* 5 mm), plants with long corolla tubes, such as red clover, are not attractive to them. Bumble bee species in Ontario have tongue lengths which range from 5-12 mm and can reach nectar in plants whose flowers have long corolla tubes.

Then again, some crops, which offer only pollen to their insect visitors, require a technique known as 'buzz pollination' in which bees must release pollen by making high frequency vibrations while they grasp the anthers or other parts of the flower. Honey bees appear to be incapable of collecting pollen in this way and so are ineffective pollinators of buzz pollinated crops (which include tomatoes, potatoes grown for seed, eggplant, peppers, and other members of the family Solanaceae).

Augmenting bumble bee populations

We now consider how bumble bee numbers might be increased in the neighbourhood of a crop. We discuss, first, measures to encourage high natural populations and secondly, the use of artificial rearing techniques to provide an immediate supply of pollinating insects.

1. **Habitat Modification.** Populations of bumble bees probably have been greatly reduced by current agricultural practices, which, even when insecticides are not used, tend to deprive them of both suitable nesting sites and a continual supply of forage sources. In the vicinity of Vineland, Ontario, for example, Boyle and Philogène (1983) reported

sighting only 5 bumble bees in the entire course of a 3-year census of orchard pollinators, during which a total of 271.5 hrs of observation were made. Our own observations (Plowright, unpublished data) also suggest that populations of bumble bees have been severely depleted in parts of the Niagara Peninsula.

Bumble bee queens usually use abandoned rodent nests as places to start their colonies, so any modification of farming technique that permits the presence of mice or voles (such as leaving strips of undisturbed land adjacent to fence rows), could possibly act to increase local population densities of bumble bees. Unfortunately, given the destructive potential of many rodents, such modifications would probably require other special measures, such as protecting fruit trees with tree-wraps to prevent increased levels of damage – which might otherwise more than cancel out the benefits resulting from improved pollination.

However, there are grounds for believing that the sizes of bumble bee populations are held down less by lack of suitable nest sites than by shortage of food. We recognize that bumble bee colonies (even more than honey bee colonies, which can to some extent survive on stored food reserves) are crucially dependent on an uninterrupted sequence of adequate forage sources throughout the entire course of their active season. This is vividly illustrated in some parts of rural Ontario, where a dearth of forage plants suitable for bumble bees often occurs in early June. In such areas we have repeatedly seen large numbers of bumble bee queens, many in evident distress, crowded on garden varieties of honeysuckle, which apparently represented the only available food sources in the area.

In our opinion, exploring techniques for providing wild bumble bees (and, indeed, other wild bee species) with a continual supply of suitable forage remains one of the most important neglected areas in apicultural research. The only work of this kind with which we are familiar is that of Nelson Pomeroy in New Zealand (see below). Even simple measures deserve investigation, such as providing willows for queens in early spring and leaving dandelions as a later source of pollen. However, we stress that the most essential component of a program to augment bumble bee forage sources is that the availability of flowers be uninterrupted. Ideally, one would hope to be able to plan a series of successively blooming plant species right up to the time that the crop, for which the pollinating bumble bees are intended, itself begins to bloom. If some or all of these flower species are actual crops, then so much the better: for example, orchard trees followed by mustard, followed in turn by red clover grown for seed.

2. **Domestication.** Bumble bee colonies have been reared in captivity since the 19th century and, from time to time, it has been suggested that domestication could provide a method for increasing the number of bees available as pollinators. Typically, the domestication process begins with the capture of wild bumble bee queens in the spring, soon after they have emerged from hibernation. Unfortunately, this practice suffers from the fact that captive colonies from queens caught locally in the spring seldom achieve maximum size by the time that they are required for crop pollination. To circumvent this problem attempts have been made, with mixed success, to carry mated queens in captivity over the winter. A more exotic solution might be to start colonies from bumble bee queens imported in late winter from more southern regions. We have found that such imported insects usually travel well and frequently produce large and early colonies.

In most rearing methods the queens are totally confined, with or without nest material, and have access to honey and pollen supplied by the experimenter. Alternatively, the queens may be allowed to collect their own food from flowers placed in a flight cage. In our laboratory, we use a standardized technique based upon the use of upholsterer's cotton as a nesting material, as described in Plowright and Jay (1966). We have modified the original procedure only in two respects: (1) we now use Teflon feeding bars in place of glass gravity feeding tubes, and (2) we have learned to recognize that many queens, rather than laying their eggs on the pollen lump supplied by us, prefer to start their colony-founding activities by hollowing out a cavity in some other part of the nest material. When that happens, we break about half a pollen lump into several pieces and place them on the floor of

the queen's new cavity. In most cases, provided that this is done soon enough, the queen uses the pollen fragments as the substrate for the cells in which she lays her first-brood eggs.

Over the past 20 years we have reared several thousand bumble bee colonies, representing over 50 of the world's 200-300 species. Rearing success varies widely, both from species to species (we consistently attain a 90% efficiency for *Bombus bimaculatus* Cr., for example, as compared to less than 10% for *B. ternarius* Say) and from year to year. Overall, we estimate that we achieve a success rate, defined as the percentage of queens installed in nest boxes that eventually rear first-brood workers, of about 50%.

Based upon our recent rearing data we are able to estimate in 1986-dollars, the unit cost of rearing bumble bee colonies of various common Ontario species (Table I).

These totals, each of which represents the cost of rearing a colony through to the stage at which it is ready for setting out in the field (i.e. a few days after the first brood workers have emerged), do not include (1) capital outlays - such as nest-boxes, feeding bars, etc., (2) rental of rearing room space, heating etc., (3) The labour involved in either catching the queen bees in the field or, alternatively, bringing them through the winter in artificial hibernation, and (4) costs of monitoring and caring for the colonies after they have been placed in the field.

TABLE I. Unit costs (in 1986 dollars) of rearing colonies of several common species of bumble bee from Ontario.

Species	Labour ($4.00/hr.)	Supplies (Cotton, honey, pollen)	Total
bimaculatus	$1.64	$0.38	$2.02
borealis	$2.34	$0.62	$2.96
fervidus	$3.10	$1.44	$4.54
griseocollis	$1.52	$0.36	$1.88
vagans	$1.82	$0.50	$2.32

With technical improvements, it should be possible to reduce these costs, but we doubt whether it will ever be possible to bring the total (i.e. including the extra components mentioned above) rearing cost for any of our Ontario bumble bee species much below $2.00 per colony. To make the picture even more depressing, we must also point out that the quality of the product obtained for these prices leaves much to be desired. One is doing well if the maximum size of the colonies set out in the field achieves an average of 50 workers. Furthermore, after placement in the field, some colonies are always lost by starvation, parasitism by cuckoo bees (*Psithyrus* spp.), or destruction by wax moths, skunks, etc.

Given those data, together with the fact that a single honey bee colony contains tens of thousands of worker bees, we believe that it is unlikely that domestication of bumble bee colonies will ever play a major part in replacing honey bees as pollinators of field crops in southern Ontario. However, the picture is rather different in some other parts of the world. In New Zealand, for example, the kiwifruit is a crop of great economic importance. Kiwifruit flowers are normally pollinated by honey bees, but in some areas the weather is often too cool and too wet for these insects to perform adequately. It seems that the conditions call for the services of bumble bees, especially the common species, *Bombus terrestris* L., which was introduced to New Zealand from Britain. In a cooperative project between Massey University and the kiwifruit growers, our former colleague at University of Toronto, N. Pomeroy, has been developing what is certainly the world's largest bumble bee domestication facility. The research aims to bring the labour costs involved in rearing colonies (from either spring-caught or artificially hibernated queens) down to a point where

it will be possible to set out 10,000 colonies of *B. terrestris* annually in each kiwifruit growing area. It should be noted that this ambitious 5-year research project does not seek to replace honey bees as the major pollinator of kiwifruit, but merely to use bumble bees as an auxiliary force in areas where providing them is cost effective. We note that the same cool conditions that limit the effectiveness of honey bees as pollinators of kiwifruit also characterize, at least in some years, northern Ontario and other parts of Canada where blueberries and cranberries are produced commercially (see Kevan *et al.* 1984, Mohr and Kevan 1987).

Domesticated bumble bees can also play a useful role as pollinators in greenhouses. Bumble bees, unlike honey bees and most other bee species, take well to foraging in greenhouse conditions. The work of Dr. Ernst Horber at Kansas State University provides a model for this type of undertaking. Horber (1971) used bumble bees to perform cross pollinations in an alfalfa and red clover breeding program. Males, which cannot sting, were removed from colonies reared in captivity and then released in cages containing the plants. Presumably greenhouse crops, such as tomatoes, cucumbers, etc., would also benefit from this technique. In our laboratory we have found that large numbers of male bumble bees can conveniently be reared from artificially hibernated queens that have not been mated. Such queens will start colonies in captivity in the normal way except that, because their eggs are unfertilized, their progeny are all male. We find that if these queens are given a few young worker bees (taken from a normal colony) to help them, each can rear up to 200 males before she becomes old and feeble. Another attractive feature of this procedure is that if one clips the wings of the queen and her adopted workers, it is possible to arrange the nest box so that only the males can fly from the colonies to take up their pollinating duties in the greenhouse.

Prospects for the future

On the basis of what we have written above, we do not consider that, except in special circumstances (e.g. for greenhouse crops), rearing bumble bees in captivity presently has any useful role to play for crop pollination in Ontario, or indeed in Canada as a whole. Where the action is, or more accurately, where it *should* be, is in carrying out habitat improvement programs in order to raise the level of wild populations of bumble bees. This is presently an uncharted area, and is likely to remain so until some government agency decides to support the required basic research. We strongly believe that one key component in a successful program to increase natural bumble bee densities must be the provision of continuously blooming sequences of forage plants.

Although we are unaware of any current research programs on habitat improvement for bumble bees, one aspect of Pomeroy's work on bumble bees and kiwifruit pollination (see above) should be mentioned in this context. Pomeroy (personal communication) has successfully used plantings of flowering radish to sustain his artificially reared colonies of bumble bees between the time that they are first set out in the field and the blooming period of the kiwifruit crop. According to his estimates, one hectare of radish bloom can support up to 400 developing colonies of *B. terrestris*. This hints, we suggest, at the tremendous impact on wild bumble bee populations that might be expected to result from a well designed program for forage enhancement.

References

Alford, D.V. 1975. Bumblebees. Davis-Poynter, London. 352 pp.

Boyle, R.M.D. and B.J.R. Philogène 1983. The native pollinators of an apple orchard: variations and significance. Journal of Horticultural Science, 58: 355-363.

Free, J.B. and C.G. Butler 1959. Bumblebees. Collins, London. 208 pp.

Heinrich, B. 1979. Bumblebee economics. Harvard University Press, Cambridge, Mass. 245 pp.

Horber, E. 1971. Bumblebees as pollinators in the breeding of alfalfa and red clover. Report of the Joint Session of the Twelfth Central Alfalfa Improvement Conference, St. Louis, Missouri, pp. 17-22.

Kevan, P.G., R.M. Gadawski, S.D. Kevan, and S.E. Gadawski 1984. Pollination of cranberries, *Vaccinium macrocarpon*, on cultivated marshes in Ontario. Proceedings of the Entomological Society of Ontario, 114: 45-53.

Mohr, N.A. and P.G. Kevan 1987. Pollinators and pollination requirements of lowbush blueberry (*Vaccinium angustifolium* Ait. and *V. myrtilloides* Michx.) and cranberry (*V. macrocarpon* Ait.) in Ontario with notes on highbush blueberry (*V. corymbosum* L.) and ligonberry (*V. vitis-ideae* L.). Proceedings of the Entomological Society of Ontario, 118: 149-154.

Plath, O.E. 1934. Bumble bees and their ways. MacMillan, New York. 201 pp.

Plowright, R.C. and S.C. Jay 1966. Rearing bumble bee colonies in captivity. Journal of Apicultural Research, 5: 155-65.

Pomeroy, N. and R.C. Plowright 1980. Maintenance of bumble bee colonies in observation hives (Hymenoptera: Apidae). Canadian Entomologist, 112: 321-26.

Sladen, F.W.L. 1912. The humble-bee, its life history and how to domesticate it. MacMillan, London. 283 pp.

THE ALFALFA LEAFCUTTING BEE, *MEGACHILE ROTUNDATA*, AND ALFALFA SEED PRODUCTION IN TIMISKAMING DISTRICT, NORTHERN ONTARIO

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Contribution No. 6 to the Workshop **'Alternative Pollinators for Ontario's Crops'** held at the University of Guelph, 12 April, 1986.

Proc. ent. Soc. Ont. 118:161-165 (1987)

Introduction

Alfalfa is the most important forest legume in Ontario and was, at one time, harvested extensively for its seed. Now Ontario produces less than 1% of its more than 1.7 million kg requirement and the value of alfalfa seed imported into Ontario is about $8.5 million (Skepasts *et al.* 1987). Most of Canada's alfalfa seed (*ca.* 3.3 million kg) is produced in the prairie provinces. Even so, about 2.6 million kg of alfalfa seeds are imported into Canada annually. Much of the rapid increase in alfalfa seed production, from less than 1 million kg per year in the 1970's, can be attributed to the domestication of an effective pollinator, the alfalfa leafcutting bee, *Megachile rotundata* Fabricius (Hymenoptera: Megachilidea) and its introduction into Alberta in 1962 (Hobbs 1962). The management of leafcutting bees for alfalfa pollination has become an important component of the apicultural industry in the prairie provinces, the northwestern United States, and elsewhere (Free 1970; McGregor 1976).

Alfalfa is dependent on insects for pollination (Free 1970; McGregor 1976). Honey bees (*Apis mellifera* L.) are not effective pollinators under most circumstances because they tend to forage poorly at alfalfa and appear to avoid the powerful tripping mechanism of the flowers (Tysdale 1940; Pederson *et al.* 1972). The apparently accidental introduction of *M. rotundata* into North America in the late 1930's (Mitchell 1937; Krombein 1948; Bohart 1962; Pederson *et al.* 1972) provided a tractable pollinator at a time when agriculture was fast changing towards large scale plantings of crops. Presumably, before that various native bees provided pollinator services for alfalfa on small fields with plenty of adjacent nesting sites.

At first it was assumed that *M. rotundata* would be useful only in the southern prairies of Canada where the long, warm, sunny days provided sufficient flying time for pollination by those bees (Hobbs 1973). At least 350 h of daylight with temperatures of 20.6 C or more were originally thought to be required (Hobbs 1967). The results of research done in the 1960's in Ontario were not promising and the shortage of flying time was cited as the limiting factor (Kukovica 1966). However, in recent years the selection of *M. rotundata* for tolerance to cool weather has produced strains which are effective pollinators in northern Alberta, Saskatchewan and Manitoba (Hobbs 1976; Pankiw *et al.* 1979; Richards 1984; Pankiw 1987). For example, Pankiw (1987) has found that in the Peace River area of Alberta as little as 190 h of daylight with temperatures above 20.6 C are enough to allow M. rotundata to effectively pollinate alfalfa there.

With the considerations of the value of alfalfa seed to Ontario, the possibility of using cool-tolerant strains of *M. rotundata* for pollination, the similarity of the temperatures during the growing season in Timiskaming with those in parts of western Canada where

alfalfa is grown for seed, and the agricultural potential of the clay-belt of northern Ontario, a four-year project on alfalfa seed production, based at New Liskeard, was started in 1983. In this report, we discuss only the research concerned with pollination and *M. rotundata*. More details of that and other aspects our research are given in Skepasts *et al.* (1984, 1985, 1987).

Materials and Methods

Two study sites were established in 1983. One was located at the New Liskeard College of Agricultural Technology (NLCAT) and the other was at the Bowmanlea Farm, near Thornloe. For the first year, at each site two plots of 2 ha each were chosen on existing alfalfa (Iroquois) stands. At the same time two plots of 4 ha each were established. These were seeded with Canada Foundation No. 1 Minto alfalfa. In 1983 one plot at each site was seeded at 71 cm, 89 cm, and 107 cm row spacing in a triplicated randomized block design. In 1984, the other plot at each site was seeded similarly, as well as at 18 cm row spacing, and in the same design.

Four leafcutting bee nesting shelters were positioned on each 4 ha plot to provide pollination of the crops. Two types of shelter were used: an "A"-frame and a square type. The shelters were covered with ultraviolet resistant polyethylene sheeting and opened to the south east to benefit from the warmth of the morning sun. A total of 105 and 51 nesting boxes were distributed among the eight shelters at each of NLCAT and Thornloe, respectively.

Cocoons of leafcutting bees were obtained initially from producers in Saskatchewan and from Agriculture Canada, Beaverlodge, Alberta. From 1984 on we were able to provide some of the bees needed from production on our own fields. At each site we provided the recommended 50,000 cocoons per ha (Pederson *et al.* 1972; Fairey and Lieverse 1984).

The cocoons were placed onto incubation trays on about 8 June and kept at 29.5 C and a relative humidity of 60 to 70%. Male bees started to emerge about two weeks later, and females five days after that. The temperature of the incubation room was readjusted to retard hatching if poor weather was delaying the blooming of the alfalfa. The bees were placed on the fields when the alfalfa had about 5 to 10% bloom. After about a week most of the adult bees had emerged and remaining cocoons and leaf debris were collected and destroyed.

The nesting boxes were collected from the beginning of July or August (depending on the year) when 75% of the tunnels were filled. The boxes were then stored at 18.5 C until the cocoons were harvested and placed in storage for the winter (see Hobbs 1973; Richards 1984; Skepasts *et al.* 1985). The numbers of cocoons harvested was recorded.

To obtain precise yields of seed, four randomly selected one m^2 plots were harvested by hand and the results were recorded for each row spacing and replication. Also, similar plots at 5, 10, 20, and 40 m distance north, south, east and west of the leafcutting bee shelters were hand harvested at each site. Machine harvesting was also done in relation to other aspects of the research project (see Skepasts *et al.* 1985).

Results

Production of alfalfa seed

The yield of seeds from alfalfa which was harvested by combine harvester varied greatly from year to year. In 1983, 331 kg/ha of seed, cleaned to certified standard was harvested, but in 1984 and 1985 the yields were only 31.9 and 71.2 kg/ha respectively. In 1986, yields were much better, at 195 kg/ha (Skepasts *et al.* 1987).

Production of leafcutting bees

In 1983, the project produced 2.5 times as many cocoons as had been initially placed on the fields: over 500,000 cocoons were harvested. Both sites, NLCAT and Thornloe had similar increases of 2.62 and 2.39 times respectively (Skepasts *et al.* 1984). However, in

1985 the average harvest was 55.9% of what was placed on the fields: on only one field with newly imported cocoons from northern Saskatchewan was there an increase (16.3%), which, from the viewpoint of the source of the bees was offset by 11.3% decline on another field stocked with those bees (Skepasts *et al.* 1985). The 1984 results were also disappointing with the highest increase being only 11%. In 1986, greater success was achieved with a modest increase of 14.7% (Skepasts *et al.* 1987).

Effects of distance and direction from shelter on seed-set

In 1983, there was no significant difference between the amounts of seed harvested at different distances (5, 10, and 20 m were used) and directions from the leafcutting bee shelters. The average yields were 976 kg/ha and 590 kg/ha at NLCAT and Thornloe respectively (Skepasts *et al.* 1984). However, in 1985, when distances up to 40 m were used with only two directions (north and south) there was a tendency for yields to be greater closer to the shelters and especially on the south side. Seed yields were generally low, ranging from 73.2 to 451.5 kg/ha with an average of only 227.3 kg/ha. Details of our results are given in Skepasts *et al.* (1985) and we are cautious about ascribing any significance to the small differences we measured.

Comparisons of shelter types

In 1985, we attempted to determine if the type of shelter ("A"-frame or square) affected seed-yield. We used plots in which the plants had been sowed at 89 cm row spacing. We found no difference; the average seed-yield for plants within 40 m of the "A"-frame was 227.5 kg/ha and was 227.0 kg/ha within 40 m of the square shelters (Skepasts *et al.* 1985).

Discussion

The success of summer seed production in alfalfa in Tamiskaming has been closely related to the summer weather. In 1983, the summer was warm and dry and production was high. Conditions in 1986 were similar in respect of the lower than average rainfall and production was fairly high. However, in 1984 and 1985 the summers were wet and cool and alfalfa seed production was very low. The production of cocoons of leafcutting bees exactly paralleled those results, as would be expected given that alfalfa is pollinated mainly by those bees and that they require relatively warm, sunny, and dry conditions to forage and provision their nests.

From our results on the type of shelter, and the distance and direction from the shelter on seed production, it seems that pollination is more or less unaffected. However, the effects of distance and direction may be important when the weather is poor. From a practical standpoint, the type of shelter may be important: the square type are easier to work in and around, whereas the "A"-frame type is lighter, easier to move and build, and requires less material to make.

From our results to date, it is difficult to estimate the financial returns that might be expected from alfalfa seed production in Tamiskaming. The wide variation in yields we obtained over four years suggests that growing alfalfa for seed in the area may be risky. Nevertheless we feel that the production of alfalfa seed in Ontario, and in northern Ontario, could develop into a worthwhile industry. Although the initial expenses of bees, shelters, incubator and storage chambers, and other equipment place a fairly high fixed cost on start-up, we estimate that seed production at 125 kg/ha is the break-even yield. From the four years of our study the total costs of producing alfalfa seed on our study sites came to $1845/ha but income was 25 % higher at $2294/ha (Skepasts *et al.* 1987). Further research on improving harvesting, e.g. by use of dessicants (see Skepasts *et al.* 1985, 1987) and on the management of the bees to overcome difficulties of disease, parasitism, and skewed sex ratios is clearly needed now that alfalfa seed production appears to have potential in Ontario. A growers' association has been formed recently (Kevan 1987) and a custom pollination industry may also develop as interest in alfalfa is rejuvinated in Ontario.

Acknowledgements

This work has been funded by a grant for Agricultural Technology Transfer under the Canada-Ontario Northern Ontario Rural Development Agreement (NORDA). We are grateful to V. Kucyk for his assistance in preparing this paper for publication.

References

Bohart, G.E. 1962. Introduction of foreign pollinators, prospects and problems. Proceedings of the I International Symposium on Pollination, Sverges Froödlareforbund Meddelande, No. 7, pp. 181-188.

Fairey, D.T. and J.A.C. Lieverse, 1984. Seed production in forage legumes. Mimeo from Agriculture Canada Research Station, Beaverlodge, Alberta T0H 0C0, No. NRG 84-20, 14 pp.

Free, J.B. 1970. Insect Pollination of Crops. Academic Press, London and New York, 544 pp.

Hobbs, G.A. 1964. Importing and managing the alfalfa leafcutter bee. Agriculture Canada Publication No. 1209, 8 pp.

Hobbs, G.A. 1967. Domestication of alfalfa leafcutter bees. Agriculture Canada Publication No. 1313, 19 pp.

Hobbs, G.A. 1968. Controlling insect enemies if the alfalfa leaf-cutter bee, *Megachile rotundata*. Canadian Entomologist, 100: 781-784.

Hobbs, G.A. 1973. Alfalfa leafcutter bees for pollinating alfalfa in western Canada. Agriculture Canada Publication No. 1495, 30 pp.

Hobbs, G.A. 1976. Selection for a univoltine strain of *Megachile (Eutricharaea) pacifica*. Canadian Entomologist, 108: 165-167.

Kevan, P.G. 1987. Alfalfa leafcutter bees and the Ontario alfalfa growers. Canadian Beekeeping, 13: 81.

Krombein, K.V. 1948. An adventive *Megachile* in Washington, D.C. Proceedings of the Entomological Society of Washington, 50:14.

Kukovica, I. 1966. A study of the reproductive capacity, foraging behaviour and environmental adaptability of the leaf-cutting bee *Megachile rotundata* (Fabricius) in southern Ontario. Unpublished M.Sc. thesis, University of Guelph, Guelph, Ontario, 210 pp.

McGregor, S.E. 1976. Insect pollination of cultivated crop plants. United States Department of Agriculture Handbook No. 496, 411 pp.

Mitchell, T.B. 1987. A revision of the genus *Megachile* in the Nearctic region. Part VIII. Transactions of the American Entomological Society, 63: 304.

Pankiw, P. 1987. Introduction of *Megachile rotundata* into the Peace River region. *In:* D.T. Fairey (Ed.), Alfalfa seed production in the Peace River region: update 1987. Joint Publication of the Peace River Branch, Alberta Alfalfa Seed Producers' Association and Department of Continuing Education, Fairview College, Fairview, Alberta, No. 87-2, pp. 11-13.

Pankiw, P., B. Siemens, and J.A.C. Lievrese, 1979. Breeding and management of *Megachile rotundata* for alfalfa seed production in northwestern Canada (Lat. 55 - 58° N). Proceedings of the IV International Symposium on Pollination, Maryland Experimental Station Special Miscellaneous Publication, 1: 273-277.

Pederson, M.N., G.E. Bohart, V.L. Marble, and E.C. Klostermeyer, 1972. Seed production practices. *In:* C.H. Hanson (Ed.), Alfalfa Science and Technology. Chapter 32, pp. 689-702.

Richards, K. W. 1984. Alfalfa leafcutter bee management in Western Canada. Agriculture Canada Publication No. 1495/E, 51 pp.

Skepasts, A.V., D.W. Taylor, and G.T. Bowman, 1984. Alfalfa seed production in northern Ontario. Highlights of Agricultural Research in Ontario, 7(1): 15-17.

Skepasts, A.V., D.W. Taylor, and G.T. Bowman, 1985. Alfalfa seed production in Tamiskaming district. New Liskeard College of Agricultural Technology and Ontario Ministry of Agriculture and Food, 14 pp. + Appendices.
Skepasts, A.V., D.W. Taylor, and G.T. Bowman, 1987. Seed from the queen of the forages. Highlights of Agricultural Research in Ontario, 10(4): in press.
Tysdale, H.M. 1940. Is tripping necessary for seed setting in alfalfa? Journal of the American Society of Agronomy, 32: 239-307.

POLLINATION AND FRUIT SET IN AMERICAN GINSENG (*PANAX QUINQUEFOLIUM* L.)

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Contribution No. 7 to the workshop **'Alternative Pollinators for Ontario Crops'** held at the University of Guelph, 12 April, 1986.

Proc. ent. Soc. Ont. 118:167-170 (1987)

Introduction

American ginseng, *Panax quinquefolium* L., is a fleshy rooted, perennial, herbaceous plant which is native to the cool, shady hardwood forests of southern Canada. It has been cultivated under wooden lath screens in southern Ontario since 1890. Today it is estimated that there are about 150 hectares of ginseng cultivated in Ontario. These plantings range from one to four years old, the economically important roots being harvested at the end of the fourth growing season. Farm gate value of dried roots is about $90/kg and an average yield is about 2500 kg/hectare.

The Plant. The ginseng plant has a main aerial stem about 30 cm long which branches into stalks or petioles at the summit (Fig. 1). At the end of each petiole there are five thin, delicate leaflets, two of these being quite small. This unit, or leaf, is often called a prong. Inconspicuous greenish white flowers rise on a stalk from the centre of the prongs. By August these little flowers set fruit, which ripen from green to a bright red. Each seed head contains 30 to 40 berries and each berry contains 1 to 3 hard-coated seeds about the size of a small pea. The above description fits plants that are at least three years old and are reproductive. One year old seedlings have only three small leaves and are not reproductive.

The economically important taproot is often branched, has a rhizome with leaf scars from annual abscission of leaves (thus allowing the plant to be aged) and an apical bud which gives rise to the aboveground growth the following year.

The Inflorescence. Inflorescence morphology is subject to variation (Fig. 2), and a range of inflorescence types occurs within the family Araliaceae (Philipson 1970). The umbel is characteristic of the Araliaceae. Choi and Shin (1982) have described 6 shapes of inflorescences in Oriental ginseng (*P. ginseng*). The two most common are a complete hemispherical umbel with all pedicels of the same length, and a simple umbel in which some pedicels are longer than others and project outside the hemisphere. Inflorescence morphology is less variable in cultivated American ginseng with only two shapes: a complete hemispherical umbel with all pedicels of the same length, and a simple umbel with several branched pedicels below it on the peduncle (Proctor 1986).

Hu (1980) reported branched inflorescences in *P. japonicus* and in *P. quinquefolium* growing in the wild. However, in the latter case, the result of branching was not the formation of normal panicles of umbels as is found in *P. japonicus* and *P. pseudoginseng*. Rather a single flower or a small umbel may diverge from the base of the peduncle, or an umbellet may arise from the center of the major umbel.

The Flowers. The nature of the flowers of ginseng appears to vary with species (Hu 1980). Carpenter and Cottam (1982) reported that American ginseng, growing in the wild, had perfect flowers and each flower had mature anthers or pistils, but not both. In addition, each inflorescence contained both functionally male and female flowers and the flowers were closely packed on the inflorescence. American ginseng flowers are small, greenish-white and five-merous (Lewis and Zenger 1982). Hu (1976) has provided a more

FIGURE 1. Typical four-year-old plant of American ginseng, *Panax quinquefolium*.

FIGURE 2. Variation in the inflorescences in *Panax quinquefolium*.

detailed description for flowers of *P. ginseng* as follows: "small, 2-3 mm across; sepals 5, green; petals 5, cream yellow, ovate, apex obtuse; stamens 5, filaments, short; pistil 1, ovary inferior, 2 locular; styles 2, united at base; disk cup-shaped".

Flower opening in the terminal hemispherical umbel usually starts in the outermost part in early June. The flowering period is usually about 6 weeks although Lewis and Zenger (1983) have reported 8 weeks for plants in Missouri and 3 weeks for plants in New York. Similarly, the number of flowers open per plant can vary from 1 to 3 or as many as 8 and seems to be related to the length of the flowering period. Shortly after the flower buds open the stamens and petals dehisce. Fruit are set between late June and late July and grow and develop until mid-August.

Pollination and Fruit Set. Bae (1978) has reported that cultivated Oriental ginseng is self-pollinating with a success rate of about 90% in bagged inflorescences of American ginseng. Pollination occurs between flowers within an inflorescence, or between plants if pollinators are present (Carpenter and Cottam 1982). Fruit and seed production does not differ in bagged and unbagged plants in some populations (Carpenter and Cottam 1982; Lewis and Zenger 1983), but does in others (Lewis and Zenger 1983). Fruits are not produced by apomixis (Carpenter and Cottam 1982; Lewis and Zenger 1983).

Sweat-bees, particularly *Dialictus* sp. and *Evylaeus* sp. (family Halictidae) appear to be the major pollinators of American ginseng (Carpenter and Cottam 1982; Duke 1980; Lewis and Zenger 1983). These generalist pollinators probably do not transfer pollen between distant individuals (Carpenter and Cottam 1982).

There is little in the literature about fruit set and development in ginseng although seed yield, in some years, has been worth more than root yield. Information about fruit set seems to be restricted to plants growing in the wild. For instance, Lewis and Zenger (1982) reported 80 to 89% of the flowering plants set fruit except in a drought year when only 47% of the flowering plants produced fruit. Lewis and Zenger (1982) attributed lack of fruit set in flowering plants to abortion following fertilization, partial fruit development caused by environmental or other factors, and sterility because of poor or no pollination. Schlessman (1985) showed that pre-fertilization abortion of ovules in one-styled flowers also affects seed production.

Fruit development starts at the outside of umbel and may have implications for ginseng growers as it has for carrot growers. Megerdichev (1974) showed that each seed on a carrot umbel starts to grow at a different time. In addition, Gray and Steckel (1983) found that plant-to-plant variation in seedling weight in the carrot crop was influenced by the order of the umbels from which the seeds were obtained and by the harvest date of the seed crop. Selecting certain seeds within the ginseng umbel, or harvesting seed at a specific developmental stage might reduce subsequent plant variation and might increase yield.

Fruit maturation usually starts about mid-August with the exocarps turning red, first in the outermost fruit of the umbel and progressing to the center. Fruit are picked when all exocarps in the umbel are red and prior to abscission, probably in early September. Yellow and orange-yellow berried mutants of Korean ginseng have been found and are being studied by the Korean Ginseng Research Institute (Bae 1978; Park 1980).

Each flower has two locules so the usual seed yield is 2 per fruit although 1 and 3 seeds are often found. Stoltz and Garland (1980) found that fruit was one-seeded (16.3%), commonly two-seeded (77.0%), and infrequently three seeded (6.5%) or four seeded (0.2%). A typical flowering 4-year-old American ginseng plant would carry 30 to 40 berries in each inflorescence with an average of 2 cream white seeds, 5 to 6 mm long, and 4 to 5 mm wide, in each berry.

References

Bae, H.W. (ed.). 1978. Korean gingseng. Korean Ginseng Research Institute, Seoul, Republic of Korea. 317 pp.

Carpenter, S.G. and G. Cottam. 1982. Growth and reproduction of American ginseng (*Panax quinquefolius*) in Wisconsin, U.S.A. Canadian Journal of Botany, 60:2692-2696.

Choi, K.T. and H.S. Shin. 1982. Morphological characteristics of inflorescence, flowering bud, fruit and leaf of Korean ginseng. Korean Journal of Ginseng Science, 6:67-74.

Duke, J.A. 1980. Pollinators of *Panax*? Castanea, 45:141.

Gray, D. and J.R. Steckel. 1983. Some effects of umbel order and harvest date on carrot seed variability and seedling performance. Journal of Horticultural Science, 58:73-82.

Hu, S.Y. 1976. The genus *Panax* (Ginseng) in Chinese medicine. Economic Botany, 30:11-28.

Hu, S.Y. 1980. Biological and cytological foundation for better ginseng to more people. *In:* Korean Ginseng Research Institute (ed.), Proceedings of the Third International Ginseng Symposium. Seoul, Korea, pp. 171-179.

Lewis, W.H. and V.E. Zenger. 1982. Population dynamics of the American ginseng *Panax quinquefolium* (Araliaceae). American Journal of Botany, 69:1483-1490.

Lewis, W.H. and V.E. Zenger. 1983. Breeding systems and fecundity in the American ginseng, *Panax quinquefolium* (Araliaceae). American Journal of Botany, 70:466-468.

Megerdichev, K.Ya. 1974. The heterogeneity of carrot seed embryos. Horticultural Abstracts, 44: Abstract No. 9731.

Park, H. 1980. Physiological response of *Panax ginseng* to light. *In:* Korean Ginseng Research Institute (ed.). Proceedings of the Third International Ginseng Symposium. Seoul, Korea, pp. 151-170.

Philipson, W.R. 1970. Constant and variable features of the Araliaceae, *In:* N.K.B. Robson, D.F. Cutler and M. Gregory (eds.), New Research in Plant Anatomy. Academic Press Inc. (London) Limited, pp. 87-100.

Proctor, J.T.A. 1986. Variation in the inflorescence of cultivated American ginseng (*Panax quinquefolium* L.). Korean Journal of Ginseng Science, 10:76-79.

Schlessman, M.A. 1985. Floral biology of American ginseng (*Panax quinquefolium*). Bulletin of the Torrey Botanical Club, 112:129-133.

Stoltz, L. and P. Garland. 1980. Embryo development of ginseng seed at various stratification temperatures. *In:* Missouri Department of Conservation (ed.), Proceedings of the Second National Ginseng Conference, Missouri Department of Conservation. Jefferson City, Missouri. pp. 43-51.

PRESIDENT'S PRIZES, 1987

Proc. ent. Soc. Ont. 118:171 (1987)

The society congratulates Martha Farkas and Pam Fisher for their exemplary presentations at the 124th Annual Meeting, held in Sudbury on 16-18 October, 1987 which resulted in their both being awarded the President's Prize at the banquet. Abstracts of their presentations are given below.

THE INCIDENCE AND LIFE HISTORY OF *IXODES COOKEI* PACKARD (ACARI: IXODIDAE), THE GROUNDHOG TICK, IN WELLINGTON COUNTY, WITH SPECIAL REFERENCE TO POWASSAN VIRUS.

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Ixodes cookei is the vector of Powassan virus, the causative agent of Powassan viral encephalitis in humans. This tick is commonly found on groundhogs, which act as reservoirs for the virus. Approximately 38% of groundhogs collected from May to August in Wellington County from 1985 to 1987 were infested with *I. cookei*, infestation being defined as there being at least one tick on the groundhog. Larvae, nymphs, and adults were all found in the spring, indicating that overwintering occurs in all three postembryonic stages. All three stages also occurred throughout the summer. Of those groundhogs that were infested, most (89%) had low levels (1-20 ticks) whereas only a few groundhogs were heavily infested, mostly with larval ticks. High levels of infestation are likely the result of a groundhog encountering a newly-hatched egg batch within the groundhog burrow. The life cycle of *I. cookei* takes approximately 3 months to complete at 25°C and at high humidity (93% to 100%). Adult females experienced a 50-fold increase in weight from the unengorged state, attaining 204.4 ± 15.4 mg, and laying 1562 ± 213 eggs over a three week period at 30°C. Transovarial transmission experiments with Powassan virus are in progress.

THE EFFECT OF PESTICIDES ON TWO SPECIES OF PARASITOIDS, *PHOLETESOR ORNIGIS* AND *PHOLETESOR PEDIAS* (HYMENOPTERA: BRACONIDAE).

PAM FISHER

Department of Environmental Biology, University of Guelph, Guelph, Ontario, N1G 2W1

The effects of pesticides on two species of braconid, *Pholetesor ornigis* Weed. and *P. pedias* Nixon was evaluated. Both insects are parasitoids of the spotted tentiform leafminer (*Phyllonorycter blancardella* Fabricus (Lepidoptera: Gracilariidae)). Potted apple trees were sprayed with azinphosmethyl, methomyl, or permethrin at the recommended field rates. Leaf samples were collected at 0, 1, 3, 5, 7, 10, and 15 days after treatment. Mortality of parasitoids was assessed after 24 h of exposure to treated apple foliage. The LT50 values for males and females of *P. ornigis* were not significantly different for any of the treatments. The LT50 values for *P. pedias* were higher than for *P. orginis* for the azinphosmethyl and permethrin treatments, however, differences between the species' mortalities on each sample were significant only at $p = 0.25$. Azinphosmethyl was more toxic than methomyl or permethrin when applied at field rates. The LT50 values for that treatment were 5 to 9 days for both species.

OBITUARIES

G. Gordon "Dusty" Dustan, formerly Officer-in-Charge of the Dominion Fruit Insect Laboratory, Vineland Station, and, later, Head of the Entomology Section, Agriculture Canada, Research Station, Vineland Station, died at Grimsby, Ontario, 24 April, 1987, in his 83rd year. He retired in 1970. He was President of the Entomological Society of Ontario in 1957-58. He is survived by his wife, Elizabeth, of Vineland Station, two daughters, Jane and Betsy, and a son, Gordon, Jr.

J.H. Howard Phillips died at his home in Vineland Station, 7 June, 1987, after a long illness. He was 74. Howard, who retired from the Agriculture Canada Research Station, Vineland Station, in 1974, had served as Head of the Entomology Section. He was a member and former director of the Entomological Society of Ontario. He is survived by his wife, Jean, a daughter Sandra, and 3 grandchildren.

CONGRATULATIONS

The Society congratulates Dr. Eugene G. Munroe and Dr. H. Glenn Wylie on their being made Honorary Members of the Entomological Society of Canada. Dr. Munroe is well known for his outstanding work in Entomology at the Biosystematics Research Centre of Canada Agriculture in Ottawa and his promotion of Entomology throughout Canada. Dr. Wylie has a distinguished record in the field of biological control of insects and has been very active in the support of Entomology for Canada and, most recently, Manitoba.

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of the

ENTOMOLOGICAL SOCIETY OF ONTARIO

Volume
One Hundred and Nineteen
1988

Published February, 1989

ISSN 0071-0768

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HABITAT ASSOCIATIONS, PATTERNS OF ABUNDANCE, AND SPECIES RICHNESS OF PHYTOSEIID MITES (ACARI: PHYTOSEIIDAE) ON A RECENT LANDFILL SITE IN LAKE ONTARIO

LORNE D. ROTHMAN

Department of Zoology, University of Toronto, Toronto, Ontario M5S 1A1

Abstract *Proc. ent. Soc. Ont.* 119:1-7

Patterns of distribution and abundance of phytoseiid mites in localized vegetation assemblages were examined on the Leslie Street Spit, Toronto, Ontario. Descriptions are given for each assemblage and habitat associations for the abundant phytoseiid species (*Amblyseius andersoni, A. okanagensis, A. meridionalis,* and *Typhlodromus bakeri*) are suggested. The surface area of habitable vegetation best explained trends in the abundance and species richness of these mites.

Introduction

Studies involving phytoseiid mites have been concerned largely with habitats of economic importance such as apple orchards (Downing and Moillet 1967; Knisley and Swift 1972; Berkett and Forsythe 1980; Solomon, 1982; Woolhouse and Harmsen 1984). Such studies have focused on overstorey foliage and have not dealt with components such as the herb layer and litter.

In this paper, patterns of distribution and abundance of phytoseiid mites between and within natural vegetation assemblages on the Leslie Street Spit, Toronto, Ontario, are examined. A variety of parameters were measured to provide a description of the habitats of these mites, and to examine trends in their abundance and species richness.

Materials and Methods

The Leslie Street Spit extends in a south-westerly direction from the Crown land located at the base of Leslie Street in Toronto (aerial photograph, Northway Survey Corporation Ltd., sheet number 86-51E). It is a man-made peninsula, extending five km into Lake Ontario (Cunningham *et al.*, 1982). Six study sites were selected near the base of the first peninsula on the spit (Fig.1). This area was constructed from material dredged from the harbour and was completed in 1975. Within this area, several vegetation types are present, largely determined by elevation above the water table. Cottonwoods now grow on dry raised areas. As the ground descends and becomes more moist, willows become more common, creating mixed transition areas. With further decreases in elevation, these mixed areas give way to pure willow scrub. In the lowest areas, wet meadows occur, often dominated by willow saplings less than 1 meter in height (Cunningham *et al.*, 1982).

The age of the area in which the study sites were located was determined using a series of aerial photographs, (provided by Northway Survey Corporation Ltd., 1450 O'Connor Dr., Toronto, Ontario), taken annually, of the spit during construction. The ages of the sites were verified by dendrochronology. Six sites (each 4m x 4m) were chosen in which to sample the spatial succession of vegetation assemblages as a function of elevation above the water table. In increasing order of elevation and dryness, the sites were: willow sapling (WSa), willow scrub (WS), mixed willow and cottonwood scrub (MS), pure cottonwood scrub (CS), and immature cottonwood forest (ICF1 and ICF2). Eight quadrats (each 1m x 1m) in each site were selected using random number tables and sampled using the point quadrat method (Kershaw 1974) to estimate overall percentage ground cover and percentage ground cover for individual species in the herb layer. Species of herbs were then ranked according to the Domin Scale (Kershaw 1974). Sampling of the herb layer was carried out from 6 June 1986 to 20 June 1986. Litter was collected from five quadrats (each 0.5 x 0.5) within each site and weighed both wet and dry. The diameter of all overstorey plants was measured at breast height (DBH). Individual basal areas within each site were then calculated and summed to determine the total basal area per site.

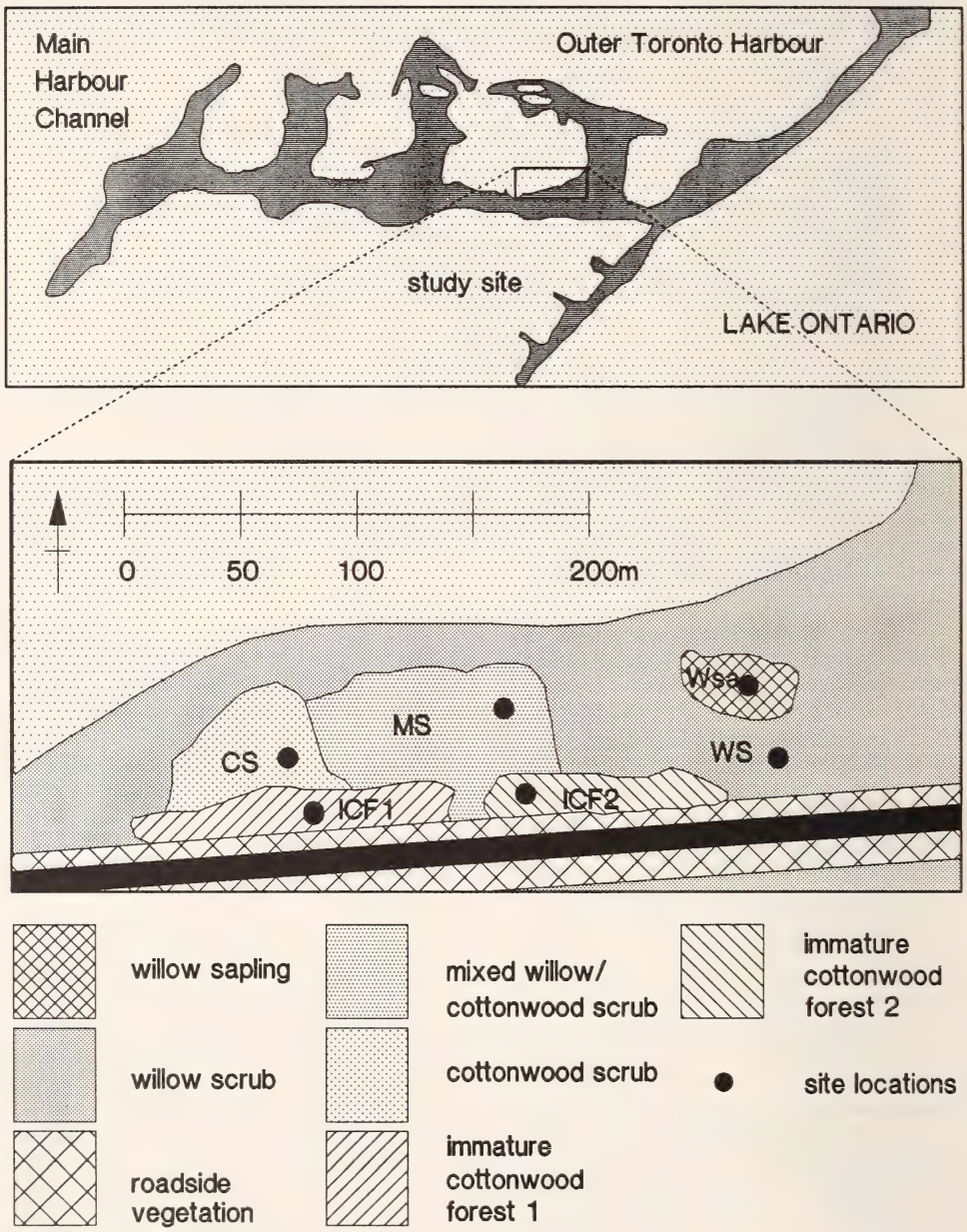

FIGURE 1. The Leslie Street Spit, showing study area and sites.

Four points within each quadrat were chosen using randon number tables every two weeks from 3 June 1986 to 4 August 1986, to sample phytoseiids in the soil and litter. The last collection was delayed for six days because of rain. A Berlese funnel (radius = 10cm) was placed on the selected point and the area covered by the funnel was removed to a depth of 4 cm. For a three week period

beginning 10 August 1986, herb and overstorey vegetation was beaten over a (30 cm x 40 cm) white plastic tray (weather permitting) for a total of 38.5 hours. The WS, MS, CS,ICF1 and ICF2 sites were each sampled seven times for one hour periods. Within these sites, sampling time was divided equally (30 minutes) between herb and overstorey layers. As the WSa site contained no overstorey, the herb layer was sampled for seven 30 minute periods. Roadside vegetation was also beaten for four 30 minute periods to determine which species were present. Phytoseiids recovered from the soil and litter samples and plastic trays were mounted and identified. Spearman's rank order correlations (Norman and Streiner 1986) were calculated to compare the various site parameters with phytoseiid abundance and species richness as measured by the number of species.

Results and Discussion

HABITAT ASSOCIATIONS. Descriptions of the six study sites are given in Tables I and II. The results of phytoseiid sampling are given in Figure 2 and Table III. It should be noted that data on mite abundance from the herb/overstorey layer and the litter/soil layer can not readily be compared because of differences in collection times and methods and therefore, only herb and overstorey results are given in Fig. 2.

TABLE I. Domin scale ratings for herb species sampled at the six study sites on the Leslie Street Spit (listed in order of decreasing dominance over the study area)(see Fig. 1).

	Domin Scale Rating for the Six Sites					
Taxon	**WSa**	**Ws**	**MS**	**CS**	**ICF1**	**ICF2**
Equisetum arvense	4	8	7	7	9	9
Solidago sp.	4	3	4	4	x	3
Potentilla anserina	4	4	4	4	0	0
Salix interior (sapling)	6	4	4	2	0	0
Equisetum hyemale	3	3	0	6	0	0
Sonchus sp.	1	4	4	1	0	0
Hieracium sp.	3	3	1	1	0	0
Lycopus americanus	3	0	3	1	0	x
Linaria vulgaris	0	4	0	0	2	0
Plantanthera hyperborea	x	4	x	0	0	0
Tussilago farfara	0	0	0	0	4	x
Equisetum nelsonii	4	0	0	0	0	0
Erigeron philadelphicus	3	0	0	0	0	0
Satureja vulgaris	0	0	2	0	1	0
Scirpus americanus	3	0	0	0	0	0
Medicago lupilina	0	2	x	0	0	0
Melilotus sp.	0	1	0	0	0	0
Populus deltoides (sapling)	0	x	x	x	x	0
Euthamia graminifolia	x	0	0	x	0	0
Lythrum salicaria	x	0	0	0	0	x
Aster lanceolatus	x	0	0	0	0	0
Juncus balticus	0	0	0	0	0	x
Oenothera sp.	x	0	0	0	0	0
Rorripa sp.	0	0	0	x	0	0

10 - 100% cover
9 - more than 75% cover
8 - 50-75% cover
7 - 33-50% cover
6 - 25-33% cover
5 - abundant (20-25%)
4 - abundant (5-20%)
3 - scattered, cover small (present in 4 of 8 sampled quadrats)
2 - very scattered, cover small (present in 3 of 8 sampled quadrats)
1 - scarce (present in 2 of 8 sampled quadrats)
x - isolated (present in 1 of 8 sampled quadrats)
0 - not present

TABLE II. Description of the six study sites on the Leslie Street Spit (see Fig. 1)

	Sites					
Measures	**WSa**	**WS**	**MS**	**CS**	**ICF1**	**ICF2**
Percentage ground cover (herb)	64.2	80.9	75.8	72.6	87.2	93.7
Percentage ground cover variance	43.3	25.0	87.9	35.8	96.3	35.9
Herb species richness	16.0	12.0	11.0	11.0	6.0	5.0
Basal area						
total (cm)	0	71.2	86.3	91.6	1319.6	1412.7
($\bar{x}$) (cm)	0	0.61	0.98	1.27	31.42	35.32
variance (cm^2)	0	0.35	1.22	1.02	52.1	64.51
Percentage of total:						
Salix sp.	0	100	43.30	2.60	0.14	0.01
Populus sp.	0	0	56.70	97.40	99.86	99.99
Litter weight						
wet – (kg/site)	10.51	16.16	14.28	7.84	37.15	38.29
dry – (kg/site)	6.65	11.82	9.08	6.02	22.61	23.41

Typhlodromus bakeri (Garman) was found almost exclusively on the overstory vegetation and was most abundant in the mixed willow/cottonwood and pure cottonwood scrub sites (Fig. 2 and Table III). Chant (1959) suggested that this species, in England, is entirely bark inhabiting. This specific association was also found in the present study as *T. bakeri* occurred predominantly on cottonwood (*Populus deltoides* (Marsh)) (Table III). The smaller number of *T. bakeri* on sandbar willow (*Salix interior* (Rowlee)) may be explained by the soft leafy nature of its trunk and stems (Britton and Brown 1970). The striking change in the relative abundance of *T. bakeri* in the immature cottonwood forest sites may have been the result of competition with *Amblyseius andersoni* (Chant) (Chant 1959).

TABLE III. The number of individuals (adults and immatures) per phytoseiid (*Amblyseius* and *Typhlodromus*) species within each of the six study sites on the Leslie Street Spit (see Fig. 1).

	Sites																	
	WSa	**WS**			**MS**				**CS**				**ICF1**		**ICF2**	
Species	**H**	**(B)**	**H**	**Os**	**(B)**	**H**	**OS**	**Op**	**(B)**	**H**	**Op**		**H**	**Op**	**H**	**Op**
A. andersoni	3		4			4	3	5		1			2	32	5	31
A. meridionalis		(33)	3		(2)								1			
A. okanagensis	1		1			1							28		33	1
A. hudsonianus			1						(1)				2		4	
A. isuki									(3)							
A. fallacis	1									1						
A. masseei														3		2
A. assiniboin															1	
A. tundra					(1)											
T. bakeri				3		1	14	25			36			16		16
T. citri																1

(B) – sample collected with Berlese funnel (soil and litter)
H – sample collected from herb layer
Os – sample collected from overstory *Salix* sp.
Op – sample collected from overstory *Populus* sp.

A. andersoni appeared to be more of a generalist with respect to habitat associations. Although strongly associated with the overstorey vegetation in the immature cottonwood forest *A. andersoni* was the only species collected in all six sites (Fig. 2). In addition, this species showed no distinct associations with the overstorey or herb layers, across the six study sites (Table III). Additional collection records for *A. andersoni* are from plum, hickory, wild peach, nightshade and *Tilia* sp. (Chant and

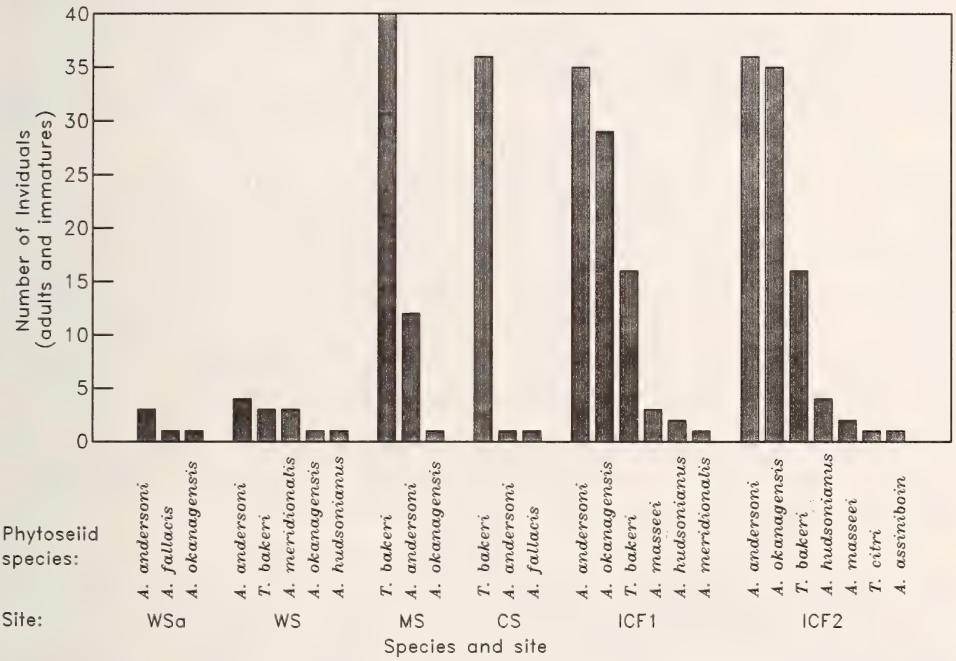

FIGURE 2. Herbs and overstorey and *Amblyseius* spp. and *Typhlodromus* spp. at the six study sites (see Fig. 1) on the Leslie Street Spit.

Hansell 1971) and apple trees in abandoned orchards (Amano 1985).

The only herb dwelling species that was abundant was *A. okanagensis* (Chant). Although present in small numbers in all but the cottonwood scrub site, this species was associated predominantly with the herb layer in both sites of immature cottonwood forest. Previous records from the herb layer are from British Columbia on "cover crop" and burdock (Chant 1957). Previous records from the overstorey layer are from peach and apple leaves in British Columbia (Chant 1957) and apple trees in commercial orchard in Maine (Berkett and Forsythe 1980).

Results of the Berlese funnel sampling show *A. meridionalis* (Berlese) to be the most abundant species associated with soil and litter, predominantly in the willow scrub site (Fig. 2 and Table III). This agrees with the previous record from soil in Italy (Chant 1959) (although information on herb and overstorey vegetation was not given). However, three females have been recorded from British Columbia on cottonwood (Chant and Shaul 1978).

Fairly distinct associations with plant assemblages are apparent for the four species mentioned above. The similarity between the sites of immature cottonwood forest, with respect to parameters measured (Table I and II) and relative abundance of these dominant species of phytoseiids further suggest the existence of within- and between- site habitat associations. Similar assemblages of phytoseiids are found within similar sites.

It is more difficult to infer habitat associations for the less abundant species. For example, single

specimens of *A. fallacis* (Garman) were present in the willow sapling and cottonwood scrub sites (Fig. 2), two different vegetation assemblages. Previous records do not help here as this species is common in eastern Canada, found on both herb and overstorey vegetation (Chant and Hansell 1971). *A. masseei* (Nesbitt), however, appears to be associated with overstorey vegetation in the immature cottonwood forest sites and *A. hudsonianus* (Chant and Hansell 1971), with the herb layer of the same habitat.

The presence of the less numerous species in the immature cottonwood forest (*A. masseei*, *A. hudsonianus*, *A. assiniboin*, (Chant and Hansell 1971) and *T. citri* (Garman and Mcgregor 1971)) did not result from immigration from populations inhabiting roadside vegetation, as few phytoseiids were found in this area and none belonged to these species.

ABUNDANCE AND SPECIES RICHNESS. Total phytoseiid abundance per site correlated significantly with percentage ground cover (r = 0.94)) and community basal area (r = 0.83) at the 5% level. Significant correlations were also observed between the abundance of phytoseiids in the herb layer and percentage ground cover (r = 0.94), and the abundance of phytoseiids in the overstorey and site basal area (r = 0.93). No significant correlation was observed between litter weight (wet and dry) and the abundance of phytoseiids in the litter. These observations suggest that as the area of the herb layer and overstorey vegetation increases, the number of potential living spaces also increases for the phytoseiids in these habitats. The litter and soil layers, however, probably offer suitable habitats for certain species only under specific conditions (e.g. *A. meridionalis*, *A. isuki* and *A. tundra* (Chant and Hansell 1971) in the scrub sites). The increase in evenness of the assemblages of phytoseiids (in terms of the relative abundance of species) from the mixed willow and cottonwood/cottonwood scrub to tthe immature cottonwood forest (Fig.2) largely reflects increases in the abundance of herb dwelling phytoseiids (Table III) resulting from the large increase in potential living spaces (i.e. percentage ground cover) (Table II).

The species richness of phytoseiids was significantly correlated (at the 5% level) with percentage ground cover, and site basal area (r = 0.94 for both). Significant correlations were also found between the number of phytoseiid species in the herb layer and percentage ground cover (r = 0.88), and the number of overstorey species and site basal area (r = 0.89).

Species richness is often dependent on habitat heterogeneity (MacArthur 1965; Janzen 1976). The richness of herb species, and the variation in percentage ground cover and site basal areas within a site, provide indications of heterogeneity. No significant positive correlation, however, was observed between the richness of species of herb dwelling phytoseiids and either the variance in percentage ground cover or the richness of herb species (Table II). Regarding the richness of herb species, it appears that individual phytoseiid species tend not to be host plant specific (during the time of sampling) as noted by Chant (1959), and the structural complexity of the herb layer is not important in determining the number of phytoseiid species. A significant correlation was observed between the richess of species of overstorey phytoseiids and the variance in site basal area (r = 0.99). However, increases in the surface of habitable vegetation may underlie the above correlation, as suggested by the observed significant correlation between site basal area and the variance in basal area within a site (r = 0.94). It is important to note, here, that significant correlations may have been found between the species richness of phytoseiids and the variance in site parameters not measured in this study. Habitat heterogeneity is not an intrinsic trait of a habitat, but is defined operationally only in context of the organism (Janzen 1976).

Regardless of the effects, if any, of heterogeneity, habitable surface area per se may have been an important factor in determining the number of phytoseiid species. Biotic richness is generally related to habitat size or the area of the region containing the biota (i.e. surface of vegetation) (Strong 1978). Sites with little ground cover, such as the willow sapling area (Table II) supported smaller populations of each species with a greater probability of local extinctions (Strong 1978) or emigration to plant assemblages with more ground cover. Habitable surface (i.e. basal area) is probably also important in determining the richness of phytoseiid species in the overstorey.

Edge effects must also be considered when examining species richness in the immature cottonwood forest sites (Fig. 1). The zone where the cottonwood stands and weedy roadside vegetation meet

may be considered a local ecotone. Phytoseiids characteristic of and possibly restricted to this ecotone may have been present in the phytoseiid collections from these sites (ICF1 and ICF2).

The results of this study show definite habitat associations for abundant species of phytoseiids during the time of sampling. The amount of habitable surface area best explained the observed trends in phytoseiid abundance and species richness. These conclusions, however, are rather tentative, as the sample sizes were small.

Acknowledgments

This study was funded by an undergraduate student award from the Natural Science and Engineering Research Council. I am grateful to Mrs. Eiko Shaul for her help in phytoseiid identification, to Dr. R.I.C. Hansell for supervising this study and to Dr. D.A. Chant for providing laboratory facilities and reviewing this manuscript.

References

Amano, H. 1985. Some aspects of the ecology of Acarina on abandoned apple trees in Ontario, Canada. Ph.D. thesis, University of Toronto. 210 pp.

Berkett, L.P. and H.Y. Forsythe. 1980. Predaceous mites (Acari) associated with apple foliage in Maine. Canadian Entomologist, 112:497-502.

Britton, N. and A. Brown. 1970. An illustrated flora of the northern U.S. and Canada. General Publishing Company Ltd. Toronto. (1) 680 pp.

Chant, D.A. 1957. Description of some phytoseiid mites (Acarina:Phytoseiidae). Part I. Nine new species from British Columbia with keys to the species of British Columbia. Part II. Redescription of eight species described by Berlese. Canadian Entomologist, 89:357-363.

Chant, D.A. 1959. Phytoseiid mites (Acarina:Phytoseiidae) Part I. Bionomics of seven species in southeastern England. Part II. A taxonomic review of the family Phytoseiidae, with descriptions of 38 new species. Canadian Entomologist, Suppl. 12:1-166.

Chant, D.A. and R.I.C. Hansell. 1971. The genus *Amblyseius* (Acarina:Phytoseiidae) in Canada and Alaska. Canadian Journal of Zoology, 49:702-758.

Chant, D.A. and E.Y. Shaul. 1978. Description of three new species in the genera *Amblyseius* Berlese and *Typhlodromus* Scheuten (Acarina:Phytoseiidae) in Canada, with descriptions of males of nine other species and some new collection records. Canadian Entomologist, 110:1059-1076.

Cunningham, G., D.M. Fraser and J. Doane. 1982. Aquatic Park survey, Metropolitan Toronto Regional Conservation Authority Report. 76 pp.

Downing, R.S. and T.K. Moillet. 1967. Relative densities of predaceous and phytophagous mites on three varieties of apple trees. Canadian Entomologist, 99:738-741.

Janzen, D.H. 1976. Why are there so many species of insects? Proceedings of the XV International Congress of Entomology, pp.84-94.

Kershaw, K.A. 1974. Quantitative and dynamic plant ecology. William Clowes & Sons, London. 308 pp.

Knisley, C.B. and F.C. Swift. 1972. Qualitative study of mite fauna associated with apple foliage in New Jersey. Journal of Economic Entomology, 10:313-319.

MacArthur, R.H. 1965. Patterns of species diversity. Biological Review, 40:510-533.

Norman, G.R. and D.C. Streiner. 1986. PDQ Statistics. B.C. Decker Inc., Toronto. 172 pp.

Solomon, M.G. 1982. Phytophagous mites and their predators in apple orchards. Annals of Applied Biology, 101:201-203

Strong, D.R. Jr. 1978. Biogeographic dynamics of insect-host plant communites. Annual Review of Entomology, 24:89-119.

Woolhouse, M.E.J. and R. Harmsen. 1984. The mite complex on the foliage of a pesticide free apple orchard: Population dynamics and habitat associations. Proceedings of the Entomological Society of Ontario, 115:1-11.

(Received 28 July 1987; accepted 3 February 1988)

THE SQUASH AND GOURD BEE, *PEPONAPIS PRUINOSA* (HYMENOPTERA: ANTHOPHORIDAE) IN ONTARIO, CANADA.

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Abstract *Proc. ent. Soc. Ont.* 119: 9-15

Peponapis pruinosa is a bee widespread in North America, but its occurrence in Canada has not been recorded in the literature. It is known as an important pollinator of cucurbits and may have extended its range with the cultivation of squash, pumpkin, and gourds.

We summarize the known Canadian distribution of this species and describe a dense nesting aggregation (over 2,000 nest entrances in 35 m^2) together with aspects of the nesting biology, architecture of the subterranean nests, and matinal foraging behaviour from Ancaster. There, the bees had become a pest in the front lawn of a private residence.

Introduction

Of the genus *Peponapis*, commonly known as the squash and gourd bees, *P. pruinosa* (Say) is the most widespread and best known. These bees are entirely dependent on members of the Cucurbitaceae for nectar and pollen to provision their nests (Hurd *et al.* 1971, 1974), although they have been recorded at the flowers of other plants (Rau 1922; Robertson 1928; M.V. Smith personal communication). They are gregarious, ground nesting bees. The genus has been treated taxonomically by Hurd and Linsley (1970) who reported the range of *P. pruinosa* in the U.S.A. and Central America. Although their maps show the range of these bees extending into southern Ontario, no mention of localities or of specimens was made. Krombein *et al.* (1979), and Mitchell (1962) also make no mention of Canadian records of *P. pruinosa*.

Even within its range in the U.S.A., and given its economic potential in the pollination of cucurbit crops (Tepedino 1981), little has been published on the biology of this bee. Mathewson (1968) described its nesting biology and internal features of the adult anatomy (1965). Hurd *et al.* (1971) discussed, in detail, the importance of *Peponapis* spp. in the pollination and evolution of *Cucurbita* spp.

Our discovery of a nesting aggregation of these bees on a lawn in a residential area of Ancaster, Ontario (43° 11′ 10″ N., 80° 0′ 50″ W.) prompted further investigation. With the permission of the homeowners, who alerted us to their problem with the bees, a short study was made in July and August, 1987.

Materials and Methods

The main nesting aggregation, in the lawn directly in front of the house, was mapped by one meter squares. The number of nest entrances in each square was counted to estimate population density. Elevations and slopes of the soil surfaces in the squares were also recorded to determine if any correlation existed between population density in the squares and these factors (Fig. 1).

An area of 0.5 m^2 and adjacent smaller remaining areas, containing 127 nest entrances, was observed every 1/2 hour for five minutes from 0700 hrs until 1800 hrs on July 29, 1987. All incoming bees were counted to give a measure of diel activity. The bees were also recorded as belonging to one of two categories: i) those entering a nest with pollen loads in their corbiculae and ii) those entering without.

Soil temperatures were measured at the surface and at a depth of 15cm using mercury therometers inserted forcibly into the soil. Soil samples were collected from the surface (to a depth of about 10 cm) within and beyond the nesting area. These were taken to the Analytical Services Laboratory, Department of Land Resource Science, University of Guelph for analysis.

Pollen samples were removed from bees collected as voucher specimens and were sent to C. Crompton, Biosystematics Research Centre, Agriculture Canada, Ottawa, for identification. Voucher specimens of bees collected during the course of our research are deposited in the Museum of the Department of Environmental Biology, University of Guelph, and at the Entomology Museum, Cornell University.

Bees laden with cucurbit pollen were photographed by scanning electron microscopy (Hitachi S-570). Samples were mounted on stubs with silver paint and sputter coated with 300 Å of gold-palladium, in the Hummer V sputter coater.

An attempt was made to excavate several nests. Although we were unable to excavate one entire tunnel, we obtained a composite picture of the nest architecture.

Records of specimens of *P. pruinosa* from Canada were requested from the insect collections at the University of Guelph (GUE), from M. Sarazin at the Canadian National Collection, Biosystematics Research Centre, Agriculture Canada, Ottawa (BRI), from R. McGinley, Entomology, Smithsonian Institution, Washington, D. C. (USNM), from G. Eickwort, Cornell University (CUI), and from G. Linsley, University of California.

Results and Discussion

The nesting habits of *P. pruinosa* were described by Mathewson (1968) and Hurd *et al.* (1974) who have provided detailed accounts. These bees were previously known to be gregarious, (although not communal in the sense of Michener 1974); however, the densities we recorded are much higher (up to 16 times greater) than those reported previously (Mathewson 1968; Michelbacher *et al.* 1971; Hurd *et al.* 1974) (Fig. 1). Hurd *et al.* (1974) stated that burrows are constructed in flat ground, yet we found burrows constructed on the slope as well as on the flat part of the lawn (Fig. 1). The bees were in such high density that they had killed patches of grass, up to 40 cm in diameter - an effect which concerned the homeowners. In addition, family members (including children) had been stung. The stings occured only when the bees become trapped in clothing or were poked in their burrows. Generally the bees appeared peaceful and unaggressive in our presence. We estimate that at least 2,000 bees were nesting in the lawn and the homeowners confirmed that the bees had been present, in annually increasing numbers, for at least 2 years.

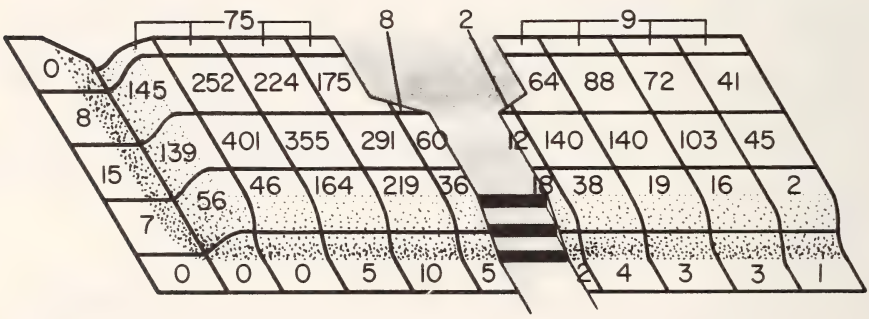

FIGURE 1. Abundance of nest entrances of *Peponapis pruinosa* in square meter plots on the study site and adjacent areas on a front lawn of a house in Ancaster, Ontario, July 29, 1987.

The composition of the soil at the surface in the nesting area was not different from that outside the area. The analyses showed that the three soil samples had a mean composition consisting of 32.8% sand, 55.7% silt, and 11.4% clay, with a pH averaging 7.0 and no detectable trace of calcium carbonate. Similar sandy soils characterized the nesting areas described by Norden on the Eastern American coast (B. Norden personal communication). The bees seemed to be nesting in greatest density in the squares of intermediate elevation which lay on a gentle slope, the densities being less in the squares with a steeper slope or no slope at all. It is likely that the combination of suitable soil with the western exposure made this an ideal nesting site.

Nest entrances were often surrounded by tumuli, especially during nest excavation periods prior to soil compaction because of bee traffic or rain, or both, around the nest entrances (Mathewson 1968). The tumuli that we observed were of the conical and symmetrical type described by Stephen *et*

al. 1969: Fig. 252. The nests we excavated were almost exactly as those described by Mathewson (1968). Although Mathewson does not attempt to classify this nest structure, it can be described as closely fitting class $Op(LCh)^n$ of Stephen et al.'s (1969) classification. The tunnels descended more or less vertically into the soil and the cells were found off to the sides of, and mostly connected by a short (ca. 1 - 2 cm) passage to the main tunnel. We found that nests went as deep as 46 cm from the surface. This depth is much greater than the maximum (12 to 22 cm) reported by Mathewson (1968), but not as deep as reported by Michelbacher *et al.* (1971) for *P. pruinosa* or by Rozen and Ayala (1987) for *P. utahensis*. Michelbacher *et al.* (1971) found cells as deep as 65 cm (not 650 cm as typeset (Linsley, personal communication)) with most falling into a range, similar to what we found, of between 13 and 25 cm. We did not find cells less than 7 cm deep. The cells we removed were ovoid, approximately 8.14 by 14.29 mm (n=7), and were oriented with the long axis vertical. They were lined with smoothly compacted soil and were filled with a liquid mixture of pollen and nectar. The eggs were found positioned in a ∩ shape on the pollen and nectar mass. The largest larvae were in the deepest cells and eggs were found closer to the surface. This indicates that the female bees dig the length of the main tunnel first, and then provision cells from the bottom up, a cell configuration referred to as regressive by Sakagami and Michener (1962) and also described by Mathewson (1968). It is likely that female eggs are laid first and deepest and that the male eggs are laid after, as is known for a number of fossorial and hole-nesting bees (Malyshev 1935).

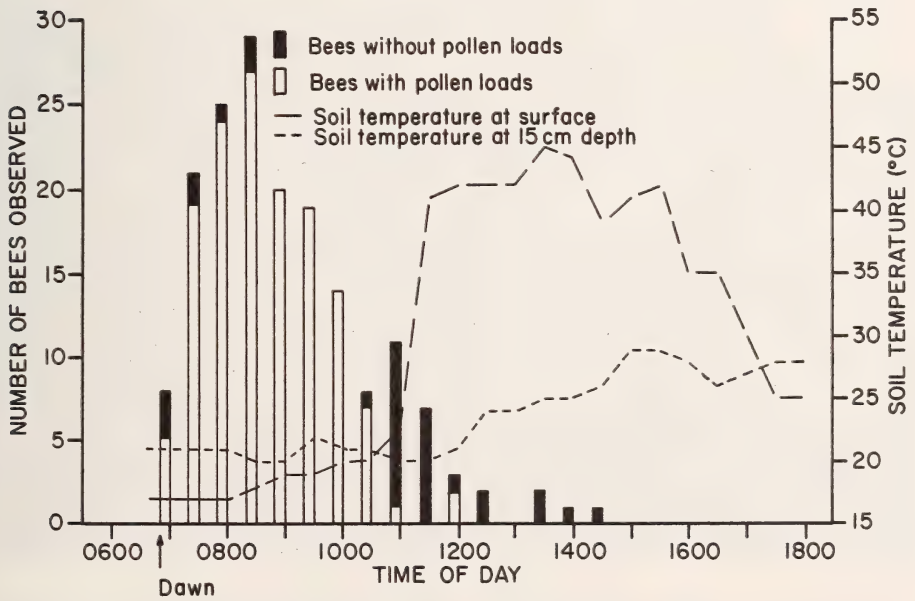

FIGURE 2. Stacked bar chart showing diel activity of *Peponapis pruinosa* in a 0.5 m^2 plot with 127 nest entrances on 29 July, 1987 in Ancaster, Ontario. Data were collected for 5 minutes every half hour when the soil temperatures at the surface and at the 15 cm depth were measured. Sharp rise in surface temperature at this time corresponds with end of shading by house.

Foraging activity in Ancaster occurred mainly in the mornings (see also Mathewson 1968; Hurd *et al.* 1974), as noted by the homeowners and from our observations on 23,28,29,30, July (Fig. 2). In

California, foraging began around 0500 hrs PDT, just before sunrise (Hurd *et al.* 1974). In Ancaster, it is still dark at 0400 hrs EDT and the data in Fig. 2 suggest that foraging starts just after 0600 hrs, which is close to the time of sunrise in Ancaster in late July. Figure 2 also indicates that the bees cease to forage by about noon. Early morning foraging coincides with the period of pollination in horticultural cucurbits: the flowers of most species of *Cucurbita* including *C. pepo* generally close by noon or shortly after (Free 1970, McGregor 1976). We observed bees digging in their tunnels in the afternoon, but not in the morning. Thus it appears that they provision cells in the morning, bringing in bright yellow loads of cucurbit pollen (Fig. 3), and use the afternoon to excavate and prepare cells for the next day.

On several occasions, females were observed entering one tunnel then immediately leaving it and flying into a neighbouring tunnel where they remained. Perhaps, when populations of nests are dense, females make mistakes when returning to their nests after foraging and recognize their error only upon entering the wrong tunnel. Hurd *et al.* (1974) also remarked on this behaviour where nest entrances were less than 2.5 cm apart, but noted that errors were less frequent when the distances between nest entrances were greater. We also noted that some females landed as much as 30 cm from their own burrows and, in wandering home, examined and entered a number of other burrows. The purpose of this behaviour is unknown, but it could serve to confuse parasites, such as parasitic miltogrammine flies which follow fossorial bees to their nests.

Bees were also observed in the foliage of a 3.5 m tall flowering almond (*Prunus triloba*) tree close to (4.0 meters) the nesting site. Although most bees appeared to be flying through the foliage, a few were seen to settle and groom themselves or just rest for a few moments on the leaves. Perhaps these bees were using the tree to orient themselves to the immediate area before leaving on a foraging trip (bees were seen to orient themselves to their individual entrance holes as well) or to thermoregulate and increase body temperature before leaving, or both.

Krombein *et al.* (1979) and Hurd *et al.* (1971,1974) refer to the squash and gourd bees as the most important pollinators of squash, gourds and pumpkins. Various cucurbits are grown in the area around Ancaster. The pollen we collected from the scopa (Fig. 3a) and plumose body hairs (Fig. 3b) of the bees was that of *Cucurbita* (Fig. 3b and c). Hurd *et al.* (1971) suggest that *P. pruinosa* has expanded its range with the cultivation of Cucurbitaceae, so it is a matter of debate and speculation as to whether the species is native to Canada.

Nevertheless, *P. pruinosa* is widely distributed through southern Ontario (Fig. 4), and our records extend the published range of this species beyond that suggested by the map of Hurd and Linsley (1970). If it is truly native to southern Ontario, there are only two native cucurbits, *Sicyos angulatus* and *Echinocystus lobata*, which could be used by the bees (Scoggan 1978). However, there is no evidence to date suggesting that *P. pruinosa* will pollinate flowers other than of the genus *Cucurbita* (R. Thorp, personal communication). The oldest specimen (1905) from Ontario (Fig. 4 caption) is from well after the introduction of cucurbit crops into Ontario.

Efforts have been made to assess the economic value of *P. pruinosa* as a pollinator for cucurbit crops (Tepedino 1981), and it has been attempted, or proposed, to introduce them into areas where cucurbits are grown (Michelbacher *et al.* 1971). In general, wild populations of these bees have been, and should be, encouraged. However, in Ancaster, these bees had become an urban pest, a situation (but much less severe) also recorded by M. V. Smith in Guelph in 1954 (personal communication).

Because southern Ontario is in the northernmost part of the range of this bee's range, and because they have both economic and nuisance qualities, it will be interesting to document more on the ecology, distribution, and value of these bees in Ontario.

FIGURE 3. Scanning electron micrographs of pollen of *Cucurbita* on the body of *Peponapis pruinosa* from Ancaster, Ontario, 28 July, 1987.
a. Scopa of *Peponapis pruinosa*, laden with cucurbit pollen. × 34
b. Dorsal abdomen of *Peponapis pruinosa* showing plumose hairs and attached cucurbit pollen grain. × 225
c. Cucurbit pollen grain, lateral to labium. × 440

FIGURE 4. The occurrence of *Peponapis pruinosa* in Ontario as evidenced by records of collections.
1. Ancaster (29 July, 1987; this study)
2. Strathroy (24 July 1922, 1 specimen, A.A. Wood, CNC)
3. St. Thomas (1 August 1923, 1 specimen, anonymous, CNC)
4. Minesing (5 August 1948, 1 specimen on Alsike clover, M.V. Smith, Guelph)
5. Guelph (4 September 1905, 1 specimen, F. Sherman, Guelph; 23 August 1973, 2 specimens, R.P. Macfarlane, Guelph; 11 August 1954, 7 specimens, M.V. Smith, Guelph)
6. Clarkson (1 August 1952, 14 specimens, D.H. Pengelly, Guelph)
There are no Canadian specimens in the collections at the Smithsonian Institution, at Cornell University, or at the University of California, Berkeley. No Canadian specimens were seen from any other U.S. collections during a 1964 revision of the species of *Peponapis* in America north of Mexico (G. Linsley, personal communication).

Acknowledgements

We are especially grateful to Mr. and Mrs. J. Michilsen, who brought the bees to our attention and allowed us to grid and dig their front lawn. We are happy to thank Dr. George Eickwort, Department of Entomology, Cornell University, Ithaca, N.Y. for confirming our identification of *Peponapis pruinosa* Say and Mr. Cliff Crompton, Biosystematics Research Centre, Agriculture Canada, Ottawa for identifying the pollen samples. We are grateful to Dr. M. Sarazin, also from the BRC for providing us with the records of collections in the National Insect Collection, to Drs. R. McGinley and B. Norden, Entomology, Smithsonian Institution, Washington, D. C. for information on the Smithsonian's records, and to Prof. G. Linsley, University of California, for his assistance on range records. Thanks

is also extended to D. Hamilton who helped with graphics and to D. Blades who helped excavate the nests. We have benefitted greatly from the advice and constructive comments of Prof. R. Thorp, University of California, Davis; Prof. G. Linsley, University of California, Berkeley; and anonymous reviewers. This research was funded by grants to P.G.K. from the Natural Sciences and Engineering Research Council of Canada (Grant A8098) and from Program 30 of the Ontario Ministry of Agriculture and Food contract with the University of Guelph.

References

Free, J.B. 1970. Insect Pollination of Crops. Academic Press Inc., New York. 544 pp.

Hurd, P.D. Jr., and E.G. Linsley. 1970. A classification of the squash and gourd bees *Peponapis* and *Xenoglossa* (Hymenoptera: Apoidea). University of California Publications in Entomology, 62. 39 pp.

Hurd, P.D., E.G. Linsley, and T.W. Whitaker. 1971. Squash and gourd bees (*Peponapis, Xenoglossa*) and the origin of the cultivated *Cucurbita*. Evolution, 25: 218-234.

Hurd, P.D. Jr., E.G. Linsley, and A.E. Michelbacher. 1974. Ecology of the squash and gourd bee, *Peponapis pruinosa*, on cultivated cucurbits in California (Hymenoptera: Apoidea). Smithsonian Contributions to Zoology, No. 168. 17 pp.

Krombein, K.V., P.D. Hurd, Jr., D.R. Smith and B.D. Burks. 1979. Catalog of Hymenoptera in America North of Mexico. Volume 2. Apocrita (Aculeata). Smithsonian Institution Press, Washington, D.C. 2209 pp.

Malyshev, S.I. 1935. The nesting habits of solitary bees, a comparative study. Eos, 11: 201-309.

Mathewson, J.A. 1965. The internal morphology of the eastern cucurbit bee, *Peponapis pruinosa* (Hymenoptera: Apoidea). Journal of the Kansas Entomological Society, 38:209-233.

Mathewson, J. A. 1968. Nest construction and life history of the eastern cucurbit bee, *Peponapis pruinosa* (Hymenoptera: Apoidea). Journal of the Kansas Entomological Society, 41:255-261.

McGregor, S.E. 1976. Insect Pollination Of Cultivated Crop Plants. United States Department Of Agriculture Handbook No. 496. 411 pp.

Michelbacher, A.E., P.D. Hurd Jr., and E.G. Linsley. 1971. Experimental introduction of squash bees (*Peponapis*) to improve yields of squashes, gourds and pumpkins. Bee World, 52:156-166.

Mitchell, T.B. 1962. Bees of the Eastern United States. Vol. 2. North Carolina Agricultural Experiment Station Technical Bulletin No. 141. 557 pp.

Michener, C. D. 1974. The Social Behavior of Bees: A Comparative Study. The Belknap Press Of Harvard University Press. Cambridge, Mass. 404 pp.

Rau, P. 1922. Ecological and behavioral notes on Missouri insects. Transactions of the Academy of Sciences of St. Louis, 24: 1-71.

Robertson, C. 1928. Flowers and Insects. Science Press, Carlinville, Ill. 221 pp.

Rozen, J. G. and R. Ayala. 1987. Nesting biology of the Squash bee *Peponapis utahensis* (Hymenoptera: Anthophoridae; Eucerini). Journal of the New York Entomological Society, 95:28-33.

Sakagami, S.F. and C.D. Michener. 1962. The Nest Architecture of the Sweat Bees (Halictinae): A Comparative Study. University of Kansas Press, Lawrence, Kansas. 135 pp.

Scoggan, H.J. 1978. Flora Of Canada, Pt 3. Dicotyledoneae (Saururaceae to Violaceae). Canada National Museum Of Natural Sciences Publications In Botany No. 7. 200 pp.

Stephen, W.P., G.E. Bohart, and P.F. Torchio. 1969. The Biology and External Morphology of Bees with a Synopsis of Northwestern America. Agricultural Experimental Station Bulletin, Oregon State University, Corvallis. 200 pp.

Tepedino, V.J. 1981. The pollination efficiency of the squash bee (*Peponapis pruinosa*) and the honey bee (*Apis mellifera*) on summer squash (*Cucurbita pepo*). Journal of the Kansas Entomological Society, 54: 359-377.

(Received 15 February, 1988; accepted 31 May, 1988)

NEW SPECIES AND PHYLOGENETIC ANALYSIS OF *LOTOPHILA* LIOY (DIPTERA: SPHAEROCERIDAE)

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Abstract *Proc. Ent. Soc. Ont.* 119: 17-33.

The Holarctic genus *Lotophila* Lioy is revised. Five species are recognized: *L. atra* (Meigen), *L. confusa* n. sp. (type locality Nuevo Leon, Mexico), *L. pallida* Hayashi, *L. bicolor* n. sp. (type locality Helumbu District, Nepal), and *L. norrbomi* (Papp) n. comb. The latter species is transferred from *Copromyza* Fallén. The synonymy of *Borborus modestus* Meigen, *B. lugens* Meigen, *B. geniculatus* Macquart, and *B. analis* Roser with *L. atra* is confirmed, and *B. aeneus* Macquart is considered a new synonym. Lectotypes are designated for *B. modestus*, *B. geniculatus*, *B. analis*, and *B. aeneus*. Variation among populations of *L. confusa* is described and discussed. Phylogenetic relationships within *Lotophila* and between it and other genera of Copromyzini are analyzed. Illustrations and a key to species are provided.

Introduction

Norrbom and Kim (1984) resurrected the genus *Lotophila* Lioy and analyzed its relationships to other taxa of the subfamily Copromyzinae. They included only one species, *L. atra* (Meigen), which breeds in dung of cattle and other animals and is one of the most common Holarctic species of Sphaeroceridae. Hayashi (1985) described a second species, *L. pallida*, from Japan, and *Copromyza norrbomi* Papp, recently described from India and Nepal (Papp 1988), also belongs in this genus. As part of a comprehensive revisionary study of the Copromyzinae, we describe two additional species of *Lotophila* in this paper, provide a key to all five species, and analyze the phylogenetic relationships within the genus.

Materials and Methods

We follow the morphological terminology of McAlpine (1981) and Marshall and Richards (1987) except as noted. The male sclerite here referred to as synsternite 6+7 has previously been considered by most sphaerocerid workers to be derived only from the sclerites of segment 6. Kim and Cook (1968) called it sternite 6 + tergite 6, whereas Griffiths (1972) interpreted it as sternite 6, with the assumption that the extra spiracle on the left side migrated from sternite 7. Throughout the Sphaeroceridae, this sclerite bears not only the two spiracles on the left side, but also two distinct pairs of sensilla trichodea. These previously overlooked sensilla strongly suggest that this sclerite is synsternite 6+7. It follows from this that the next sclerite, sometimes partially fused with synsternite 6+7, is sternite 8, not sternite 7. The "genital arch" of Norrbom and Kim (1984) therefore can not be a fusion of sternite 8 and the epandrium, and it is here interpreted as just the epandrium. We refer to the parts of the aedeagus according to their actual dorsoventral orientation, which is opposite the original condition in the Diptera due to the fact that the aedeagus is bent forward in the Muscomorpha. The parts of the distiphallus are labelled in figures 6 and 7.

Acronyms for depositories of specimens cited in the text are as follows: Canadian National Collection, Ottawa (CNC); Muséum d'Histoire naturelle de Genève (MHNG); Museum National d'-Histoire Naturelle, Paris (MNHNP); National Institute of Agricultural Sciences, Tsukuba, Ibaraki-ken, Japan (NIASJ); Naturhistorisches Museum, Wien (NMW); Staatlisches Museum für Naturkunde, Stuttgart (SMNS); University of Guelph, Ontario (GUE); National Museum of Natural History, Smithsonian Institution (USNM); Utah State University, Logan (USUL); Zoological Institute, University of Lund (ZIL).

We follow the system of Marshall (1985) to indicate character weighting in the cladogram showing our hypothesis of phylogenetic relationships among the species of *Lotophila* (Fig. 1). Species of the sister group (*Dudaia* Hedicke, *Afroborborus* Curran, *Borborillus* Duda, *Metaborborus* Vanschuytbroeck, and *Gymnometopina* Hedicke), as well as other Copromyzini (*Crumomyia* Macquart, *Alloborborus* Duda, and *Copromyza* Fallén), were examined for purposes of outgroup comparison.

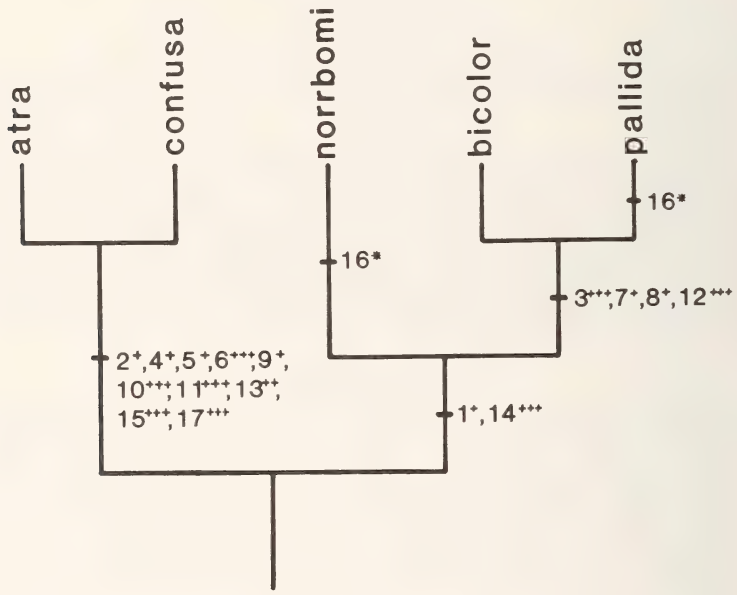

FIGURE 1. Hypothesis of phylogenetic relationships among species of *Lotophila*. Numbers refer to the apomorphic states of characters listed in Tables I and II. Character weighting system follows Marshall (1985). Characters with (+++) are complex, unique or rare in the Copromyzini, and considered unlikely to be the result of homoplasy; characters with (+) are of uncertain polarity or are highly variable in other Copromyzini; and those with (++) are intermediate. Characters with (*) represent homoplasy.

Lotophila Lioy

(part) *Borborus*; Meigen 1830: 198; Becker 1905: 23.
Lotophila Lioy 1864: 1113 (Type species – *Borborus lugens* Meigen, by designation of Richards 1930: 264, = *B. ater* Meigen); Norrbom and Kim 1984: 305; Hayashi 1985: 561; Pitkin 1988: 30; Papp 1988: 466.
(part) *Olina*; Becker 1905: 27.
Borborus (*Olina*); Duda 1923: 58, 99.
Scatophora; Spuler 1925: 1.
Copromyza (*Olina*); Richards 1930: 263, 315.
Borborus (*Borborus*); Duda 1938: 35.
Copromyza (*Olinea*) Richards 1961: 561 (*nomen nudum*).
Copromyza (*Olinea*) Richards 1965: 719 (Type species – *Borborus ater* Meigen, by original designation).
Copromyza (*Lotophila*); Papp 1984: 74.

Diagnosis. Differing from all other Copromyzini except *Achaetothorax* Hedicke by the absence

of a ventroapical spur on the hind tibia. *Lotophila* is easily distinguished from *Achaetothorax* by the lack of rows of stout, spinelike ventral setae on the hind femur, and in having the scutum entirely microtrichose.

Description. Mostly black, 2.4-4.0 mm long. Head – largely microtrichose, subquadrate; frons yellow or orange anteriorly; genal seta small; ocellar setae posterior to median ocellus; postocular setae in single row. Thorax – scutum and scutellum entirely microtrichose, but varying in density giving appearance of faint stripes between acrostichal and dorsocentral setae; acrostichal setae in 2 rows, often a few additional setae posteriorly; usually 3 (1+2) dorsocentral macrosetae, but anterior 2 often poorly or sometimes not at all differentiated; scutellum with 2-5 pairs of marginal setae, if more than 2, all stout and subequal; katepisternum without dorsal macroseta. Legs – mid tibia with whorl of small preapical setae, usually with 1-2 small anterior setae and often 1 small posteroventral seta between basal 2/5 and 3/4; hind tibia with small preapical dorsal seta, without ventroapical spur or anteroventral seta; male fore and hind metatarsi without hooklike apical spurs. Wing – cell dm elongate, crossvein dm-cu in apical third of wing; vein M extending to wing margin; vein Cu_1 ending short distance beyond dm-cu, not extending to margin; crossveins r-m and dm-cu unbanded; r-m at 1/3 to 1/2 distance from bm-cu to dm-cu. Male abdomen – synsternite 6-7 without posterior median lobe, membrane posterior to its right tip often sclerotized and sometimes fused to synsternite; epandrium usually without lateral cleft; hypandrial apodeme greatly reduced; cerci fused to epandrium; postphallic sclerite present between basiphallus and interparameral sclerite (sternite 10); basiphallus with epiphallus reduced but with median ventral apodeme (preepiphallus); distiphallus with the following: transverse medial sclerite dorsobasally, usually with 2 lateral lobes; slender elongate dorsomedial sclerite; pair of multitoothed, dorsally projecting lateral sclerites; and pair of large lateral sclerites, strongly sclerotized basally, less so in apical half, and with subapical hook or acute apex. Female abdomen – terminalia long and telescoping; 2 spermathecae, apodeme opposite duct opening small, its apex membranous.

Remarks. Spuler (1925) considered *Scatophora* Robineau-Desvoidy (1830) to be the valid name for this genus, and its type species, *S. carolinensis* Robineau-Desvoidy (by designation of Spuler 1925), to be the valid name for the species we recognize as *L. atra* (Meigen) (Robineau-Desvoidy 1830 was published earlier in the year than Meigen 1830). This synonymy is doubtful, as Spuler based it only on Robineau-Desvoidy's description of *Scatophora* as having the hind tibia without an apical spine. As indicated by Duda (1938), Robineau-Desvoidy also stated that *S. carolinensis* was "2 lignes 1/3" (approximately 4.9 mm) long, whereas *L. atra* is never more than 4.0 mm in length. Robineau-Desvoidy's statements "pattes entremêlées de noirâtre et de fauve" (legs of intermixed blackish and tawny) and "ailes assez fuligineuses" (wings rather fuliginous) also do not fit *L. atra*. Because their descriptions are so brief and the types are apparently lost (there are no sphaerocerid types in the Robineau-Desvoidy collection in the MNHNP), it is unlikely that *Scatophora* and the other Robineau-Desvoidy names attributed to the Sphaeroceridae (see Papp 1984) will ever be recognized.

Relationships to other Copromyzini. *Lotophila* is the sister group of a monophyletic group that includes *Gymnometopina* Hedicke, *Metaborborus* Vanschuytbroeck, *Dudaia* Hedicke, *Afroborborus* Curran (Norrbom and Kim 1984, 1985), and *Borborillus* Duda (at least *B. uncinatus* (Duda) and *B. vitripennis* (Meigen)). The latter five genera share at least two synapomorphies: 1) male abdominal synsternite 6-7 with a medial posterior lobe; and 2) the male cerci separated from the epandrium. *Lotophila* shares with these taxa the following apomorphies of the male terminalia: 1) the presence of a postphallic sclerite between the basiphallus and the interparameral sclerite (sternite 10); and 2) the epandrium (genital arch) without lateral clefts. The only male specimen of *L. norrbomi* that we have examined has what appears to be a cleft on the right side of the epandrium, but because the left side is entirely fused and no clefts are present in the other species of *Lotophila*, we continue to regard their loss, at least on the left side, as a synapomorphy. Norrbom and Kim (1984) also stated that the cerci were partially cleft from the epandrium in *L. atra* and that this partial separation could be interpreted as an additional synapomorphy. Reexamination of this structure in *L. atra* and *L. confusa* indicates that what Norrbom and Kim interpreted as a cleft is an internal ridge. The cerci are fused to the epandrium (the plesiomorphic state) in all species of *Lotophila*.

Probable synapomorphies indicating the monophyly of *Lotophila* include the loss of the ventroapical spur on the hind tibia, the shape of the dorsally projecting sclerites of the distiphallus, and the presence of the ventral medial apodeme on the basiphallus. The loss of the spur on the hind tibia in *Achaetothorax* and *Lotophila* clearly occurred independently, as indicated by numerous synapomorphies each taxon shares with other genera. Sclerites that are possibly homologous with the dorsally projecting sclerites of the distiphallus of *Lotophila* are present in most *Gymnometopina*, *Dudaia*, and *Metaborborus* species, but they are shorter and do not have as many teeth as in *Lotophila*. In the outgroup, except in some species of *Crumomyia* Macquart and *Dudaia*, the basiphallus does not have a ventral medial apodeme. We tentatively hypothesize that the occurrence of the apodeme in these other two genera is the result of homoplasy.

TABLE I. Characters and character states used in phylogenetic analysis of the species of *Lotophila*. Character state 0 is hypothesized as plesiomorphic and state 1 as derived unless otherwise stated.

1. Face microtrichial pattern – 0) entirely microtrichose; 1) lower corners with bare spot. Variable in outgroup, polarity is uncertain.
2. Frons microtrichial pattern – 0) entirely microtrichose; 1) with large medial bare area(s).
3. Anterior fronto-orbital seta – 0) more than half as long as posterior seta; 1) reduced, about 1/3 as long as posterior seta or absent.
4. Anepimeron microtrichial pattern – 0) entirely microtrichose; 1) largely bare.
5. Meron microtrichial pattern – 0) microtrichose, at least medially; 1) often with medial bare spot.
6. Scutellar marginal bristles – 0) 2 pairs; 1) 4-5 pairs.
7. Fore coxa color – 0) at least base dark brown to black; 1) entirely yellow. Variable in outgroup, polarity is uncertain.
8. Femora color – 0) mostly black, at least basally; 1) mostly yellow, with apices sometimes dark brown. Variable in outgroup, polarity is uncertain.
9. Fore femur microtrichial pattern – 0) entirely microtrichose; 1) with large posterior bare area. Variable in outgroup, polarity is uncertain.
10. Male sternite 5 – 0) without apodeme or with symmetrical basal apodeme; 1) with asymmetrical basal apodeme, more well developed on left side.
11. Epandrium – 0) not expanded anterodorsally; 1) expanded anterodorsally.
12. Cercus – 0) well developed; 1) small, poorly differentiated from epandrium.
13. Surstylus – 0) anterior and ventral or posteroventral margins not forming strongly acute angle; 1) anterior and posteroventral margins forming sharply acute angle.
14. Dorsally projecting sclerites of distiphallus – 0) slender, straight, with small apical teeth; 1) broad, curved, with large marginal and apical teeth.
15. Lateral sclerite of distiphallus – 0) strongly sclerotized part short, gradually curved dorsally, or entirely straight; 1) strongly sclerotized part elongate, straight, with apex turned dorsally.
16. Lateral sclerite of distiphallus – 0) strongly sclerotized part without apical teeth; 1) strongly sclerotized part with at least 2 apical teeth.
17. Paramere – 0) apical lobe without large lateral lobe; 1) apical lobe with large lateral lobe.

Relationships within Lotophila. Tables I and II list the characters and their states that we consider relevant for the analysis of the phylogenetic relationships within *Lotophila*. Characters also analyzed but considered autapomorphic for particular species include the following: *L. atra* – female abdominal sternite 4 weakly sclerotized; *L. norrbomi* – meron almost entirely bare, basal sclerite of distiphallus with lateral lobes poorly developed, medial sclerite of distiphallus with subapical lobes, lateral sclerite of distiphallus with large dentate lobes at apex of strongly sclerotized part; *L. bicolor* – epandrium posterodorsally expanded, medial sclerite of distiphallus forked apically; *L. pallida* – anepisternum entirely microtrichose, female abdominal sternites 2-4 weakly sclerotized, male abdominal sternites 2-3 weakly sclerotized, male abdominal sternite 5 with a symmetrical basal apodeme.

The most parsimonious cladogram based on the characters of Tables I and II is represented in Fig.

TABLE II. Character state distributions in the species of *Lotophila*.

Character	*atra*	*confusa*	*norrbomi*	*bicolor*	*pallida*
1	0	0	1	1	1
2	1	1	0	0	0
3	0	0	0	1	1
4	1	1	0	0	0
5	1	1	0	0	0
6	1	1	0	0	0
7	0	0	0	1	1
8	0	0	0	1	1
9	1	1	0	0	0
10	1	1	0	0	0
11	1	1	0	0	0
12	0	0	0	1	1
13	1	1	0	0	0
14	0	0	1	1	1
15	1	1	0	0	0
16	0	0	1	0	1
17	1	1	0	0	0

1. Several obvious apomorphies suggest that *L. atra* and *L. confusa* form a monophyletic subgroup, which is probably the sister group of the other three species. Of those three, *L. bicolor* and *L. pallida* appear more closely related. *Lotophila norrbomi* might be more closely related to *L. atra* and *L. confusa* than to *L. bicolor* and *L. pallida*, especially if we interpreted the polarities of characters 1, 7 and 8 incorrectly. These characters involve color and microtrichial patterns, which vary greatly in the Copromyzini, and we consider them more subject to homoplasy than character 14, a complex structural character. We interpret the presence of a symmetrical basal apodeme on male sternite 5 in *L. pallida* as an independently derived character state rather than a synapomorphy that *L. pallida* shares with *L. atra* and *L. confusa*, which have an asymmetrical apodeme, because of the different shapes of the apodemes and because of the distribution of other character states. Character 16, which suggests a closer relationship between *L. norrbomi* and *L. pallida*, is here considered the result of homoplasy.

Key To The Species Of *Lotophila*

1. Scutellum with 4-5 pairs of marginal setae; frons with large shiny bare area medially (Fig. 2A-B); anepimeron largely bare, shiny (Fig. 2C-D); fore femur with large posterior shiny area 2
   Scutellum with 2 pairs of marginal setae; frons, anepimeron (Fig. 3), and fore femur entirely microtrichose 3
2. Bare shiny area of frons usually divided into 3 parts (Fig. 2B); fore coxa entirely dark brown; female abdominal sternite 4 as strongly sclerotized as other sternites; distiphallus of male

(Fig. 6B-D) with apex of weakly sclerotized apical part of lateral sclerite strongly acute, ending close to medial sclerite; apex of strongly sclerotized basal part of lateral sclerite gradually dorsally curved ..... *confusa* n. sp.
Bare shiny area of frons undivided (Fig. 2A); fore coxa usually with at least apex yellow; female abdominal sternite 4 weakly sclerotized, poorly differentiated from pleural membrane; distiphallus (Fig. 6A) with weakly sclerotized apical part of lateral sclerite with acute subapical lobe far removed from medial sclerite; apex of strongly sclerotized basal part of lateral sclerite sharply dorsally turned ..... *atra* (Meigen)

3. Hind femur mostly dark brown or black, sometimes with yellow spot or band subapically; meron (Fig. 3A) mostly bare, shiny; distiphallus with apex of strongly sclerotized basal part of lateral sclerite elongate, multitoothed, resembling dorsally projecting sclerite (Fig. 6E); distiphallus with basal sclerite broad, platelike, with lateral lobes very small (Fig. 7B) ..... *norrbomi* (Papp)
Hind femur yellow with apical 1/4 to 1/5 dark brown; meron (Fig. 3B) microtrichose, dull; distiphallus with apex of strongly sclerotized basal part of lateral sclerite at most with 2 teeth, not projecting dorsally (Fig. 6F-G); distiphallus with basal sclerite narrower, with lateral lobes large (Fig. 7C-D) 4
4. Anepisternum entirely microtrichose, dull; abdominal sternites 2-3 of male and 2-4 of female weakly sclerotized; surstylus (Fig. 5F-G) elongate, only slightly wider at apex than at base; distiphallus (Fig. 6F, 7C) with medial sclerite simple, not forked apically ..... *pallida* Hayashi
Anepisternum (Fig. 3B) mostly bare, shiny, except narrowly microtrichose along dorsal margin and in lower posterior corner; all abdominal sternites of male strongly sclerotized, female unknown; surstylus (Fig. 4C) triangular, much broader apically than at base; distiphallus (Fig. 6G, 7D) with medial sclerite forked apically ..... *bicolor* n. sp.

Lotophila atra (Meigen)

(Fig. 2A,C, 4A, 5A-B, 6A, 7A, 8A)

Borborus ater Meigen 1830: 203 (Lectotype ♂ (NMW), "Von Hrn. von Winthem", locality not stated, probably W. Germany: Hamburg (see Pont 1986); designated by Norrbom and Kim 1984: 307).
Borborus modestus Meigen 1830: 203 (Lectotype ♂ (NMW), France: Montpellier, Winthem; here designated).
Borborus lugens Meigen 1830: 205 (Lectotype ♀ (NMW), France: region of Lyon, Winthem; designated by Norrbom and Kim 1984: 307).
Borborus geniculatus Macquart 1835: 567 (Lectotype ♂ (MNHNP), France; here designated).
Borborus analis Roser 1840: 64 (Lectotype ♂ (SMNS), W. Germany: Würtemberg; here designated).
Borborus aeneus Macquart 1849: 500 (Lectotype ♂ (MNHNP), Algeria: environs of Algiers or Constantine, IV, Lucas; here designated). n. syn.
Lotophila lugens; Lioy 1864: 1113.
Olina geniculata; Becker 1905: 27.
Olina ferruginea Becker 1908: 198 (Holotype ♂ (probably Zoological Museum, Humboldt Universität, Berlin), Madeira; not examined, synonymy following Duda 1938: 36).
Borborus (*Olina*) *geniculata*; Duda 1923: 99.
Scatophora carolinensis; Spuler 1925: 1.
Copromyza (*Olina*) *hirtipes*; Richards 1930: 315.
Borborus (*Borborus*) *ater*; Duda 1938: 35.
Copromyza (*Olinea*) *atra*; Richards 1961: 562, 1965: 719.
Lotophila atra; Norrbom and Kim 1984: 306 (in part); Hayashi 1985: 563; Pitkin 1988: 30; Papp 1988: 466.
Copromyza (*Lotophila*) *atra*; Papp 1984: 74.

Description. 2.5-4.0 mm long. Head – frons with anterior yellow or orange area usually discrete,

narrow and transverse or, if broader, M-shaped; frons with broad medial bare shiny area extending posteriorly lateral to ocelli (Fig. 2A); anterior fronto-orbital seta about half as long to subequal to posterior seta; gena bare except anterior and extreme ventral margins; face entirely microtrichose. Thorax (Fig. 2C) – with following areas bare and shiny: postpronotal lobe laterally and often posterodorsally, anepisternum except upper posterior corner, anterior 3/5 of anepimeron, katepisternum except posterior dorsal margin and narrowly along sternal suture; meron often with medial bare spot; scutellum with 4-5 pairs of short stout marginal setae, apical pair slightly longer. Legs – femora and tibiae blackish except extreme bases and apices yellow; fore coxa usually with at least apex yellow; fore femur with large posterior shiny area without microtrichia. Male abdomen – sternites 2-5 strongly sclerotized; sternite 5 irregular, shaped like broad inverted U, basally with broad apodeme more strongly developed on left side; epandrium (Fig. 4A) relatively small but expanded anterodorsally, without lateral cleft; cercus well developed; surstylus (Fig. 5A-B) triangular, anterior margin concave and forming acute angle with posteroventral margin, the latter not strongly concave subapically; paramere (Fig. 8A) with short anterior lobe, apical lobe with large lateral lobe; distiphallus (Fig. 6A, 7A) with transverse basal sclerite moderately broad, its lateral lobes well developed; dorsally projecting sclerite slender, almost straight, with only apical teeth; lateral sclerite with apex of strongly sclerotized part acute, sharply turned dorsally, weaker apical part with subapical acute lobe well separated from medial sclerite; medial sclerite simple. Female abdomen – sternite 4 weakly sclerotized, poorly differentiated from pleural membrane.

Distribution. Middle latitudes of Holarctic Region. See Norrbom and Kim (1984) for more detailed data (but note that the records from Tibet, Arizona, and Mexico apply to *L. confusa*). Papp (1988) also reported this species from northern Pakistan.

Remarks. Norrbom and Kim (1984) included within *L. atra* several populations that we recognize here as a distinct species, *L. confusa*.

All of the putative type specimens discussed in this section, including the paralectotypes, are *L. atra*. The Meigen specimens from the NMW generally have the same types of labels. 1) a small label with the species name in Meigen's writing, as verified by Dr. Ruth Lichtenberg, curator of the NMW Diptera collection. 2) a label with "Coll. Winth." in machine printing and a species name in freehand; these were added when the Winthem Collection was incorporated into the NMW general collection; the writing is of a museum worker at that time, it is not Duda's as stated by Norrbom and Kim (1984). 3) a red "TYPE" label, also not original; the holotype of *Borborus clunicrus* Duda (1923) has such a label, thus they may have been added after this date.

The lectotype and 5♂ paralectotypes of *B. ater* each have a "Coll. Winth., ater" label, a red "TYPE" label, and a label with "Olina geniculata" in Duda's writing. The lectotype of *B. modestus* has the following labels: "Montpellier" in freehand; "modestus" in Meigen's writing; "Coll. Winth., modestus"; "geniculatus Macq." in Duda's writing; and a red "TYPE" label. The lectotype of *B. lugens* has labels with "lugens" in Meigen's writing, "Coll. Winth., lugens", "geniculata Mcq. d. Duda" in Duda's writing, and a red "TYPE" label. The lectotype of *B. analis* has labels with "Borborus analis, m." in what is probably Roser's writing, "Borboris analis R. 35.", and a Becker determination label with "Olina geniculata Meig". Only single putative syntypes of each of the last 3 species were found, but because Meigen and Roser did not state the number of specimens they had, we have designated these specimens as lectotypes.

There are two male syntypes of *B. geniculatus* in Box 8 of the Macquart Collection in the MNHNP. Both have labels with "MUSEUM PARIS, Lille, Macquart". The lectotype also has a label with "Borborus geniculatus" in Macquart's writing and one with "970". The paralectotype has a label with "M: 102 Borborus geniculatus" in Macquart's writing. There is also a male that we do not consider a paralectotype with a label with "Borborus geniculatus ?" in Macquart's writing. Macquart's personal collection in Lille may contain additional paralectotypes; he mentioned females as well as males in the description. Macquart (1849) stated that the types of *B. aeneus* were female, but this is probably an error because his figure (Pl. 6, Fig. 12) is of a male, and the 3 putative syntypes of *B. aeneus* in the Macquart Collection of the MNHNP, in a box labelled "No. 6, Mission H. Lucas, Algérie", are males. All 3 have machine printed labels with "MUSEUM PARIS, ALGERIE, COLL. H. LUCAS 78-49". The lectotype also has a blue label with "270", matching the number for this

species in Macquart (1849), and a label with "Borborus aeneus Macqt. sp. nov." in Macquart's writing. One paralectotype also has a blue label with "270" and a label with "Borborus aeneus Macqt.": the other has a blue label with "437". Macquart's figure shows the hind tibia with an apical spur, but this is probably an error because the legs are obviously stylized; the fore tibiae have apical spurs, which are never present in Copromyzinae, and the tarsi, especially the hind metatarsi, are inaccurate for any sphaerocerid.

Specimens examined. Lectotypes of *B. ater*, *B. modestus*, *B. lugens*, *B. analis*, *B. geniculatus*, and *B. aeneus*; 5♂ paralectotypes of *ater*, 1♂ paralectotype of *B. geniculatus*, and 2♂ paralectotypes of *B. aeneus* (see "Remarks"). We have examined over 800 specimens, the complete data for which we will not list here. Many were previously listed by Norrbom and Kim (1984). These included Nearctic specimens from the Canadian provinces of British Columbia, Alberta, Ontario, Quebec, New Brunswick, Nova Scotia, and Newfoundland, and all states of the United States except N. Dakota, Wyoming, Utah, Nevada, Delaware, Kentucky, Mississippi, Alabama, Louisiana, Texas, Arizona, Alaska, and Hawaii. We have also seen Palaearctic specimens from Norway, Sweden, Denmark, England, Scotland, The Netherlands, Belgium, France, W. Germany, Switzerland, Austria, Spain, Rumania, the Soviet Union (Uzbek), Crete, Morocco, Algeria, and the Azores.

TABLE III. Characters varying among populations of *L. confusa* and *L. atra*.

18. Frons microtrichial pattern – a) with 3 bare areas; b) with 1 bare area.
19. Color of fore coxa – a) partly yellow; b) entirely dark.
20. Strongly sclerotized part of lateral sclerite of distiphallus – a) apex sharply turned; b) apex gradually curved.
21. Weakly sclerotized part of lateral sclerite of distiphallus – a) with apical hooks far from medial sclerite; b) with apex acute, ending at medial sclerite; c) with apex acute, extending beyond medial sclerite.
22. Anepisternum microtrichial pattern – a) dorsal margin microtrichose; b) only posterior corner microtrichose.
23. Postpronotal lobe microtrichial pattern – a) entirely microtrichose; b) with a small lateral bare spot; c) with a large lateral and dorsal bare spot.
24. Surstylus – a) posteroventral margin convex or slightly concave subapically; b) posteroventral margin strongly concave subapically.

TABLE IV. Character state distributions in populations of *L. confusa* and *L. atra*.

Character	*atra*	*confusa* Mexico	*confusa* Arizona	*confusa* Alaska	*confusa* China
18	b	a (rarely b)	a	a (rarely b)	a
19	a (rarely b)	b	b	b	b
20	a	b	b	b	b
21	a	b	b	b	c
22	b	a	b	b	a
23	c	a/b	b	b	a
24	a	b	b	b	a

Lotophila confusa n. sp.

(Fig. 2B,D, 5C-E, 6B-D, 8B)

(part) *Lotophila atra*; Norrbom and Kim 1984: 306.

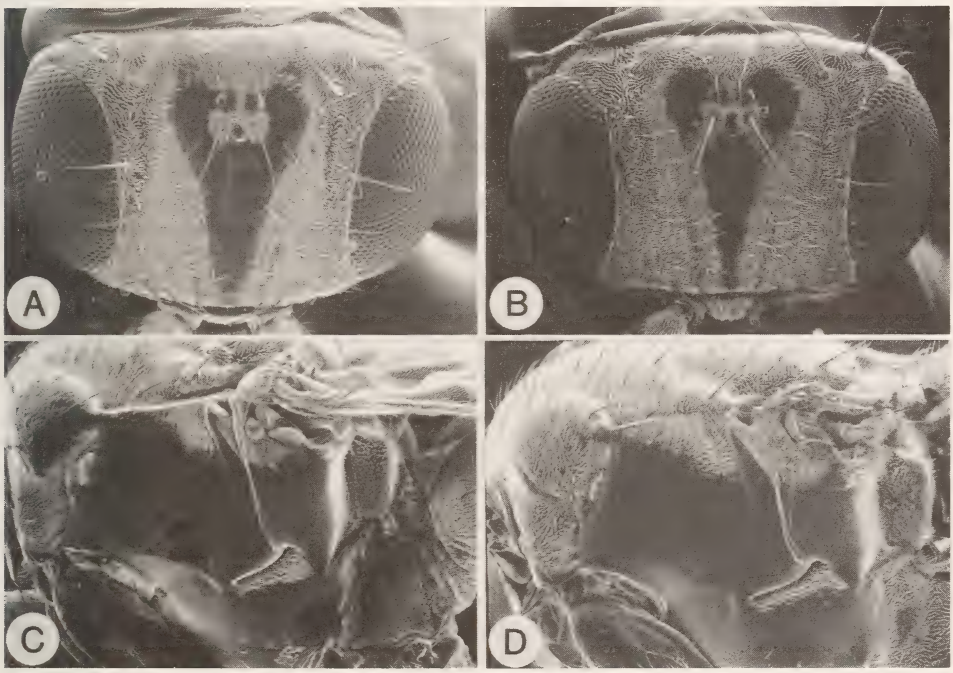

FIGURE 2. Scanning electron photomicrographs: A, C – *L. atra*, U.S.A., Virginia; B, D – *L. confusa*, Mexico, Mexico; A, B – head, dorsal view; C, D – thorax, left lateral view.

Description. 2.7-3.5 mm long. Head – frons with anterior yellow or orange area usually discrete, narrow and transverse or, if broader, M-shaped; frons usually with 3 bare shiny areas, 1 medially and 1 on each side of ocelli (Fig. 2B), these rarely connected; anterior fronto-orbital seta about half as long to subequal to posterior seta; gena bare except anterior and extreme ventral margins; face entirely microtrichose. Thorax – with following areas bare and shiny: anepisternum except upper posterior corner and sometimes (specimens from Mexico and China) dorsal margin (Fig. 2D), anterior 3/5 of anepimeron, katepisternum except posterior dorsal margin and narrowly along sternal suture; meron often with medial bare spot; postpronotal lobe sometimes with small lateral bare spot but never bare dorsally; scutellum with 4-5 pairs of short stout marginal setae, apical pair slightly longer. Legs – femora and tibiae blackish except extreme bases and apices yellow; fore coxa entirely dark brown to black; fore femur with large posterior shiny area without microtrichia. Male abdomen – sternites 2-5 strongly sclerotized; sternite 5 irregular, shaped like broad inverted U, basally with broad apodeme more strongly developed on left side; epandrium (similar to Fig. 4A) relatively small but expanded anterodorsally, without lateral cleft; cercus well developed; surstylus (Fig. 5C-E) triangular, anterior margin concave and forming acute angle with posteroventral margin, the latter strongly concave subapically (except in specimen from China, Fig. 5C); paramere (Fig. 8B) with short anterior lobe, apical lobe with large lateral lobe; distiphallus (Fig. 6B-D) with transverse basal sclerite moderately broad,

its lateral lobes well developed; dorsally projecting sclerite slender, almost straight, with only apical teeth; lateral sclerite with apex of strongly sclerotized part acute, gradually dorsally curved, weaker apical part with apex strongly acute, elongate, extending to or (in specimen from China, Fig. 6D) slightly beyond medial sclerite; medial sclerite simple. Female abdomen – sternites 2-5 strongly sclerotized.

Distribution. Highlands of northern and central Mexico, Arizona, and Szechwan; Alaska at lower elevations. Probably also occurring in Rocky Mountains and more extensively, especially at high elevations, in the eastern Palaearctic Region.

Remarks. The populations that we recognize here as *L. confusa* present an interesting systematic problem. Norrbom and Kim (1984) indicated that specimens examined from China, Arizona, and Mexico differed in some respects from typical *L. atra*, but treated them as that species. Discovery of additional material, especially the Alaskan population, and additional study indicates that they represent at least one distinct species. These populations differ consistently from *L. atra* in the shape of the apices of both the strongly and weakly sclerotized parts of the lateral sclerite of the distiphallus, the sclerotization of female sternite 4 (at least in females from Mexico and Alaska, none are known yet from Arizona or China), usually the color of the fore coxa (which varies in *L. atra*), and usually the microtrichial pattern of the frons, in which the bare area is divided (except in 1 of 33 specimens from Mexico and 3 of 17 from Alaska).

The variation in several characters among these populations and *L. atra* is shown in Tables III and IV. The specimens from Alaska and Arizona are most similar, which suggests that additional populations of *L. confusa* may occur in the Rockies. The specimen from China differs most in the characters of the male genitalia, but it and specimens from Mexico have the most similar microtrichial patterns, with the entire dorsal margin of the anepisternum microtrichose and usually the postpronotal lobe entirely microtrichose. Some specimens from northern Mexico have a small lateral bare spot on the postpronotal lobe. The Mexican, Arizonan, Alaskan, and especially the Chinese populations may eventually prove to represent different species, but given the number of specimens on hand, their geographic distributions, and the character state distributions among them, we believe it is untenable to recognize them as such at this time.

Etymology. The name of this species is derived from the Latin "confusio" which refers to its previous taxonomic status.

Holotype. (CNC), MEXICO: Nuevo Leon, E slope Cerro Potosí, 9200 ft, "human dung", V.1971, A. Newton.

Paratypes. All from Mexico. Same data as holotype, 3♂1 ♀ (GUE), 2 (USNM); Nuevo Leon, Cerro Potosí, NW of 18 de Marzo, 3000 m., 27.VI.1986, M. Sörensson and B. Mårtensson, 2♂ (ZIL) 1♂1 ♀ (USNM); Durango, El Salto, 4.VIII.1971, D. W. Davis, 2♂6 ♀ (USUL), 1♂2 ♀ (USNM); Veracruz, 21 mi. W of Orizaba, 4.IX.1974, W. Hanson and G. Bohart, 1 ♂ (USNM); Mexico, 10 mi. E of Toluca, 8900 ft., 31.VII.1954, J. G. Chillcott, 4♂2 ♀ (CNC), 2♂2 ♀ (USNM); Popocateptl, 12,000 ft., 11.VIII.1938, G. O. Lee, 1 specimen without abdomen (USNM).

Additional specimens examined. UNITED STATES: Arizona: White Mts., Coulter Ranch, 9200 ft., 28.VI.1947, J. L. Sperry, 1♂ (USNM); Alpine, 23.VI.1947, J. L. Sperry, 1 ♂ (USNM); Alaska: Richardson Hwy., km. 206, dung traps and sweeping, 9-20.VI.1987, S. A. Marshall, 8♂4 ♀ (GUE), 2♂ 2♀ (USNM); Richardson Hwy., 20 mi. S of Delta Jct., Donnelly Dome, dung trap, 20.VIII.1985, S. A. Marshall, 1♂ (GUE); CHINA: "Tibet border, Yu-Long-Gong" [Szechwan, U Long Kong, nr. Tatsienlu (= Kangding), approx. 200 km E Tibet border], 14,000 ft., 14.VIII.1930, D. C. Graham, 1♂ (USNM).

Lotophila norrbomi (Papp), n. comb.

(Fig. 3A, 4B, 6E, 7B, 8C)

Copromyza norrbomi Papp 1988: 467 (Holotype ♂ (MHNG), INDIA: W. Bengal, Darjeeling Dist., Tonglu, 3100 m, 16.X.1978, C. Besuchet & I. Löbl).

Description. 3.3-3.8 mm long. Head – frons entirely microtrichose, with anterior yellow or

orange area discrete, usually M-shaped; anterior fronto-orbital seta slightly more than half as long as posterior seta; genal bare area T-shaped, at midpoint height of microtrichose area about 2/3 that of bare area; face microtrichose except large bare spot in each lower corner. Thorax (Fig. 3A) – postpronotal lobe and anepimeron entirely microtrichose; anepisternum bare except very narrowly along dorsal and posterior margins; meron bare except dorsally; katepisternum bare except posterior half of dorsal margin and narrowly along sternal suture; scutellum with 2 pairs of marginal setae, basal pair smaller than apical pair. Legs – femora black, at least basally; hind femur entirely black except for ventral spot or complete band of yellow or orange at 4/5; fore coxa entirely black; fore femur entirely microtrichose. Male abdomen – sternites 2-5 strongly sclerotized; sternite 5 rounded basally, without apodeme, posterior corners not strongly narrowed; epandrium (Fig. 4B) relatively small, not unusually expanded, with lateral cleft only on right side; cercus well developed; surstylus triangular, anterior margin convex; paramere (Fig. 8C) with strong posterior bend and with subapical cluster of medial setae; distiphallus (Fig. 6E, 7B) with transverse basal sclerite broad, platelike, its lateral lobes minute; dorsally projecting sclerite broad, strongly dorsolaterally curved, with large apical and subapical teeth; lateral sclerite with strongly sclerotized part short, with broad strongly dentate dorsally curved apical lobe, weaker apical part slender, elongate; medial sclerite with pair of small subapical lobes. Female abdomen – sternites 2-5 strongly sclerotized.

Distribution. This species is known only from the mountains south of the Himalayas. The type locality is in northeast India, in a district between Nepal, Sikkim, and Bhutan. Papp (1988) also reported a male from Nepal and the specimens we examined came from that country.

Remarks. We have not examined the holotype, but Papp's description, especially of the color of the legs and the microtrichial pattern of the anepisternum, and his figure of the distinctive distiphallus suggest that the specimens we examined are conspecific with it. In Papp's figures, the surstylus is more rounded posteriorly and the paramere is slightly differently shaped than in the male we examined. These apparent differences may be due to variation in these characters or they may be the result of slight differences in orientation when the specimens were drawn. Papp placed this species in *Copromyza*, although he stated that there are no small marginal scutellar setae on the type, and his figure of the genitalia shows no lateral cleft on the left side of the epandrium. Both of these characters are present in *Copromyza*. He did not mention the postphallic sclerite or the hind tibial spur in the description, but the former presumably is present, and the latter absent in the holotype, as in the specimens examined and the other species of *Lotophila*.

Specimens examined. Nepal: 28°00′N, 85°00′E [Helumbu District], 10,500 ft., Malaise trap 6, 26.V.1967, Canadian Nepal Expedition, 1♂ (CNC); same, except date 20.V.1967, 1♀ (CNC); same, except date 1.VI.1967, 1♀ (GUE) 1♀ (USNM).

Lotophila pallida Hayashi

(Fig. 5F-G, 6F, 7C, 8D)

Lotophila pallida Hayashi 1985: 561 (Holotype ♂ (NIASJ), Japan: Hokkaido, Oshima, Nanae, 22.VIII.1982, T. Hayashi).

Description. 2.5-4.0 mm long. Head – frons entirely microtrichose, with anterior yellow or orange area broad, diffuse; anterior fronto-orbital seta absent; genal bare area triangular, its anterior margin well posterior to genal seta; face microtrichose except small bare spot in each lower corner. Thorax – postpronotal lobe, anepisternum, anepimeron, and meron entirely microtrichose; only katepisternum, except dorsal margin and narrowly along sternal suture, bare and shiny; scutellum with 2 pairs of marginal setae, basal pair smaller than apical pair. Legs – femora mostly yellow, apical 1/4 of hind femur and sometimes apices of fore and mid femora dark brown; fore coxa entirely yellow; fore femur entirely microtrichose. Male abdomen – sternites 2-3 weakly sclerotized, sternites 4-5 strong; sternite 5 trapezoidal, with posterior corners strongly narrowed, basally with broad symmetrical apodeme; epandrium large, but normal in shape, without lateral cleft; cercus small, poorly differentiated from epandrium; surstylus (Fig. 5F-G) elongate, only slightly wider apically than basally; paramere (Fig. 8D) with large anterior lobe; distiphallus (Fig. 6F, 7C) with transverse basal sclerite

moderately broad, its lateral lobes well developed; dorsally projecting sclerite moderately broad, slightly curved, with large apical and subapical teeth; lateral sclerite with 2 large spinelike teeth at apex of strongly sclerotized part, weaker apical part slender, elongate, with fine marginal dentitions; medial sclerite simple. Female abdomen – sternites 2-4 weakly sclerotized, sternite 5 strong.

Distribution. Known only from Japan.

Specimens examined. JAPAN: Hokkaido, Nanae, 20.VIII.1982, T. Hayashi, 1♂1♀ paratype (USNM); Honshu, Tokyo, Mt. Takao, 22.VI.1983, T. Hayashi, 1♂1♀ paratype (USNM); Shikoku, Ishizuchi Mt. Nat'l. Park, Tsuchigoya, 1400 m., 11-18. VIII. 1980, S. Peck, 3♂2♀ (GUE), 2♂1♀ (USNM).

Lotophila bicolor n. sp.

(Fig. 3B, 4C, 6G, 7D, 8E)

Description. 3.3-4.0 mm long. Head – frons entirely microtrichose, with anterior yellow or orange area broad, diffuse; anterior fronto-orbital seta small, about 1/3 length of posterior seta; genal bare area subtriangular, its anterior margin near genal seta; face microtrichose except large bare spot in each lower corner. Thorax (Fig. 3B) – postpronotal lobe, anepimeron, and meron entirely microtrichose; anepisternum bare except narrowly along dorsal margin and in lower posterior corner; katepisternum bare except posterior half of dorsal margin and narrowly along sternal suture; scutellum with 2 pairs of marginal setae, basal pair smaller than apical pair. Legs – femora mostly yellow, apical 1/5 of hind femur and sometimes apices of fore and mid femora dark brown; fore coxa entirely yellow; fore femur entirely microtrichose. Male abdomen – sternites 2-5 strongly sclerotized; sternite 5 subrectangular, its posterior corners not strongly narrowed, basally without apodeme; epandrium (Fig. 4C) large, strongly expanded posterodorsally, without lateral cleft; cercus small, linear, poorly differentiated from epandrium; surstylus triangular, its anterior margin concave and forming almost right angle with ventral margin; paramere (Fig. 8E) trilobed apically, posterior margin with minute spines; distiphallus (Fig. 6G, 7D) with transverse basal sclerite narrow, its lateral lobes well developed; dorsally projecting sclerite broad, strongly dorsomedially curved, with numerous marginal teeth; lateral sclerite without teeth at apex of strongly sclerotized part, weaker apical part slender, elongate; medial sclerite forked apically. Female unknown.

Distribution. Known only from the type locality in Nepal.

Etymology. The name of this species is derived from the Latin "bi" and "color", in reference to the color of the hind femur.

Holotype. ♂ (CNC), Nepal: 28°00′ N. 85°00′ E. [Helumbu District], 10,500 ft., Malaise trap 6, 1.VI.1967, Canadian Nepal Expedition.

Paratypes. Same data as holotype, except date 26.V.1967, 1♂ (GUE); same, except date 22.V.1967, 1♂ (USNM).

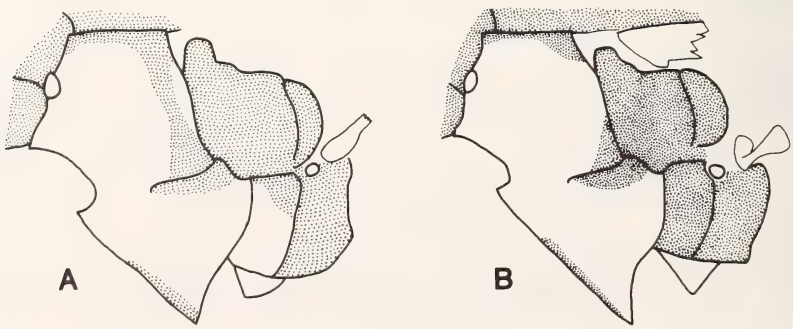

FIGURE 3. Thorax, left lateral view: A – *L. norrbomi*, Nepal; B – *L. bicolor*, Nepal.

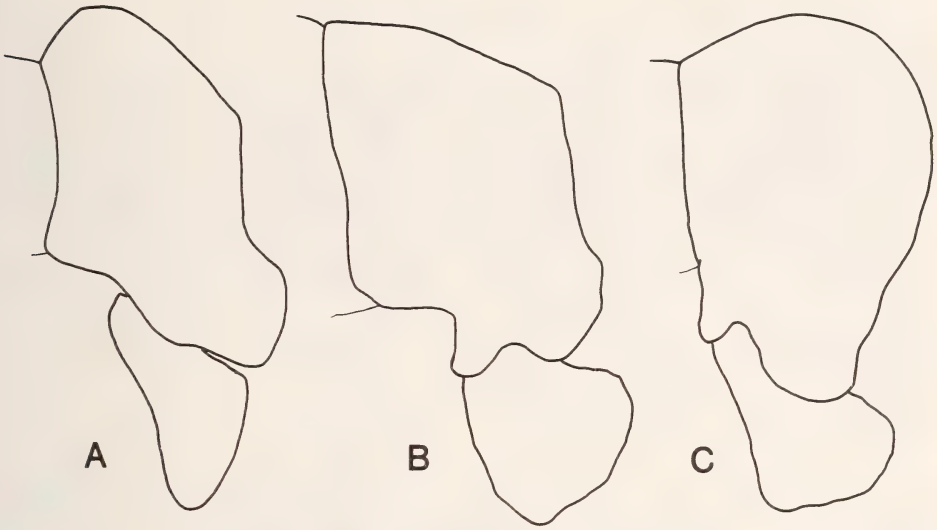

FIGURE 4. Epandrium, surstylus, and cercus, lateral view: A – *L. atra*, Sweden; B – *L. norrbomi*, Nepal; C – *L. bicolor*, Nepal.

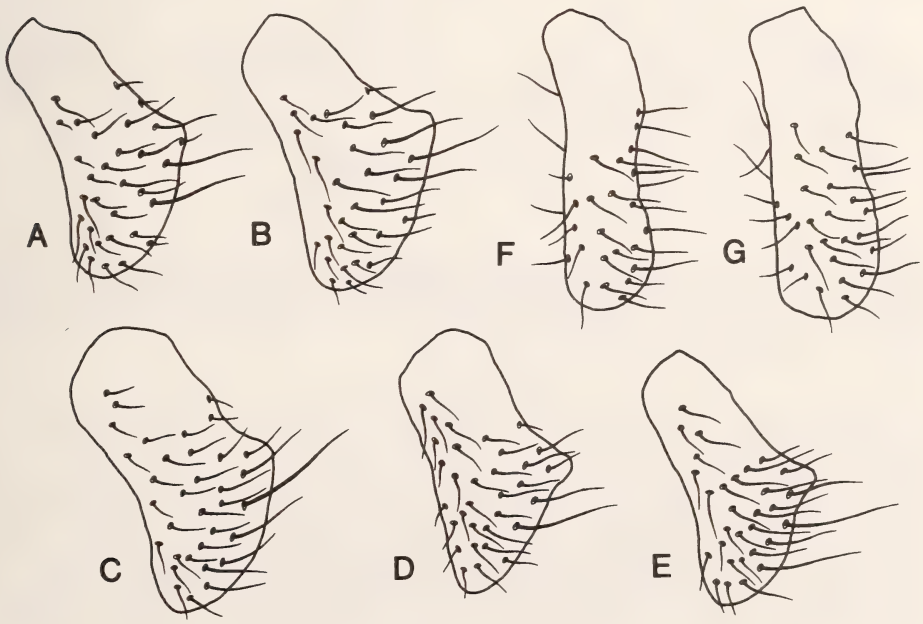

FIGURE 5. Left surstylus, lateral view: A – *L. atra*, Sweden; B – *L. atra*, Crete; C – *L. confusa*, China, Szechwan; D – *L. confusa*, U.S.A., Arizona; E – *L. confusa*, U.S.A., Alaska; F – *L. pallida*, Japan, Shikoku; G – *L. pallida*, Japan, Hokkaido.

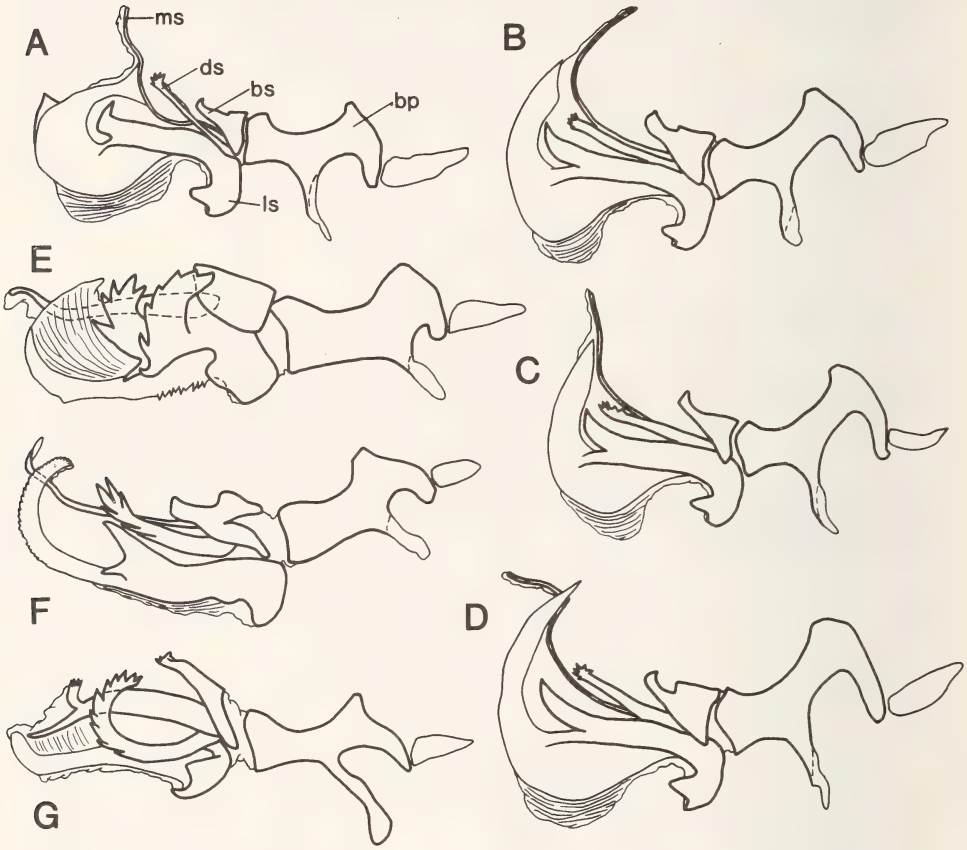

FIGURE 6. Aedeagus, left lateral view: A – *L. atra*, Sweden; B – *L. confusa*, Mexico, Mexico; C – *L. confusa*, U.S.A., Alaska; D – *L. confusa*, China, Szechwan; E – *L. norrbomi*, Nepal; F – *L. pallida*, Japan, Shikoku; G – *L. bicolor*, Nepal; bp – basiphallus; bs – basal sclerite; ds – dorsally projecting sclerite; ls – lateral sclerite; ms – medial sclerite.

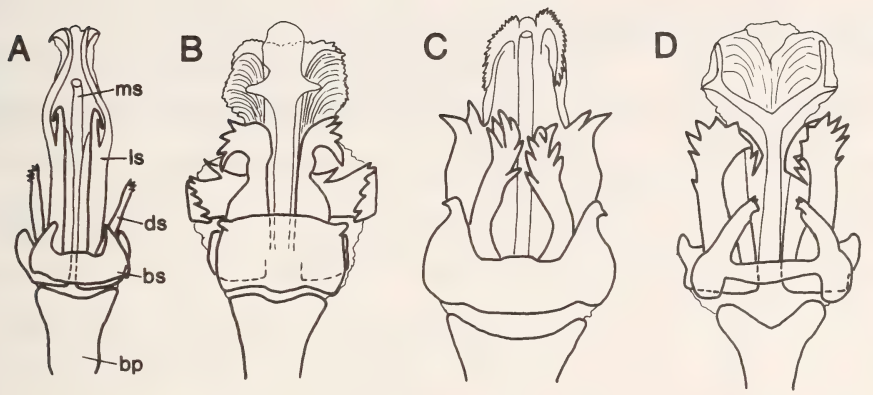

FIGURE 7. Distiphallus, dorsal view: A – *L. atra*, Sweden; B – *L. norrbomi*, Nepal; C – *L. pallida*, Japan, Shikoku; D – *L. bicolor*, Nepal; bp – basiphallus; bs – basal sclerite; ds – dorsally projecting sclerite; ls – lateral sclerite; ms – medial sclerite.

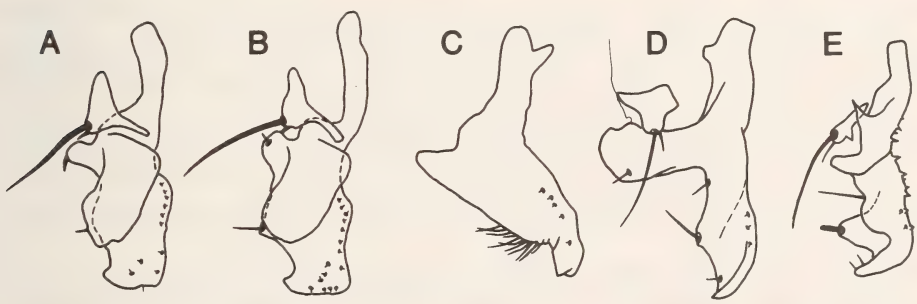

Figure 8. Left paramere, lateral view: A - *L. atra*, Sweden; B - *L. confusa*, Mexico, Mexico; C – *L. norrbomi*, Nepal; D – *L. pallida*, Japan, Shikoku; E – *L. bicolor*, Nepal.

Acknowledgments

We thank H.P. Tschorsnig (SMNS), H.J. Teskey (CNC), W. Hanson (USUL), and R. Danielsson (ZIL) for the loan of study material, T. Hayashi (Saitama Medical School), for the paratypes of *L. pallida* sent to the USNM in an exchange, and especially R. Lichtenberg (NMW) and L. Matile (MNHNP), for their assistance and hospitality to A.L. Norrbom during visits to their institutions to study type material. H.Y. Han (Pennsylvania State University), B.R. Pitkin (British Museum Natural History), J. Cumming (Biosystematics Research Centre, Ottawa), and P.M. Marsh, R.V. Peterson, and F.C. Thompson (Systematic Entomology Laboratory) kindly reviewed drafts of the manuscript. Norrbom's visits to the NMW and MNHNP were supported in part by a grant from the Samuel Williston Fund.

References

Becker, T. 1905. Cyclorrhapha Schizophora: Holometopa, pp. 1-273. *In*: T. Becker, M. Bezzi, K. Kertesz, and P. Stein, eds., Katalog der Paläarktischen Dipteren, Bd. IV. Budapest.

Becker, T. 1908. Dipteren der Insel Madeira. Mitteilungen der Zoologische Museum Berlin, 4: 181-206.

Duda, O. 1923. Revision der altweltlichen Arten der Gattung Borborus (*Cypsela*) Meigen (Dipteren). Archiv für Naturgeschichte, 89(A): 35-112.

Duda, O. 1938. Sphaeroceridae (Cypselidae). *In*: E. Lindner, ed., Die Fliegen der Palaearktischen Region, Bd. VI (57). Stuttgart. 182 pp.

Griffiths, G.C.D. 1972. The Phylogenetic Classification of Diptera Cyclorrhapha with Special Reference to the structure of the male postabdomen. W. Junk, The Hague, 340 pp.

Hayashi, T. 1985. Notes on *Lotophila* Lioy (Diptera, Sphaeroceridae) from Japan, with a description of a new species. Kontyû, 53: 561-564.

Kim, K.C. and E.F. Cook. 1968. A comparative external morphology of adult Sphaeroceridae (Diptera). Miscellaneous Publications of the Entomological Society of America, 5: 78-100.

Lioy, P. 1864. I Ditteri distributi secundo un nuovo metodo di classificazione naturale. Atti dell' I.R. Istituto Veneto di Scienze, Lettere ed Arti, 9: 1087-1126.

Macquart, J. 1835. Histoire naturelle des Insectes. Diptères, 2: 1-703. *In*: N.E. Roret, ed., Collection des suites à Buffon. Paris.

Macquart, J. 1849. Diptères. *In*: H. Lucas, Histoire Naturelle des Animaux Articulés, pt. 3, Insectes. Exploration scientifique de l'Algérie pendant les années 1840, 1841, 1842. Sciences physiques III, Zool. Paris. 527 pp.

Marshall, S.A. 1985. A revision of the New World species of *Minilimosina* Rohácek (Diptera: Sphaeroceridae). Proceedings of the Entomological Society of Ontario, 116: 1-60.

Marshall, S.A. and O.W. Richards. 1987. Sphaeroceridae, pp. 993-1006. *In*: J.F. McAlpine, B.V. Peterson, G.E. Shewell, H.J. Teskey, J.R. Vockeroth, and D.M. Wood, coords., Manual of Nearctic Diptera, vol. 2. Agriculture Canada Monograph No. 28. 674 pp.

McAlpine, J.F. 1981. Morphology and terminology – adults, pp. 9-63. *In*: J.F. McAlpine, B.V. Peterson, G.E. Shewell, H.J. Teskey, J.R. Vockeroth, and D.M. Wood, coords., Manual of Nearctic Diptera, vol. 1. Agriculture Canada Monograph No. 27. 674 pp.

Meigen, J.W. 1830. Systematische Beschreibung der bekannten europäischen zweiflügeligen Insekten. Vol. 6. Hamm, 401 pp.

Norrbom, A.L. and K.C. Kim. 1984. The taxonomic status of *Lotophila* Lioy, with a review of *L. atra* (Meigen) (Diptera: Sphaeroceridae). Proceedings of the Entomological Society of Washington, 86: 305-311.

Norrbom, A.L. and K.C. Kim. 1985. Taxonomy and phylogenetic relationships of *Copromyza* Fallén (s.s.) (Diptera: Sphaeroceridae). Annals of the Entomological Society of America, 78: 331-347.

Papp, L. 1984. Family Sphaeroceridae (Borboridae), pp. 68-107. *In*: A. Soos and L. Papp, eds., Catalogue of Palaearctic Diptera, Vol. 10. Akademiai Kiado, Budapest.

Papp, L. 1988. Sphaerocerinae and Copromyzinae (Sphaeroceridae, Diptera) from the Oriental Region. Revue Suisse de Zoologie, 95: 461-469.

Pitkin, B.R. 1988. Lesser dung flies, Diptera: Sphaeroceridae. Handbooks for the Identification of British Insects. Vol. 10, Part 5e. 175 pp.

Pont, A.C. 1986. A revision of the Fanniidae and Muscidae described by J.W. Meigen (Insecta: Diptera). Annelen des Naturhistorischen Museums Wien, 87(B): 197-253.

Richards, O.W. 1930. The British species of Sphaeroceridae (Borboridae, Diptera). Proceedings of the Zoological Society of London (1930), no. 18: 261-345.

Richards, O.W. 1961. Notes on the names of some Diptera Sphaeroceridae. Annals and Magazine of Natural History (Ser. 13), 3: 561-564.

Richards, O.W. 1965. Family Sphaeroceridae (Borboridae), pp. 718-726. *In*: A. Stone, C.W. Sabrosky, W.W. Wirth, R.H. Foote, and J.R. Coulson, eds., A Catalog of the Diptera of America North of Mexico. U. S. Department of Agriculture, Agricultural Handbook No. 276. 1696 pp.

Robineau-Desvoidy, J.B. 1830. Essai sur les Myodaires. Mémoires présentés par divers Savans a

l'Académie Royale des Sciences de l'Institut de France. Sciences Mathématiques et Physiques (Paris), 2: 1-813.

Roser, C.L.F. von. 1840. Erster Nachtrag zu dem im Jahre 1834 bekannt gemachten Verzeichnisse in Würtemberg vorkommender zweiflügliger Insekten. Correspondenzblatt des Königlich Würtembergischen Landwirtschaftlichen Vereins (Stuttgart) (N. S.), 17: 49-64.

Spuler, A. 1925. North American species of *Borborus* Meigen and *Scatophora* Robineau-Desvoidy. Bulletin of the Brooklyn Entomological Society, 20: 1-16.

(Received 14 July 1988; accepted 5 September 1988)

RESIDUAL ACTIVITY OF INSECTICIDES ON FRESHLY HARVESTED AND PREVIOUSLY STORED WHEAT, AND ON VARIOUS CARRIERS EXPOSED TO CONCRETE SURFACES

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Abstract *Proc. ent. Soc. Ont.* 119: 35-42

The amounts of residues of the insecticides chlorpyrifos-methyl, pirimiphos-methyl and malathion, applied separately at 3-6 ppm, were not significantly different (P>0.05) on either freshly harvested (new) or previously stored (old) wheat after 1 year, decreasing 25.9 and 13.7%, 10.4 and 7.6%, and 46.7 and 37.0%, respectively. Bimonthly bioassays with adult *Tribolium castaneum* indicated there were comparable or higher mortalities with lower dosages of insecticide on new wheat, possibly reflecting some differentiation of insecticide accumulation within new and old seeds. Continuous exposure of adults of *T. castaneum* to all wheat samples treated with 6 ppm of the insect growth regulator fenoxycarb for 4 weeks at each sampling date resulted in their having no offspring, even with exposure to material which had been in storage for 1 year. Application rates of insecticides on new and old wheat should not differ, because degradation rates are similar. Chlorpyrifos-methyl, pirimiphos-methyl, malathion, and the pyrethroid cypermethrin at 1% active ingredient on carriers of sand, wood shavings, or wheat flour, on concrete surfaces, also give effective control of *T. castaneum* for 1 year. The concrete, beneath the sand carriers, remained highly toxic with all insecticides; flour carriers were effective with all insecticides except malathion; wood shavings were not effective with any insecticide. Chlorpyrifos-methyl, pirimiphos-methyl, fenoxycarb, and cypermethrin have greater residual activity on wheat and several experimental carriers than does malathion under Western Canadian storage conditions.

Introduction

Several contact insecticides are used world-wide as stored-grain protectants against insect infestation (Harein 1982). The insecticides, which must meet stringent effectiveness and safety criteria (Sinha and Watters 1985), are applied to the grain as sprays or dusts and are effective from months to years. Factors affecting their degradation following application include temperature, moisture content of the grain, insecticide type and formulation (Harein 1982), and physical and physiological properties of the seeds (Rowlands 1975).

Premium grade malathion has been used world-wide on stored cereals since the mid-1950s, and is currently the main insecticide for use on cereals and empty storage structures in Canada. Resistance to malathion is now common in stored-product insects in most countries and is spreading in the United States (Haliscak and Beeman 1983) and Canada (White and Watters 1983, White and Loschiavo 1985). The organophosphorus insecticides chlorpyrifos-methyl and pirimiphos-methyl have been recently registered for use on stored grain in the United States, and the insect growth regulator fenoxycarb (White 1986) and the pyrethroid cypermethrin (Watters *et al.* 1983) are potential alternatives to malathion.

Wheat does not germinate readily without 4-8 weeks of dry storage after harvest (Villiers 1972) when seed maturation is completed. The physiological activity of freshly harvested grain could affect degradation rates of insecticides applied immediately after harvest as opposed to after several months of storage. Rowlands (1976) reported that metabolic degradation of insect growth regulators occasionally was faster on freshly harvested wheat than on mature wheat at 19% moisture content. The effect of grain age on insecticide degradation in wheat stored at typical, dry moisture contents of 12-14%, is unknown.

Information is needed on the behavior of new contact insecticides in empty storage structures and more effective methods of application. Concrete is commonly used in floors and walls of some granaries and grain elevators. Because most insecticide sprays are hydrolized in a few days on this highly alkaline surface (White 1984), control of insect populations is difficult. One alternative is to use various carriers for the insecticides.

The aims of this study were to determine the degradation rate of several potential grain protectants on freshly harvested and previously stored wheat under Western Canadian storage conditions;

and to determine the residual effectiveness of insecticides on sand, wood shaving, or wheat flour carriers applied to concrete surfaces for up to 1 year.

Materials and Methods

A. Grain

Types of wheat. Fifteen kilograms of wheat ((*Triticum aestivum* L., cv. Neepawa), which had been in storage in a steel granary at Glenlea, Manitoba for 2 years, and 15 kg of newly harvested wheat (cv. Neepawa), in storage for 1 week, were obtained. The moisture content of both lots of wheat was 12.6%, wet mass basis, and was raised to about 13.5% by adding distilled water and mixing the grain. Seed germination at the beginning of the experiment was 30% (n = 100 seeds) in the "new" wheat and 99% (n = 100) in the "old" wheat. All of the wheat was cleaned to remove foreign seeds and broken kernels.

Insecticide treatment. The samples of new and old wheat were each split into five 3-kg lots which were individually spread on a sheet of plastic in a fume hood and sprayed with acetone solutions of: the organophosphorus insecticides malathion, chlorpyrifos-methyl, pirimiphos-methyl; the insect growth regulator fenoxycarb; and a control treatment of acetone only. Gas chromatography was used to determine concentrations of insecticide in the commercial formulations used. Solutions of 100 ml were prepared by mixing acetone with malathion (95.0%, wt:wt), chlorpyrifos-methyl (50.8%, wt:wt), pirimiphos-methyl (62.4%, wt:wt) and fenoxycarb (125g/L). A Paasche air-brush was used to apply 12 ml of each diluted chemical to either the new or old wheat (3 kg) to yield calculated concentrations of 6 ppm. The acetone was then allowed to evaporate for 24 h, the grain was thoroughly mixed and placed in three cotton bags, each holding 1 kg of wheat (4 insecticides + controls x 3 replicate bags = 15 bags of new wheat and 15 bags of old wheat).

Storage and sampling. The bags of wheat were placed in an unheated barn at the Winnipeg Research Station in mid-September 1985. Temperatures were monitored continuously with a thermograph, and grain samples of 100 g per bag were taken initially and then every 2 months for 1 year. Samples from each bag were analyzed for moisture content by oven-drying the wheat at 130°C for 19 h (Anonymous 1975).

Bioassay. Residual activity of the insecticides was measured by exposing adults of the red flour beetle, *Tribolium castaneum* (Herbst) to the grain. There was no malathion resistance present in the population of insects used. Three replicates of 25 adults, that were 2-8 weeks old, were placed in plastic vials (5 cm high, 2.4 cm diam.) containing 4 g of wheat from each treatment (i.e., new wheat : 4 insecticides + controls x 3 bags x 3 replicates = 45 vials; old wheat = 45 vials). The vials were then capped with screened lids and held at 30 ± 1°C, 70 ± 5%RH. For wheat from the malathion, chlorpyrifos-methyl, and pirimiphos-methyl treatments, adults were removed after 24 h and classified as walking or knocked down. All adults were then placed in corresponding vials containing 4 g of untreated wheat and 0.5 g of ground wheat to facilitate feeding. After a further 7 days at 30 ± 1°C and 70 ± 5%RH the insects were removed and classified as living or dead. Control insects were placed on the acetone-treated wheat from the control bags. The fenoxycarb treatment was not assayed for adult knockdown. Untreated ground wheat (0.2 g/vial) was added to the wheat treated with fenoxycarb and adult insects were left on the grain for 4 weeks at 30 ± 1°C, 70 ± 5%RH before living adults and immatures were counted. Controls consisted of adult insects on untreated new and old wheat, with 0.5g ground wheat/vial, at the same temperature and relative humidity for 4 weeks.

Chemical assay. New and old wheat treated with malathion, chlorpyrifos-methyl, or pirimiphos-methyl from each bag was analyzed for chemical residues at each sampling date. Insecticides were extracted with acetone, separated from lipids with gel-permeation chromatography and quantified by gas chromatography (White 1985).

For each sample, 10 g of wheat were ground for 1 min in a coffee grinder. Subsamples of 4 g were then placed in steel tubes with two steel balls and 30 ml of acetone. The tubes were shaken on a Burrell wrist-action shaker for 1 hour. The acetone/lipid extract was filtered with a Buckner funnel under a vacuum. Acetone was then evaporated at 44-48°C in a rotary evaporator under vacuum. The remaining lipid extract was redissolved in 3 ml of pesticide-grade ethanol, filtered through glass wool, and transferred to the top of a glass column containing a 35 cm deep, 1.9 cm diam bed of Sephadex

LH-20 that was prepared and packed in absolute ethanol. The column was eluted with pesticide-grade ethanol and the fraction of ethanol containing insecticide, but little lipid, was collected (malathion, 90-120 ml; chlorpyrifos-methyl, 100-145 ml; pirimiphos-methyl, 90-120 ml). The ethanol was removed by rotary evaporation at 55-59°C under vacuum and the extract redissolved in hexane.

Internal standards of analytical grade insecticide (99.8-100%) were placed in the solutions. The standards were: pirimiphos-methyl for malathion and chlorpyrifos-methyl solutions, and pirimiphos-ethyl for pirimiphos-methyl solutions. Samples were analyzed in triplicate by injecting 3 µl of solution into a gas chromatograph (Perkin-Elmer Sigma 3B) having a nitrogen-phosphorus detector and a glass column (90 cm long, 6.4 mm i.d.) packed with 3% OV-17 on chromosorb W-HP100/120, and using a data integrator (Sigma 15). Analyses were run isothermally at 200°C, using N_2 at 25 ml/min as the carrier gas. Recovery efficiency for all three insecticides was consistently above 96%. Differences among mean residue levels after 1 year of storage were compared by analysis of variance and Duncan's new multiple range test (Duncan 1955).

B. Substrates

Types of substrates and insecticide treatment. Sand, wood shavings, and wheat flour carriers were treated with malathion (95.0%, wt:wt), chlorpyrifos-methyl (50.8%, wt:wt), pirimiphos-methyl (62.4%, wt:wt), and the pyrethroid cypermethrin (40.0%, wt:wt) diluted in acetone. The active ingredient of each insecticide on each carrier was calculated to be 1%. Insecticide solutions were applied to the carriers by pipette; the carriers were then each mixed and spread on plastic for 24 h to allow the acetone to evaporate.

The sand particles were less than 425 µm, the flour particles were less than 250 µm and the average size of wood shavings was 6.2 mm long, 3.2 mm wide, 0.15 mm thick. The initial moisture contents of the carriers were 0.2% (sand), 11.3% (wood shavings), and 12.5% (flour).

Thirty new, concrete blocks, 45 cm long x 25 cm wide x 4 cm thick, were used. Fifteen of the blocks each had 15 copper rings, 5 cm diam x 2.1 cm high, attached at the base with paraffin wax. Three rings on each block were controls (one containing sand, one wood shavings, and one flour) and three held insecticide-treated carriers (sand, wood shavings, flour) for each of the four insecticides (4 insecticides + controls x 3 carriers = 15 rings). The sand and flour were about 1 mm deep on the concrete with 2.76 g of sand, 0.45 g of wood shavings, and 2.18 g of flour placed in each ring. Another concrete block was sprayed with each insecticide in acetone, or acetone alone (control), to yield deposits of 0.5 g AI/m^2 (5 blocks). Fifteen copper rings were then attached to each of these blocks, and three rings were used for bioassays on each sampling date. All concrete blocks were placed in an unheated barn at the Winnipeg Research Station in May 1985.

Bioassays were made of the carriers and the concrete under them once the carriers were removed after 1, 3, 6, 9, and 12 months of storage. On each sampling date eight concrete blocks, three with carriers and five which had been sprayed (4 chemicals + control) were returned to the laboratory and the carriers removed from the rings by aspiration and placed in glass vials. Twenty-five adults of *T. castaneum* were placed in each vial with the carriers (3 vials per carrier-insecticide treatment) for 24 h at 25 ± 1°C, 70 ± 5%RH, and then were counted for knockdown. The insects were then placed on untreated wheat flour for 3 days at 25 ± 1°C, 70 ± 5%RH before mortality was assessed. Once the carriers were removed from the rings, 25 adult insects were placed in each ring on the concrete and held at 25 ± 1°C, 70 ± 5%RH for 24 h to determine mortality. The sprayed blocks were also bioassayed with three replicates of 25 adults/ring on each sampling date. Data were analyzed by analysis of variance and Duncan's new multiple range test.

Results and Discussion

Residual insecticide activity on new vs. old wheat

The moisture content of the new and old wheat fluctuated slightly with changes in the ambient relative humidity during the study. The highest mean moisture contents of the wheat were 14.1% in March, which corresponds to about 72%RH in intergranular air spaces, and the lowest moisture contents were 12.2% in May, which corresponds to about 58%RH (Brooker *et al.* 1974). Mean moisture contents in the new wheat were consistently higher than in the old wheat but the differences were not

significant (P>0.05). The degradation of insecticides on stored cereals is a function of enzymatic activity both within the seed (Rowlands 1975) and by seed-borne fungi (Mostafa *et al.* 1972, Anderegg and Madisen 1983) and the rates of insecticide breakdown increase as moisture content and temperature rise (Harein 1982). Temperatures in the storage environment ranged from annual lows of -15°C to highs of 27°C with average diurnal fluctuations of 5°C from April to October and 2°C for November to March. The temperatures were more moderate than in outdoor conditions but reflect conditions within small Manitoban granaries (White *et al.* 1986).

The insecticides used in this study are not now registered for use on stored cereals in Canada, with the exception of premium grade malathion at 8 ppm. In the United States, chlorpyrifos-methyl is registered as a grain protectant on wheat and pirimiphos-methyl is registered on stored corn and export wheat at 5 to 8 ppm. Fenoxycarb is not registered but has been very effective at controlling stored-product insects (White 1986).

The decreasing amounts of residues with time of the organophosphorus insecticides (Table I) were reflected by the decreasing mortality of *T. castaneum* in the bioassays (Table II). Malathion residues decreased most rapidly during 1 year of storage, the next was chlorpyrifos-methyl whereas pirimiphos-methyl decreased only slightly (Table I). In all wheat samples, appreciable decreases in insecticide levels did not occur until the following July-September after 10 to 12 months of storage when temperatures were high.

TABLE I. Insecticide residues (ppm), (mean ± SE)[a] in wheat treated with various insecticides and stored under simulated Western Canadian storage conditions (−15 to 27°C) for up to 1 year (September to September).

Grain age (previous time in storage)		Time posttreatment (months)							Mean decrease in 12 months (%)
	Insecticide	1 week	2	4	6	8	10	12	
New wheat (1 week)	Chlorpyrifos-methyl	5.6 ± 0.4	5.5 ± 0.8	6.3 ± 0.3	5.4 ± 0.4	5.9 ± 0.2	4.9 ± 0.4	4.2 ± 0.4	1.4 (25.9)
	Pirimiphos-methyl	3.1 ± 0.4	3.2 ± 0.5	3.5 ± 0.7	3.4 ± 0.5	3.2 ± 0.5	2.9 ± 0.5	2.8 ± 0.4	0.3 (10.4)
	Malathion	5.0 ± 0.8	4.6 ± 0.6	4.0 ± 0.6	4.6 ± 0.7	3.9 ± 0.7	2.9 ± 0.6	2.7 ± 0.5	2.3 (46.7)
Old wheat (2 years)	Chlorpyrifos-methyl	6.0 ± 0.2	6.0 ± 0.3	6.5 ± 0.3	6.4 ± 0.2	6.5 ± 0.6	5.9 ± 0.3	5.2 ± 0.3	0.8 (13.7)
	Pirimiphos-methyl	3.0 ± 0.4	3.3 ± 0.5	3.8 ± 0.7	3.3 ± 0.4	3.5 ± 0.6	3.4 ± 0.6	2.8 ± 0.4	0.2 (7.6)
	Malathion	5.3 ± 0.3	5.7 ± 0.4	5.5 ± 0.3	5.7 ± 0.4	4.6 ± 0.4	3.6 ± 0.2	3.3 ± 0.2	2.0 (37.0)

[a]n = (3 replicate analyses per bag, 3 bags per treatment).

In 1 year, there were no significant differences (P>0.05) in quantities of insecticide degraded between new and old wheat for chlorpyrifos-methyl, pirimiphos-methyl and malathion treatments. Insecticide degradation was slightly faster in the new than old wheat, but the differences were not apparent within a few months of grain treatment which could be expected if post-harvest maturity of the seed were a factor. Cereal seeds in storage are mature 4-8 weeks after harvest (Villiers 1972) and germination in the new wheat rose from initial levels of 30% to 100% within that time. Germination in both new and old wheat was 98-100% at the end of this experiment.

Insect mortality in the assays declined when mean insecticide levels in new and old wheat, respectively, were: 4.9 (91% mortality) and 5.2 ppm (98% mortality) for chlorpyrifos-methyl, 2.9 (71% mortality) and 3.4 ppm (77% mortality) for pirimiphos-methyl, and 3.9 (77% mortality) and 3.6 ppm (17% mortality) for malathion. Knockdown was often slightly greater than mortality, indicating some recovery of incapacitated insects. Organophosphorus insecticides and juvenile hormone anologues (Rowlands 1975) are lipophilic and tend to accumulate in the germ and inner seed coat of kernels (Mensah *et al.* 1979; Rowlands and Bramhall 1977) where *T. castaneum* usually feed. It is possible that residues of the insecticides in different parts of the seeds were affected by the timing of the application on freshly harvested or old seed leading to comparable or higher mortality with lower doses of insecticide on new wheat (Table I, II).

Fenoxycarb residues were not measured because of a lack of appropriate gas chromatograph

equipment and a poorly developed methodology for extracting it from grain. This novel insect growth regulator acts as a juvenile hormone mimic, preventing successful pupation, and directly killing larvae or sterilizing adults (White 1986). Both new and old wheat treated with 6 ppm fenoxycarb had no immatures present when adults were exposed for 4 weeks, even after 1 year of storage. In the controls of both new and old wheat, means ranging from 16 to 65 larvae and pupae were present in wheat from various sampling dates. However, there were no significant differences between the two types of wheat.

TABLE II. Mortality (mean ± SE) of *Tribolium castaneum* exposed at 30 ± 1°C for 24 h to wheat which was treated with various insecticides and stored under simulated Western Canadian storage conditions (−15 to 27°C) for up to 1 year.

Grain age (previous time in storage)		Time posttreatment (months)													
		1 week		2		4		6		8		10		12	
	Insecticide	KD[b]	M[b]	KD	M	KD	M	KD	M	KD	M	KD	M	KD	M
New wheat (1 week)	Chlorpyrifos-methyl	100	100	100	100	100	100	100	100	100	100	97 ± 3	91 ± 5	84 ± 6	80 ± 7
	Pirimiphos-methyl	100	100	100	100	100	100	100	100	100	100	83 ± 6	71 ± 8	92 ± 4	92 ± 4
	Malathion	100	100	100	99 ± 1	100	100	100	100	78 ± 13	77 ± 12	32 ± 15	27 ± 12	53 ± 14	49 ± 14
Old wheat (2 years)	Chlorpyrifos-methyl	100	100	100	100	100	100	100	100	100	100	100	100	99 ± 1	98 ± 2
	Pirimiphos-methyl	100	100	100	100	100	100	100	100	100	100	83 ± 9	77 ± 11	72 ± 9	69 ± 9
	Malathion	100	100	100	100	100	100	100	100	100	100	17 ± 7	17 ± 8	23 ± 6	21 ± 6

[a]n = (3 replicate analyses per bag, 3 bags per treatment).
[b]KD = knockdown in 24 h, M = mortality 7 d after exposure.
Note: control mortality was always 0%.

Pirimiphos-methyl was the most stable organophosphorus insecticide on the dry wheat during 1 year of storage and malathion was the least stable. Although some insecticide levels appeared to fall faster in the newly harvested wheat than in the old wheat, the differences were not significant. Therefore, the age of stored wheat should not be considered in determining the rate of insecticide application.

Substrates

Concrete blocks sprayed with malathion, chlorpyrifos-methyl, or pirimiphos-methyl were not toxic to *T. castaneum* one month after treatment, but 100% of the beetles were killed one day after treatment. The pyrethroid, cypermethrin, which has been tested in storage environments (Watters *et al.* 1983), continued to knock down adults one month after the concrete was treated but was ineffective by 3 months (Table III).

The sand, wood shavings, and flour carriers were all treated with 1% active ingredient of insecticide corresponding to levels in a commercial dust formulation of malathion on flour. All of the carriers and insecticides still produced 100% mortality in insects one year after the experiment began. However, the concrete under the carriers often became less toxic to the insects with time, reflecting degradation of insecticides in contact with the surface (Table III).

Sand was the best carrier for all of the insecticides. The material had fine particles, was inert and had low moisture levels at the surface. Unfortunately, sand is a potential contaminant of food products and would have limited application in storage environments. Flour was also an excellent carrier for all of the insecticides except for malathion which allowed some insect survival by 3 months and gave poor control by 12 months. Insecticide degradation was most obvious with malathion. Wood shavings were not effective in transferring insecticide to the concrete, partially because the large particles had less contact with the concrete surface than did sand or flour.

Very thin layers of sand or flour treated with 1% chlorpyrifos-methyl, pirimiphos-methyl, or cypermethrin would provide control of *T. castaneum* on concrete for up to 1 year under Western

Canadian storage conditions. Removal of the carriers would leave the concrete toxic to the insects for several more days (Okwelogu 1968).

TABLE III. Mortality (%) of adult *Tribolium castaneum* after a 24-hour exposure at 25 ± 1°C, 70 ± 5%RH to concrete surfaces which were under various carriers containing 1%AI insecticide for up to 1 year, or to concrete sprayed with insecticides.

Storage Time (months)			Carrier			Sprayed concrete (0.5 g/m^2)
	Month	Insecticide	Sand	Wood Shavings	Flour	
1	June, 1985	Malathion	100	8 ± 4	100	0
		Chlorpyrifos methyl	100	3 ± 3	100	0
		Pirimiphos methyl	100	9 ± 5	100	0
		Cypermethrin	100	3 ± 1	100	95 ± 5
3	August	Malathion	100	0	88 ± 4	0
		Chlorpyrifos methyl	100	0	100	0
		Pirimiphos methyl	100	5 ± 3	100	0
		Cypermethrin	100	0	100	0
6	November	Malathion	100	11 ± 6	71 ± 6	0
		Chlorpyrifos methyl	100	5 ± 4	96 ± 4	0
		Pirimiphos methyl	100	8 ± 2	100	0
		Cypermethrin	100	27 ± 18	100	0
9	February	Malathion	100	9 ± 4	52 ± 4	0
		Chlorpyrifos methyl	79 ± 16	4 ± 4	100	0
		Pirimiphos methyl	99 ± 1	10 ± 2	100	0
		Cypermethrin	100	14 ± 17	100	0
12	May	Malathion	94 ± 4	0	27 ± 12	0
		Chlorpyrifos methyl	97 ± 1	0	100	0
		Pirimiphos methyl	100	0	100	0
		Cypermethrin	100	0	100	0

[a]Mean ± SE, n = 3 replicates of 25 adults
Control mortality on all carriers and sufaces was 0%; initial mortality on sprayed surfaces was 100% for all insecticides.

Acknowledgement

I thank R.J. Bell for technical assistance and I. Wise, P. Barker, J. Mills and T. Atkinson of this station for reviewing the manuscript. This is Contribution No. 1320 from the Agriculture Canada Research Station, Winnipeg.

References

Anderegg, B.N., and L.J. Madisen. 1983. Degradation of ^{14}C-malathion in stored corn and wheat inoculated with *Aspergillus glaucus*. Journal of Economic Entomology, 76: 733-736.

Anonymous. 1975. Moisture measurement-grain and seeds. ASAE method S352. Agricultural Engineers Yearbook. American Society of Agricultural Engineers, St. Joseph, Michigan. 690 pp.

Brooker, D.B., F.W. Bakker-Arkema, and C.W. Hall. 1974. Drying Cereal Grains. The Avi Publishing Company, Westport, Connecticut. 200 pp.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics, 11: 1-41.

Haliscak, J.P., and R.W. Beeman. 1983. Status of malathion resistance in five genera of beetles infesting farm-stored corn, wheat, and oats in the United States. Journal of Economic Entomology, 76: 717-722.

Harein, P.K. 1982. Chemical control alternatives for stored-grain insects. pp. 319-362 *in* C.M. Christensen [ed.] Stored Grains and Their Products. American Association of Cereal Chemists, St. Paul, Minnesota.

Mensah, G.W.K., F.L. Watters, and G.R.B. Webster. 1979. Insecticide residues in milled fractions of dry or tough wheat treated with malathion, bromophos, iodofenphos, and pirimiphos-methyl. Journal of Economic Entomology, 72: 728-731.

Mostafa, I.Y., I.M.I. Fakhr, M.R.E. Bahig, and Y.A. El-Zawhry. 1972. Metabolism of organophosphorus insecticides. XIII. Degradation of malathion by *Rhizobium* spp. Archiv fuer Mikrobiologie, 86: 221-224.

Okwelogu, T.M. 1968. The toxicity of malathion applied to washed concrete. Journal of Stored Product Research, 4: 259-260.

Rowlands, D.G. 1975. The metabolism of contact insecticides in stored grains. III. 1970-1974. Residue Reviews, 58: 113-155.

Rowlands, D.G. 1976. The uptake and metabolism by stored wheat grains of an insect juvenile hormone and two insect hormone mimics. Journal or Stored Product Research, 12: 35-42.

Rowlands, D.G., and J.S. Bramhall. 1977. The uptake and translocation of malathion by the stored wheat grain. Journal of Stored Product Research, 13: 13-22.

Sinha, R.N., and F.L. Watters. 1985. Insect Pests of Flour Mills, Grain Elevators, and Feed Mills and Their Control. Agriculture Canada Publication 1776E, Supply and Services Canada, Ottawa, Ontario. 290 pp.

Villiers, T.A. 1972. Seed Dormancy. Ch. 3 *in* T.T. Kozlowski, [ed.] Seed Biology. Volume II. Germination control, metabolism, and pathology. Academic Press, New York. 422 pp.

Watters, F.L., N.D.G. White, and D. Coté. 1983. Effect of temperature on the toxicity and persistence of three pyrethroid insecticides applied to fir plywood for control of *Tribolium castaneum*. Journal of Economic Entomology, 76: 11-16.

White, N.D.G. 1984. Research on contact insecticides used as structural treatments to control stored-product insects. Proceedings of the 31st Annual Meeting of the Canadian Pest Management Society, Winnipeg. pp. 50-57.

White, N.D.G. 1985. Uptake of malathion and pirimiphos-methyl by rye, wheat, or triticale stored on treated surfaces. Journal of Economic Entomology, 78: 1315-1319.

White, N.D.G. 1986. Control of *Tribolium castaneum* and *Cryptolestes ferrugineus* with the insect growth regulator fenoxycarb on wheat or structural surfaces. *In* Proceedings of the 4th International Working Conferences on Stored Product Protection, Tel Aviv, Israel. pp. 566-575.

White, N.D.G., and S.R. Loschiavo. 1985. Testing for malathion resistance in field-collected populations of *Cryptolestes ferrugineus* (Stephens) and factors affecting reliability of the tests. Journal of Economic Entomology, 78: 511-515.

White, N.D.G., R.N. Sinha, and J.T. Mills. 1986. Long-term effects of an insecticide on a stored-wheat ecosystem. Canadian Journal of Zoology, 64: 2558-2569.

White, N.D.G., and F.L. Watters. 1983. Incidence of malathion resistance in *Tribolium castaneum* and *Cryptolestes ferrugineus* populations collected in Canada. *In* Proceedings of the 3rd International Working Conference on Stored-Product Entomology, Manhatten, Kansas. pp. 290-302.

ABSENCE OF PARASITISM IN AN OUTBREAK OF THE CEREAL LEAF BEETLE, *OULEMA MELANOPUS* (COLEOPTERA: CHRYSOMELIDAE), IN THE CENTRAL TOBACCO GROWING AREA OF ONTARIO

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Abstract *Proc. ent. Soc. Ont.* 119:43-46

An outbreak of the cereal leaf beetle (CLB), *Oulema melanopus* (L.), in the central tobacco growing area of Ontario was attributed to the absence of parasitism. Only one of 832 eggs was parasitized by *Anaphes* sp., and no larvae were parasitized by *Tetrastichus julis* (Walker). Elsewhere in the province populations of CLB were low and parasitism by *T. julis* was 74% in 1987 and 90% in 1988. In the outbreak area, cereals are grown with annual tillage in a two-year rotation with tobacco, whereas in other areas cereals are often grown as a companion crop for alfalfa and fields are not tilled following harvest of the cereal crop. Because tillage is known to kill about 95% of the overwintering parasite, *T. julis*, tillage in the tobacco rotation probably accounts for the absence of the parasite.

Introduction

The cereal leaf beetle, (CLB) *Oulema melanopus* (L.), is an introduced pest of small grains in North America that was first noted in southern Michigan, U.S.A., in the early 1960's (Castro *et al.* 1965). In Ontario, following its initial discovery in 1965 near the Michigan border (Brown 1966), the beetle spread rapidly eastward and northward to occupy most of the grain producing areas south of Hwy. 17. Larval populations reached economically important levels in 1973, and in 1974 chemical treatments were required for the first time in some fields (Bereza 1973, 1974). However, the outbreak in Ontario was short-lived. A sharp drop in population density in 1975 and 1976 followed a similar decline in the midwestern U.S.A. This drop was attributed to a combination of factors including mortality due to introduced parasitoids (Haynes and Gage 1981).

The CLB has many natural enemies in its native Europe. Several of them were successfully colonized in the U.S.A. during the mid to late 1960's (Maltby *et al.* 1971; Dysart *et al.* 1973). One of these, an egg parasite, *Anaphes flavipes* (Foerster) (Hymenoptera: Mymaridae), was subcolonized in Ontario in the early 1970's (Krombein *et al.* 1979). This species is important in biological control in the U.S.A. (Haynes and Gage 1981; Lampert and Haynes 1985), but its impact on the CLB in Ontario was not confirmed.

A second species, the larval endoparasite, *Tetrastichus julis* (Walker) (Hymenoptera: Eulophidae), was released in Ontario in 1974 at 4 south-central locations (Harcourt *et al.* 1977). This wasp dispersed widely across Ontario, apparently from earlier releases in Michigan and other states as well as our own, and in 1975 Harcourt *et al.* (1977) recorded an average parasitism rate of 84% in Ontario. *T. julis* controlled its host so effectively that insecticides were seldom applied during the next decade. However, in 1985 numbers of the pest on cereals rose to 2 or 3 larvae per tiller in parts of Norfolk Co. in western Ontario making it necessary to spray several fields (Bereza 1985). In 1986, spraying became more extensive west of Simcoe in the Silver Hill-Langton area of Norfolk Co. (K. Bereza, personal communication).

The present study was conducted in response to the outbreak of CLB in Norfolk Co. We had 3 objectives: 1) to determine whether the egg parasite, *A. flavipes*, was established in Ontario, 2) to determine the status of *T. julis* in the outbreak area of Norfolk Co. as compared to elsewhere in Ontario, and 3) to determine a probable cause for the reported outbreak.

[1]Contribution number 1149

Materials and Methods

Suitable sites for collecting eggs of the CLB in the outbreak area of Norfolk Co. were determined on the basis of the number of adults collected in early May in 2 samples of 25 sweeps per field. Each year, eggs were collected from 3 fields with the highest populations of adults. Leaves of winter wheat with eggs attached were transported to the laboratory in jars held in a cooler, placed individually in small plastic capsules, and incubated at room temperature. The contents of the capsules were examined for CLB larvae and *A. flavipes* adults each year between 20 May and 15 June.

Beetle larvae representing the outbreak area were collected in the Silver Hill-Langton area from 2 fields on 29 May 1987, 2 fields on 4 June 1987 and from 2 fields on both 2 and 13 June 1988. One area outside of Norfolk Co., which was infested with CLB, was located in the Vineland area of Niagara Co. Although numbers were much lower than in the outbreak area, a total of 86 larvae was collected from 3 fields on 2 and 9 June 1987, and 82 larvae from 2 fields on 10 June 1988. Larvae from all locations were placed in 70% alcohol for dissection later; in samples containing more than 100 larvae, results were based on a subsample of 50 specimens.

Results and Discussion

CLB adults became numerous in the Silver Hill-Langton area of Norfolk Co. from mid to late May, and infestations of 8 to 10 larvae per tiller occurred in some fields in both 1987 and 1988. However, surveys conducted across southern Ontario by extension personnel in 1987 and 1988 showed that CLB populations remained low throughout the rest of the province (K. Bereza, personal communication).

Numbers of adult CLB in our sweep-net collections taken from fields in Norfolk Co. ranged from 0 to 13 adults per 25 sweeps. Of the total eggs collected each year from 3 fields, 0 of 160 in 1987 and 1 of 672 in 1988 were parasitized. The damaged adult parasite was identified by J. Huber of the Biosystematics Research Institute, Ottawa, Ontario as *Anaphes* sp. probably *flavipes*. Sixteen CLB eggs were also collected in the Niagara area in 1988 as a result of 6 hours of searching fields in the area where larvae were collected the previous year. None of these eggs was parasitized. We conclude that *A. flavipes* is present in Ontario but not of economic importance. Of the non-parasitized eggs, about 50% yielded CLB larvae. Dissection of the remaining eggs revealed that they either contained unemerged larvae or lacked recognizable contents.

Dissection of CLB larvae revealed no parasitism by *T. julis* in the outbreak area of Norfolk Co., but in Niagara Co., where populations of the CLB were low, the mean rate of parasitism was 74% in 1987 and 90% in 1988 (Table 1). These high rates are similar to those previously reported by Ellis *et al.* (1978).

Our results clearly indicate a difference in the rates of parasitism by *T. julis* between areas of high and low CLB population densities. With the exception of Norfolk Co., most areas of Ontario have low numbers of CLB and a high rate of parasitism indicating that populations of CLB are not reaching economic levels. One possible cause of the low rate of parasitism and hence the outbreak in Norfolk Co. is the different system of crop rotation used in this tobacco growing region of Ontario as compared to elsewhere in the province. Throughout most of the province, spring grain is often grown as a companion crop for alfalfa. Hence, no cultivation occurs the following fall or spring allowing the overwintering parasitic larvae to complete their development within their host cocoons in the soil (Harcourt *et al.* 1977). Our surveys support this hypothesis because none of the farmers surveyed in the outbreak area grew their grain as a companion crop for alfalfa.

In Norfolk Co., tobacco is grown in a 2-year rotation with small grains and the soil is tilled annually in the spring and/or fall. Tillage reduces the parasite population by destroying more than 95% of the overwintering population (Haynes *et al.* 1973), but CLB populations are unaffected because the adults emerge from the soil in the summer and leave the fields to overwinter.

Any cultural practice that reduces cultivation following grain crops would increase parasite survival. Zero-tillage could be considered, or the 2-year rotation of grain and tobacco could be expanded to a 3-year (grain, alfalfa, tobacco) rotation with alfalfa under-seeded in the grain. If neither of these suggestions is practical, then a non-host alternative to oats, barley or wheat (e.g. rye) should be grown in rotation with tobacco.

TABLE I. Parasitism of cereal leaf beetle by *Tetrastichus julis* in two areas of southern Ontario.

Area Year Date	Field	Larvae Dissected (N)	Larvae Parasitized (N)	Parasitism (%)
Silver Hill-Langton				
1987				
29 May	1	50	0	0
	2	50	0	0
4 June	3	80	0	0
	4	15	0	0
1988				
2 June	5	50	0	0
	6	50	0	0
13 June	5	50	0	0
	6	50	0	0
Niagara				
1987				
2 June	1	30	26	86
	2	50	34	68
9 June	3	6	4	67
Total		86	64	74
1988				
10 June	4	4	3	75
	5	78	71	91
Total		82	74	90

Acknowledgments

We thank K. Bereza and J. Winnicki of the Ontario Ministry of Agriculture and Food (OMAF) for surveying for larvae and for collecting samples of larvae from the Niagara area in 1987. This research was supported in part by a grant from OMAF.

References

Bereza, K. 1973. Field and forage crops. Canadian Agricultural Insect Pest Review, 51: 24.

Bereza, K. 1974. Cereal leaf beetle. Canadian Agricultural Insect Pest Review, 52: 16.

Bereza, K. 1985. Insects and related pests of cereal crops – Ontario. Canadian Agricultural Insect Pest Review, 63: 1.

Brown, G.S. 1966. Foreign insects threatening Ontario agriculture and forestry. Proceedings of the Entomological Society of Ontario, 96 (1965): 11-13.

Castro, T.R., R.F. Ruppel and M.S. Gomulinski. 1965. Natural history of the cereal leaf beetle in Michigan. Quarterly Bulletin of the Agricultural Experimental Station, Michigan State University, 47: 623-653.

Dysart, R.J., H. L. Maltby and M.H. Brunson. 1973. Larval parasites of *Oulema melanopus* (L.) in Europe and their colonization in the United States. Entomophaga, 18: 133-167.

Ellis, C.R., D.G. Harcourt and D. Dubois-Martin. 1978. The current status in Ontario of *Tetrastichus julis* (Hymenoptera: Eulophidae), a parasitoid of the cereal leaf beetle. Proceedings of the Entomological Society of Ontario, 109: 23-26.

Harcourt, D.G., J.C. Guppy and C.R. Ellis. 1977. Establishment and spread of *Tetrastichus julis* (Hymenoptera: Eulophidae) a parasitoid of the cereal leaf beetle in Ontario. Canadian Entomologist, 109: 473-476.

Haynes, D.L., R.K. Brandenburg and P.D. Fisher. 1973. Environmental monitoring network for pest management systems. Environmental Entomology, 2: 889-899.

Haynes, D.L. and S.H. Gage. 1981. The cereal leaf beetle in North America. Annual Review of Entomology, 26: 259-287.

Krombein, K.V., P.D. Hurd, Jr., D.R. Smith and B.D. Burks. 1979. Catalogue of Hymenoptera in America North of Mexico. Vol. 2. Smithsonian Institute Press. Washington, D.C. p. 1029.

Lampert, E.P. and D.L. Haynes. 1985. Population dynamics of the cereal leaf beetle, *Oulema melanopus* (Coleoptera: Chrysomelidae), at low population densities. Environmental Entomology, 14: 74-79.

Maltby, H.L., F.W. Stehr, R.C. Anderson, G.E. Moorehead, L.C. Barton and J.D. Paschke. 1971. Establishment in the United States of *Anaphes flavipes*, an egg parasite of the cereal leaf beetle. Journal of Economic Entomology, 64: 693-697.

(Received 20 December 1987; accepted 13 September 1988)

WITHIN-PLANT DISTRIBUTION OF EGGS AND LARVAE OF THE IMPORTED CABBAGEWORM ON CAULIFLOWER

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Abstract *Proc. ent. Soc. Ont.* 119:47-51

The within-plant distribution of eggs and larvae of the imported cabbageworm (ICW), *Artogeia rapae* (L.) (Leipidoptera: Pieridae) on cauliflower, 'Andes', varied with leaf surface and leaf age. Eggs and early instars (I-III) of ICW were most frequently found on the lower surface of leaves during the plants' growth interval from transplanting to head formation and on the lower surface of middle leaves from head formation to harvest. From head formation to harvest, most late instars (IV-V) of ICW were on either surface of head or middle leaves. Sampling plans which encompass all of the regions of the plant would likely provide better estimates of insect populations on cauliflower than sampling plans restricted to the head region of the plant.

Introduction

The imported cabbageworm (ICW), *Artogeia rapae* (L.) (Lepidoptera: Pieridae) is an important pest of cruciferous crops in southern Ontario (Harcourt 1963). Larvae damage plants by chewing holes in leaves or by contaminating the developing head with frass or both (Harcourt 1978). Sampling methods, based on whole-plant samples, have been developed for larvae of ICW on Brussels sprouts (Theunissen and den Ouden 1985) and on cabbage (Hoy *et al.* 1983; Cartwright *et al.* 1987). These methods are dependent on the distribution of larvae on the plant as well as within the field. The distribution of larvae of ICW in fields of cabbage is described by a negative binomial distribution (Harcourt 1961).

Knowledge of the distribution of lepidopterous eggs and larvae on cauliflower must be obtained before plants can be properly sampled in pest management programs. The location of eggs and young larvae of ICW on cruciferous plants is related to the ovipositional behaviour of females. Eggs are laid on the undersurface (Richards 1940) of older leaves (Ives 1978).

The objective of our study was to document the distribution of eggs and larvae of ICW on cauliflower grown in southern Ontario.

Materials and Methods

Seedlings of cauliflower, 'Andes', were transplanted from a seedbed to the field on 23 June 1986 at the University of Guelph Horticultural Research Station, Cambridge, Ontario. Plots consisted of plants spaced at approximately 0.5 m apart in six rows spaced about 0.9 m apart. Each row contained approximately 30 plants. Plots were replicated four times. The first two and last two plants as well as the outer row of each plot served as a buffer. Plots were not treated with insecticides. Sampling commenced on 14 July (three weeks after transplanting) and continued at weekly intervals (except the week of 5 August) until 12 September (one week before harvest). Plants were sampled between the hours of 09:00 and 16:00 on sunny or overcast days. Growth and development of cauliflower were divided into two intervals: from transplanting to head formation (14 July to 11 August) and from head formation to harvest (18 August to 12 September). At least 50% of the plants from each plot had formed their heads by 18 August. Each week, forty plants were sampled from transplanting to heading and twenty plants were sampled from heading to harvest. The location of each egg, early instars (I to III), and late instars (IV and V) of ICW on a plant was categorized into zones defined by the upper and lower surfaces of leaves, and age and location of leaves. From transplanting to heading, young leaves were those that were less than 300 cm^2 and located around the growing point of the plant, and all other leaves were considered older. Young leaves were visually estimated to comprise about 40% of the area of plants from transplanting to harvest. From heading to harvest, the ages of leaves were

defined as head, middle, or outer leaves. Head leaves were those that were less than 300 cm^2 and located around the developing head. Outer leaves were the four outermost leaves of the plant. Middle leaves were in the region between the head and the outer leaves. Six zones describing the location of individuals on a plant were defined from heading to harvest. The head, middle, and outer leaves were visually estimated to consist of 30, 50, and 20%, respectively, of the leaf surface from heading to harvest.

Mean numbers of eggs and larvae were tabulated in the categories described above, analyzed by ANOVA, and means were compared by a protected least squares difference (LSD) test ($P \leq 0.05$) (SAS Inst. 1985).

Results and Discussion

Eggs and larvae of ICW were not distributed equally on cauliflower. Analyzing the data over a five week period during pre-heading and a four week period during post-heading showed that the week to week variation was significant. From transplanting to heading, more eggs of ICW were laid on the lower surface of leaves than on the upper surface (Fig. 1). More eggs were found on the lower surface of middle leaves from heading to harvest than on any other area of the plant (Fig. 1). This

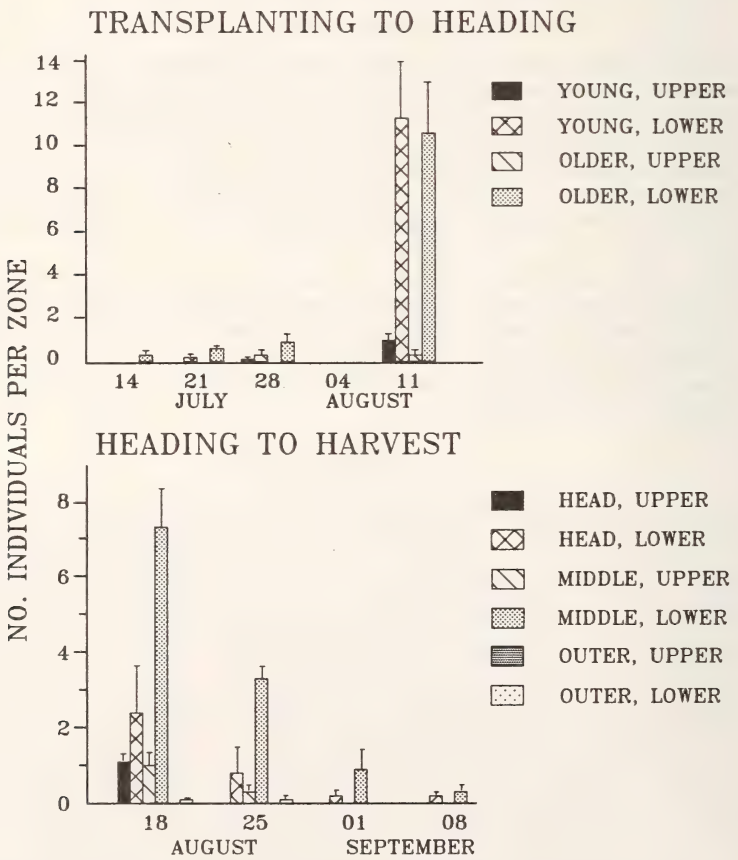

FIGURE 1. Mean number (± S.E.) of eggs of ICW on the upper or lower surface of young or older leaves of 'Andes' cauliflower from transplanting to heading or on the upper or lower surface of head, middle, or outer leaves from heading to harvest, Cambridge, Ont., 1986.

trend was significant for 18 and 25 August only. Richards (1940) reported that females of ICW deposited 86% of their eggs on the lower epidermis of leaves of cole crops. About 91% of the eggs of ICW in our study were located on the lower surface of leaves.

Most early instars of ICW were located on the lower surface of leaves from transplanting to heading (Fig. 2). From heading to harvest, significantly more early instars of ICW were found on the lower

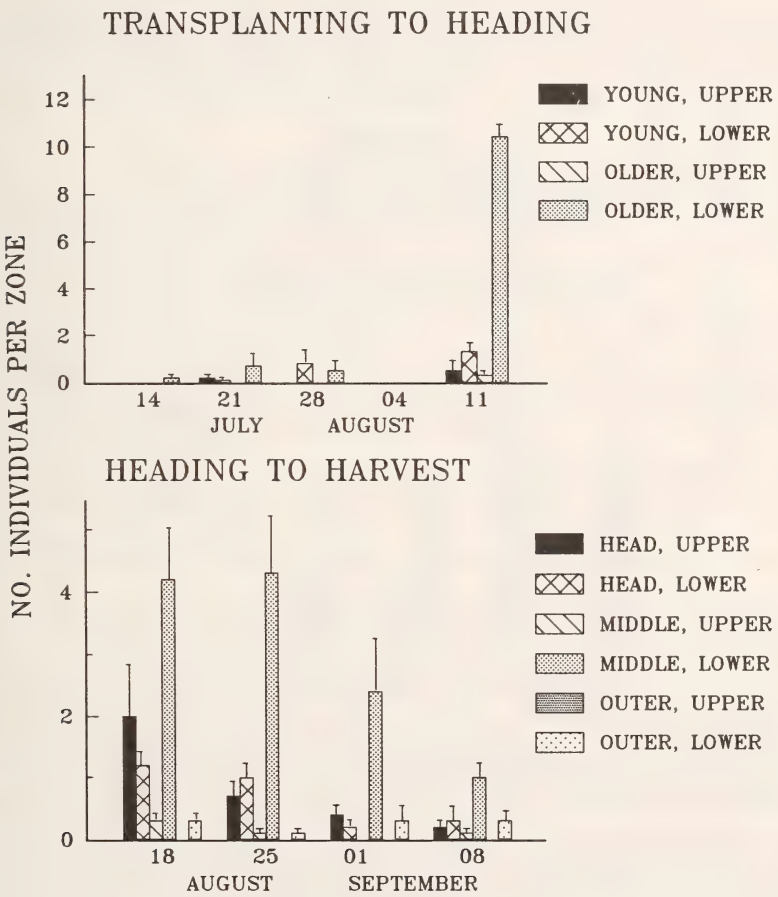

FIGURE 2. Mean number (± S.E.) of early instars of ICW on the upper or lower surface of young or older leaves of 'Andes' cauliflower from transplanting to heading or on the upper or lower surface of head, middle, or outer leaves from heading to harvest, Cambridge, Ont., 1986.

surface of middle leaves than any other area of the plant (Fig. 2). Similar numbers of late instars of ICW were located on all four areas of the plant from transplanting to heading (Fig. 3). From transplanting to heading more late instars of ICW were found on the upper and lower surfaces of head and middle leaves than were found on either surface of outer leaves (Fig. 3). The upper surface of head leaves tended to have more late instars of ICW than other areas of the plant (Fig. 3). This trend was not always significant, however.

The location of eggs and early instars of ICW is related to the oviposition behaviour of females. Females of ICW deposit more eggs on older, but not senescing, leaves than on younger ones (Ives 1978). Young larvae are only slightly mobile (Harcourt 1963) and therefore remain close to the site of

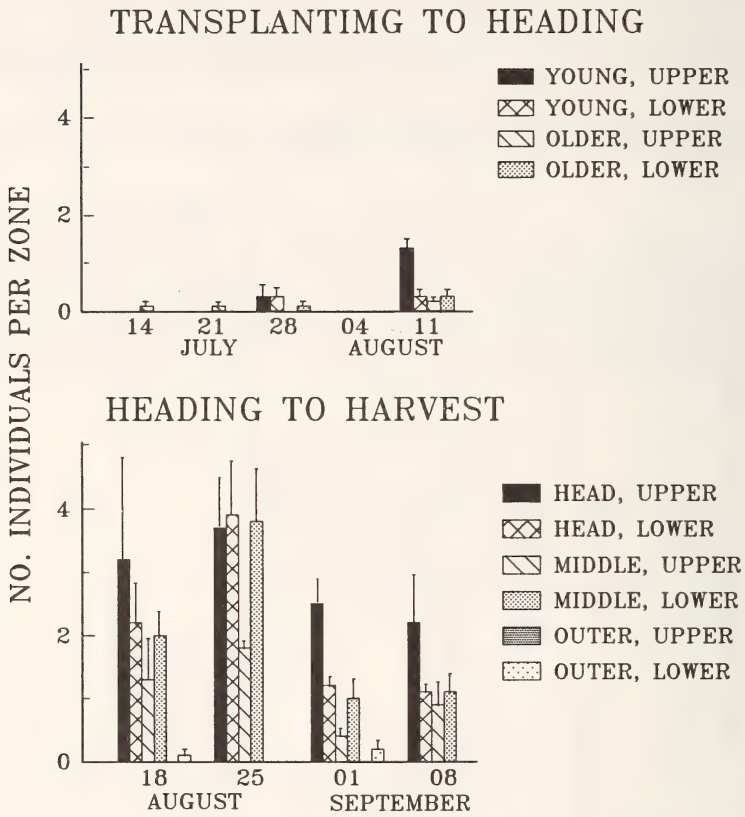

FIGURE 3. Mean number (± S.E.) of late instars of ICW on the upper and lower surface of young or older leaves of 'Andes' cauliflower from transplanting to heading or on the upper or lower surface of head, middle, or outer leaves from heading to harvest, Cambridge, Ont., 1986.

oviposition. The location of eggs and larvae of ICW on a plant may be related to the survival of the individual rather than the nutrition quality of the leaf. Jones and Ives (1979) argued that females of ICW could best promote survival of their offspring by laying eggs on middle-aged leaves rather than younger or older ones. Younger plant tissue, although nutritionally better, would not support many larvae from the first stadium to pupation. During the growth interval from heading to harvest, the predominance of early instars of ICW on the lower surface of middle leaves and the predominance of late instars on the upper surface of head leaves concurs with the suggestion of Harcourt (1963) that older larvae move to the head region as they mature. Late instar larvae of ICW prefer young leaf tissue (Hoy and Shelton 1987).

Determining the distribution patterns of ICW on individual cauliflower plants adds to the knowledge of the biology of these pests and could aid in the design of sampling programs. Sears *et al.* (1985) used the head and surrounding ten wrapper and frame leaves of cabbage as a sample unit in an attempt to reduce sampling effort for lepidopterous pests. The development of management schemes for lepidopterous pests using these partial-plant samples was not as effective as using whole-plant samples. Younger larvae of ICW located on the outer leaves of plants were not detected with partial plant samples and would later move to the head region during the fourth and fifth stadia. Stewart and

Sears (1989) found no difference in the number of lepidopterous larvae detected with quarter-plant samples relative to whole-plant samples. From the data reported herein, samples of cauliflower that encompass the head, middle, and outer leaves of the plant are more likely to represent the true population of larvae on a plant than would samples restricted to the head region.

Acknowledgement

The technical assistance of R. McGraw and D. Kitchen, and the statistical advice of O.B. Allen is gratefully acknowledged. Support for this research was provided by the Ontario Ministry of Agriculture and Food and by Agriculture Canada. This is Contribution No. 674 Agriculture Canada, Research Station, Charlottetown, Prince Edward Island, C1A 7M8.

References

Cartwright, B., J.V. Edelson, and C. Chambers. 1987. Composite action thresholds for control of lepidopterous pests on fresh-market cabbage in the lower Rio Grande Valley in Texas. Journal of Economic Entomology, 80: 175-181.

Harcourt, D.G. 1961. Spatial pattern of the imported cabbageworm, *Pieris rapae* (L.) (Lepidoptera: Pieridae), on cultivated Cruciferae. Canadian Entomologist, 93: 945-952.

Harcourt, D.G. 1963. Biology of cabbage caterpillars in eastern Ontario. Proceedings of the Entomological Society of Ontario, 93: 61-74.

Harcourt, D.G. 1978. Cabbageworm. Ontario Ministry of Agriculture and Food. Agdex 252/625, 3 pp.

Hoy, C.W., C. Jennison, A.M. Shelton, and J.T. Andaloro. 1983. Variable-intensity sampling: a new technique for decision making in cabbage pest management. Journal of Economic Entomology, 76: 139-143.

Hoy, C.W. and A.M. Shelton. 1987. Feeding response of *Artogeia rapae* (Lepidoptera: Pieridae) and *Trichoplusia ni* (Lepidoptera: Noctuidae) to cabbage leaf age. Environmental Entomology, 16: 680-682.

Ives, P.M. 1978. How discriminating are cabbage butterflies? Australian Journal of Ecology, 3: 261-276.

Jones, R.E. and P.M. Ives. 1979. The adaptiveness of searching and host selection behaviour in *Pieris rapae* (L.). Australian Journal of Ecology, 4: 75-86.

Richards, O.W. 1940. The biology of the small white butterfly (*Pieris rapae*), with special reference to the factors controlling its abundance. Journal of Animal Ecology, 9: 243-288.

S.A.S. Institute Inc. 1985. SAS Procedures Guide for Personal Computers, Version 6 Edition. Cary, N.C.: SAS Institute Inc., 373 pp.

Sears, M.K., A.M. Shelton, T.C. Quick, J.A. Wyman, and S.E. Webb. 1985. Evaluation of partial plant sampling procedures and corresponding action thresholds for management of Lepidoptera on cabbage. Journal of Economic Entomology, 78: 913-916.

Stewart, J.G. and M.K. Sears. 1989. Quarter-plant samples to detect populations of imported cabbageworm (Lepidoptera: Pieridae) and diamondback moth (Lepidoptera: Plutellidae) on cauliflower. Journal of Economic Entomology, in press.

Theunissen, J. and H. den Ouden. 1985. Tolerance levels for supervised control of insect pests in Brussels sprouts and white cabbage. Zeitschrift für angewandte Entomologie, 100: 84-87.

(Received 5 July 1988; accepted 4 November 1988)

EVALUATION OF THE TOXICOLOGICAL EFFECTS AND FIELD EFFICACY OF AN INSECTICIDAL SOAP AGAINST THE SPRUCE BUDWORM (LEPIDOPTERA: TORTRICIDAE)

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Abstract *Proc. ent. Soc. Ont.* 119:53-62

Fossil Flower's insecticidal soap (IS) was tested in laboratory and field studies against the spruce budworm, *Choristoneura fumiferana* (Clemens). In the laboratory, a 4% solution (v/v) of formulated IS had both acute and sublethal effects. Although there was variability in observed sublethal effects among different instars and treatments, in general, the treatments significantly ($p=0.05$) increased larval mortality, reduced the dry weight of frass pellets, delayed pupal development for 6th instars, reduced pupal weight and emergence, and lowered female fecundity. Sixth instars preferred the diet which had IS incorporated rather than the control diet without IS. Pupal weight was reduced more when larvae ingested IS than when IS was applied topically. Based on corrected mortality, more early instars (3rd and 4th) died when treated with IS than late instars (5th and 6th). In the laboratory, the larval parasitoid, *Apanteles fumiferana* Viereck, completed development normally and suffered mortality only when its host was killed by the treatments. In the field, single and double applications of 0.4% and 2.0% IS failed to reduce spruce budworm populations or provide foliage protection although these applications may have had a limited effect on larval development, emergence, and pupal parasitism. The current recommended rates of IS would not effectively control spruce budworm.

Introduction

The insecticidal properties of fatty acids and their soaps have been recognized since the turn of the century; however, their effectiveness against greenhouse and ornamental pests has only been demonstrated in the last 15 years (Pinnock *et al.* 1974; Puritch *et al.* 1982; Abbasi *et al.* 1984; Osborne and Petitt 1985; Wilson and Moore 1986). Recent bioassays suggest that insecticidal soaps may be useful against some insects that defoliate forests. Puritch (1978) observed significant mortality of both western spruce budworm, *Choristoneura occidentalis* Freeman, and the blackheaded budworm, *Acleris gloverana* (Walsingham), after applications of insecticidal soaps. To date, no soaps have been tested against the eastern spruce budworm (SBW), *Choristoneura fumiferana* (Clemens), and although they are considered to have low toxicity, little information is available about the effects of these soaps on beneficial species such as parasitoids.

SBW is the most damaging insect pest in Ontario's boreal forest, having caused by 1985, tree mortality on over 14 million hectares (Howse and Applejohn 1986). Current use of organophosphorous and carbamate insecticides for control of this insect in Ontario's forests, over 90% of which are crown forests, has become controversial. Alternative methods of control, one of which is the use of insecticidal soaps, are being investigated. Here, we describe results of experiments which examined the: 1) effects of Fossil Flower's insecticidal soap (IS) (Fossil Flower Natural Bug Controls, Mississauga, Ontario) on SBW feeding, development and survival after ingestion or topical application; 2) impact of IS on one larval parasitoid of the SBW; and 3) effectiveness of IS for control of SBW in the field.

Materials and Methods

Laboratory Studies

SBW were obtained from the Forest Pest Management Institute, Sault Ste. Marie, Ontario. All larvae were exposed during the 2nd instar to parasitism by *Apanteles fumiferanae* Viereck. Parasitoids were obtained from a colony maintained by V. Nealis (Great Lakes Forestry Centre, Sault Ste. Marie, Ontario). Newly moulted larvae were selected by stage according to Retnakaran (1980) and reared individually in 6 ml vials containing 1 g plugs of synthetic diet (Grisdale 1970). The vials containing the larvae were ventilated daily and each diet plug was replaced at 48-h intervals. All studies were done under a regime of 19±1°C, 60-80% RH and 16:8 L:D photoperiod.

The insecticidal activity of Fossil Flower's IS was studied by 1) incorporating a solution contain-

ing 40 ml formulated IS (50% potassium salts of fatty acids) per litre water into the rearing diet; 2) dipping nontreated diet plugs into the solution; and 3) spraying each larva to runoff with the solution and then removing each to nontreated diet plugs. Topical sprays of IS were applied using a mist applicator calibrated to deliver 0.04 ml/cm^2. This rate, although 10 times higher than that recommended for field application against tortricid species, was used in order to magnify subtle effects and observe readily apparent differences. Because we suspected that IS could have insect growth regulator (IGR) activity such as deformed larvae and pupae, the compound was compared with a bonafide moult-inhibiting IGR, Hoechst's (Regina, Saskatchewan) HOE-00522 (4% v/v 1-(3,5-dichloro-2-4-difluorophenyl)-3-(2,6-difluorobenzoyl)-urea) incorporated into the diet as in 1). With the exception of HOE-00522, each of these 4 treatments was applied to 3rd, 4th, 5th and 6th instars so that there were 24 larvae in each stage per treatment. HOE-00522 was not applied to 3rd instar larvae. An additional 24 larvae in each instar were left on artificial diet not treated as controls. This design was replicated twice and analyzed with the aid of 2-way Analysis of Variance (ANOVA) and Duncan's (1955) multiple range test following arcsine transformation of the percentage data.

The effect of the treatments on SBW was determined by comparing overall larval mortality, time to pupation (larval development), time to adult eclosion (pupal development), pupal weight, and adult longevity for each sex. When female SBW were mated to males that underwent the same treatment, the fecundity (number of eggs laid and percentage of eclosed eggs per female) of the females was also measured. Feeding by individual 5th and 6th instars, 3-4 days after ecdysis, was determined from weights of frass pellets produced over a 24-h period and air dried at 19±1°C for 2 weeks. The effect of the treatments on the larval parasitoid *A. fumiferanae* was measured by examining those parasitoids that emerged successfully or were found upon dissection of dead SBW larvae. For emerged parasitoids, survival and developmental time were compared in the 4 treatment groups and the controls using ANOVA.

In trials with foliage, 20 4th instars were allowed to establish on randomly selected buds of newly flushed balsam fir (*Abies balsamea* (L.) Mill.) (1 larva/bud). After 24 h, half of the buds (each with a single larva attached) was sprayed with 0.04 ml/cm^2 IS while the remaining half of the buds were treated with the same volume of water to serve as controls. Each treated bud was placed in an individual 10-mL cup which was then covered with a cardboard lid and inverted. Larval mortality was assessed after 48 h with moribund larvae considered alive. This experiment was replicated twice under the standard laboratory conditions.

The effect of IS on SBW pupae was also studied by spraying 38 pupae 24 h after ecdysis in the manner previously described. Another 38 pupae were sprayed with water, to serve as controls. The treated and nontreated pupae where placed individually into 6 mL holding vials and the percentage survival was assessed daily until ecdysis occurred. This procedure was replicated twice under the standard laboratory conditions.

Feeding preference tests were done by placing 4 diet plugs in a 10-cm-diameter petri dish; 2 of these plugs had IS incorporated (4% v/v) and 2 were not treated. The treated plugs alternated with the control plugs, each 3 cm apart from one another. Two 6th instars were placed in the centre of each of 9 dishes and their distribution on the diet plugs was recorded after 48 h; 3 replicate tests were conducted. Fluorescent bulbs placed ca. 0.5 m above the dishes provided uniform overhead lighting. This experiment and the previous two were analyzed using Ostle and Mensing's (1975) Chi-square test (χ) for proportions with binomial distributions.

Field Studies

Field trials were conducted in a 22-year-old plantation of white spruce (*Picea glauca* (Moench) Voss) near Hearst, Ontario (84°W,50°N). To estimate SBW populations, 38 dominant or codominant trees, evenly divided between white spruce and volunteer balsam fir, were randomly selected. On 14 June IS was applied at the recommended rate of 0.4% v/v (in water) on 7 of the balsam fir and 7 of the white spruce. Because no change in SBW populations was evident in the week following the first application, IS was reapplied 11 days later at the same concentration to 8 of these 14 trees and to an additional 3 balsam fir and 3 white spruce. Again, as no effects were apparent, 7 days after the second treatment, IS was applied at 2% v/v to an additional 5 balsam fir and 5 white spruce.

Five treatment regimes were thus established. These included: 1) 6 trees treated once with 0.4% IS on 14 June; 2) 6 trees treated once with 0.4% IS on 25 June; 3) 8 trees treated twice with 0.4% IS on 14 and 25 June; 4) 10 trees treated once with 2% IS on 2 July; and 5) 8 trees left as controls. The controls included 4 nontreated trees and 4 trees sprayed with water alone on 2 July. The initial spray date was selected to coincide with that developmental stage of the SBW when operational applications of aminocarb or *Bacillus thuringiensis* Berliner (*B.t.*) were conducted by provincial agencies.

IS was applied until runoff (ca. 10 min) on each date between 19:00 and 22:00 h, from a backpack mistblower calibrated to release at 3.5 L/min. Rates of application (mL/m^3 foliage) were calculated on the basis of applicator flow rate, individual tree volume and the time required. Tree volume was derived by measuring the height and the diameter of the crown at the base of each tree and then assuming that the tree had a perfect conical shape to estimate the volume of a cone. Weather conditions were recorded daily 15 km from the site.

Populations of SBW were estimated by counting insects on one branch sample taken from the upper mid-crown of each tree, 1-3 days before and after each spray. To assess SBW development, the number of larvae and their instars were recorded for all sample dates (McGugan 1954). An instar index was used to summarize SBW development. This value was obtained by multiplying the frequency of SBW collected at each stage by the stage number (i.e., 1-6, 1st to 6th instars; 7, pupae; 8, adults), summing these values and then dividing the sum by the total number of SBW collected. Defoliation was estimated using the Dorais-Hardy method of assessment on a single branch taken from the midcrown of each sample tree on 10 July (Sanders 1980). Population reductions resulting from the application of IS were computed by means of a modified Abbott's formula (Retnakaran 1982) based on pre- and post-spray population densities of SBW larvae. Pupae collected from the branches were held in ventilated vials under field conditions until adult eclosion or until pupal parasitoids emerged. The parasitoids were identified as described by Tilles and Woodley (1984).

Pre- and post-spray densities of SBW found on trees of each species and the resulting defoliation of those trees were compared for each application date by means of 2-tail Student's t-test. The total percentage of emergence, pupal parasitism and SBW larvae in each instar over the season were analyzed following arcsine transformations with ANOVA and Duncan's (1955) multiple range test.

Results

Laboratory Studies

Treatments with 4% Fossil Flower's IS (50% potassium salts of fatty acids) and with the IGR, HOE-005522, were not selectively toxic to either male or female SBW. Both sexes were represented in approximately equal numbers, therefore, the results were pooled for further analysis of each treatment group. In each case, when applied to 3rd, 4th and 5th instars, all treatments significantly increased larval mortality over that in the controls (Table I). This was particularly apparent with HOE-00522 which provided 100% mortality. During the 6th instar, only IS applied topically and HOE-00522 resulted in significant larval mortality. Several treatments reduced the dry weight of frass pellets over that of the controls.

The pupal stadium was extended slightly following treatment with IS but the delay was significant only when IS was applied topically to 6th instars (Table I). To a limited extent, pupal weights were reduced when SBW larvae ingested IS with the diet and when IS was applied topically to the diet during the 5th instar or to the larvae during 5th and 6th instars. Where female larvae completed development to the adult stage, treatment with IS generally reduced fecundity although there was considerable variation observed. These differences were significant (P=0.05) where IS was administered topically on the 4th and 6th instars and through ingestion by 3rd and 5th instars. In general, adult longevity was not affected by the IS treatments, while the percentage of eggs hatching was reduced significantly following most of the treatments.

IS incorporated in the diet or applied topically and HOE-00522 reduced successful emergence of *A. fumiferanae* from its SBW host (Table II). Parasitoid development in the host was extended significantly by HOE-00522 but not by either of the IS treatments. In most cases, dissections of dead SBW larvae showed that the parasitoid failed to emerge because the host died before parasitoid development was complete.

TABLE I. Effects of an insecticidal soap and chitin inhibitor growth regulator on spruce budworm when applied to 3rd, 4th, 5th and 6th instars.

Instar	Treatment	Larval mortality (%)	Larval development (days)	Frass dry weight (mg)	Pupal development (days)	Pupal weight (mg)	Adult longevity (days)	No. of eggs laid/ femal[eA]	Eclosed eggs (%)
3rd	Control	45.8a[B]	22.1a	-	7.5a	91a	15.5a	58.0a	53.4a
	IS-diet[C]	75.0b	24.0a	-	12.0a	41a	5.0b	0b	-
	IS-dip	100.0b	-	-	-	-	-	-	-
	IS-topical	83.3b	21.0a	-	9.7a	95a	15.0a	27.0a	1.0b
4th	Control	29.2a	16.8a	-	8.1a	89a	15.3a	16.4a	82.5a
	IS-diet	62.5b	18.2a	-	9.3a	43a	13.6a	10.0a	16.7b
	IS-dip	50.0b	16.4a	-	8.3a	78a	15.2a	11.5a	0b
	IS-topical	62.5b	18.8a	-	8.7a	77a	15.5a	9.7b	9.7b
	HOE-00522	100.0b	-	-	-	-	-	-	-
5th	Control	8.3a	14.8a	0.7a	8.1a	97a	16.4a	103.0a	38.6a
	IS-diet	45.8b	13.8a	0.1b	8.1a	46c	13.1b	7.0b	0b
	IS-dip	62.5b	14.4a	-	9.0a	72b	13.7ab	23.0ab	0b
	IS-topical	62.5b	12.6a	0.3b	8.8a	76b	13.9ab	47.0a	1.0b
	HOE-00522	100.0b	-	-	-	-	-	-	-
6th	Control	4.2a	6.3a	3.4a	8.0a	87a	15.8a	139.2a	65.7a
	IS-diet	4.2a	6.2a	1.1b	8.8ab	66b	15.8a	82.2ab	57.3ab
	IS-dip	4.2a	6.5a	-	8.6ab	99a	16.3a	82.3a	43.5b
	IS-topical	54.2b	5.6a	2.3ab	9.6b	80ab	17.0a	10.0b	15.9c
	MOE-00522	95.8b	6.0a	2.1ab	-	-	-	-	-

[A]n = mean of 14 females per treatment (range 8-22) based on matings producing fertile eggs.

[B]Instars analyzed separately. Means followed by the same letter within each instar and category are not significantly different (P 0.05; Duncan's (1955) multiple range test). Represents pooled values for both replicates; n = 48 larvae per treatment.

[C]IS, Fossil Flower's insecticidal soap (4% v/v) 50% potassium salts; IS-diet, IS incorporated into synthetic diet; IS-dip, synthetic diet dipped in 4% IS; IS-topical, IS sprayed on spruce budworm larvae fed synthetic diet not treated; HOE-00522, Hoechst's chitin-inhibitor growth regulator (4% v/v) incorporated in synthetic diet.

TABLE II. Effect of an insecticidal soap and a chitin inhibitor growth regulator on *Apanteles fumiferanae* when applied to parasitized 4th instar spruce budworm.

Treatment	n	Parasitoid survival (%)[A]	Parasitoid development (days)
Control	18	89a	8.6a
IS-diet[B]	19	37c	8.6a
IS-topical	19	53b	10.0a
HOE-00522	9	33c	18.0b

[A]Means followed by the same letter within each category are not significantly different (P >0.05; Duncan's (1955) multiple range test).

[B]See footnote B, Table I.

When 4th instars were allowed to establish themselves on tips of balsam fir and were sprayed with IS, larval mortality increased significantly over that of the controls; 55.0% of the treated larvae died in comparison with 0% of the control larvae (χ^2_s=9.05; df=1; P=0.01).

Of those pupae sprayed directly with 4% IS, only 29.8% emerged successfully; 86.4% of the pupae sprayed with water alone emerged, representing a 65% reduction in adult emergence (χ^2_s=9.82; df=1; P=0.01). There were no morphological or juvenile hormone effects noted in the pupae or adults of these treated insects as might be expected if the IS had acted as an IGR.

Of the 54, 6th instars allowed to choose nontreated diet versus 4% IS incorporated diet, 42 larvae were found feeding on the IS diet after 48 h while only 12 larvae were established on the nontreated diet (different at χ^2_s=14.36; df=1; P=0.01).

Field Studies

Weather conditions at the time of all 3 applications were similar; daily temperatures and relative humidities averaged 15.9 ± 1.5°C and 56 ± 12%, respectively. No rainfall was recorded during, or for 2 days following, any of the applications. At the time of the first application on 14 June, the greatest proportion of SBW larvae were 4th or 5th instars (index = 4.7). By 25 June, the larval index had progressed to 5.7 and by 2 July, most larvae had reached the 6th instar; 5 to 12% had already pupated (index = 6.0).

SBW populations were generally not affected by the soap applications (Table III). Natural mortality of SBW larvae was similar in the 2 control groups, ranging from 14.3 to 32.2%, while larval mortality on treated trees ranged from 0 to 37.4% and was not significantly different from that of the controls. Only the second, single application of IS on 25 June reduced SBW populations by 31% on balsam fir and by 30% on white spruce. The third spray on 2 July also significantly reduced larval populations but only on balsam fir. Despite fewer larvae, there was no evidence that the IS treatments provided significant foliage protection. Defoliation was generally higher on the treated trees than on the control trees (Table III).

In the field, the applications of IS produced extremely variable responses in SBW development, adult emergence, and pupal parasitism (Table IV). On balsam fir, more larvae were found on the treated trees than on the nontreated trees, suggesting a slight delay in larval development as a result of the IS application. On white spruce, those trees sprayed on 2 July had lower adult emergence and greater pupal parasitism by *Apecthis ontario* (Cress.), *Meterous tachynotus* Vier. and *Winthemia amoena* (Mg.) than the control trees or those trees sprayed earlier (i.e., on 14 June). These two effects of IS application on SBW feeding in white spruce are probably linked, in that greater pupal parasitism will always lead to lower adult emergence. Both effects should be considered sublethal, however, as they contribute, either separately or in combination, to a general reduction in SBW populations.

Table III. Experimental field applications of insecticidal soap on spruce budworm populations near Hearst, Ontario, 1985.

Treatment Date	Treatment (mL IS/m^3 foliage)[A]	No. of Sample Trees	Spruce budworm density[B] Pre-spray Bf	Pre-spray Sw	Post-spray Bf	Post-spray Sw	% Population reduction[C] Bf	% Population reduction[C] Sw	% Defoliation Bf	% Defoliation Sw
14 June	2.5	14	14(1)	43(9)	25(6)	39(1)			91(5)	96(1)
	control	14	11(2)	50(7)	9(2)	42(4)	0	0	70(5)	74(5)
25 June	5.8	6	16(3)	31(4)	8(4)	14(6)			87(3)	77(9)
	control	8	11(2)	31(7)	8(1)	20(3)	31[D]	30[D]	70(5)	74(5)
14 June & 25 June	2.5 & 4.2	6	15(2)	32(5)	16(2)	15(2)			55(15)	85(6)
	control	8	9(3)	46(6)	8(1)	20(3)	0	0	70(5)	74(9)
2 July	211.2	10	20(3)	25(3)	16(5)	39(6)			78(5)	80(9)
	control i)[E]	4	4(2)	17(9)	6(5)	20(10)	47[D]	0	63(3)	80(5)
	ii)	4	11(0)	31(18)	7(5)	20(2)	0	0	70(5)	68(8)

[A]IS, active ingredient of Fossil Flower's insecticidal soap; Bf, balsam fir; Sw, white spruce; m^3 foliage based on individual tree volumes.

[B]Mean number of spruce budworm per 45-cm branch tip, with standard errors indicated in parentheses; two significant digits.

[C]% population reduction = $1 - \frac{\text{post-spray density in treatment}}{\text{pre-spray density in treatment}} \times \frac{\text{pre-spray density in control}}{\text{post-spray density in control}} \times 100$ from Retnakaran (1982).

[D]Significant reduction at the P = 0.05 level (Student's t-test).

[E]Control trees: i) sprayed 2 July with 0.8 L water/m^3 foliage; ii) not sprayed.

TABLE IV. Proportion of spruce budworm in the larval stage, adult emergence and pupal parasitism by species of host tree following applications of insecticidal soap near Hearst, Ontario, 1985.

Host tree	Treatment Date(s)	n[A]	SBW larvae (% of total)	Adult emergence (%)	Pupal parasitism (%)
Balsam fir	14 June	15	85ab[B]	78ab	2a
	25 June	15	90a	81a	7a
	14,25 June	20	89a	66a	12a
	2 July	15	-	58a	15a
	Control	28	78b	55a	14a
White spruce	14 June	15	78a	64a	4a
	25 June	15	85a	53ab	33b
	14,25 June	20	88a	46ab	9a
	2 July	15	-	38b	13ab
	Control	28	75a	62a	4a

[A]n, number of branch samples

[B]Host trees analyzed independently; means followed by the same letter within each column are not significantly different ($P > 0.05$; Duncan's (1955) multiple range test).

Two modes of action for insecticidal soaps have been proposed: 1) as IGRs, by interfering with cellular metabolism and, thus, growth hormones during metamorphosis (McFarlane and Henneberry 1965; Andrews and Miskus 1972; Puritch 1975, 1978), or 2) as contact insecticides, by blocking spiracles and interfering with respiration (Abbasi *et al.* 1984). In the present study, although 6th instars preferred the diet incorporated with IS to that not treated, the dry weight of their frass was reduced, as was the case with the IGR. Although this reduction in feeding may result from other toxicological effects which weaken larvae, a failure to feed or a change in feeding is one the effects associated with chitin-inhibiting IGRs (Retnakaran *et al.* 1985). Further physiological studies on the mode of action of IS would be of interest, as they would better examine the possible growth regulating effects of this compound.

As with most insecticidal compounds, soaps may produce either acute mortality or sublethal debilitation. Both effects were evident in the present study. These included: larval and pupal mortality, slightly extended pupal development for 6th instars, reduced pupal weight and reduced female fecundity. The sublethal effects were more apparent when 5th and 6th instars were treated than when 3rd or 4th instars were treated. As suggested by the feeding study conducted with the 6th instars, these effects might be associated with changes in feeding or assimilation. The sublethal effects of insecticidal soaps or IGRs have been examined in a few studies (Retnakaran *et al.* 1985; Alford and Holmes 1986). Puritch (1978) observed IGR-like effects on pupae of *Tenebrio molitor* L. following treatment with fatty acid salts and Madore *et al.* (1983) found that mating success and egg production of SBW were reduced after larval treatment with a chitin-inhibiting IGR.

Parasitism of SBW appeared to be inconsistently affected by the application of IS. In the field, variable changes in parasitism were observed for IS applied during SBW pupation as opposed to treatments of earlier larval instars. This suggests that pupae treated with IS may be more available for parasitoid oviposition than nontreated pupae. In the laboratory, the larval parasitoid *A. fumiferanae* developed normally despite exposure of its host to IS. Parasitoid mortality occurred only when SBW was also killed (before the 5th instar). *B.t.* produced a similar, indirect effect on a larval parasitoid of the tobacco budworm, *Heliothis virescens* (Fabr.) (Thomas and Watson 1986) while only a direct effect of diflubenzuron on a larval parasitoid of the gypsy moth, *Lymantria dispar* (L.), was reported by Grannett and Weseloh (1975). Further studies are needed to clarify both direct and indirect effects of insecticidal soaps on beneficial insects in order to make recommendations for their use in the field.

Field applications of IS at the current label rate may lower SBW populations to a limited extent through their sublethal effects on the larvae. In the short term, however, they will not cause sufficient larval mortality to suppress SBW populations nor will they prevent defoliation. Although higher rates (4%) such as those used in the laboratory might have a greater impact, in the field, both the behaviour of young SBW larvae and the presence of tree foliage will likely reduce the chances of larvae actually contacting the spray. In Ontario, because of the high costs associated with treating extensive forested areas, IS would need to be applied aerially for the control of SBW. Aerial applications would provide considerably less coverage to individual trees than would handheld mistblowers. At the present time, therefore, neither type of IS application can compete successfully with the standard control methods of provincial agencies (i.e., *B.t.* and broad-spectrum insecticides) and IS is not currently recommended for SBW suppression.

Acknowledgements

We thank B. Goulet and P. Radonicich of Fossil Flower Natural Bug Controls for the IS, I. MacDonald of Hoechst for the HOE-00522, S. Micelli, M. Clarkson and G. Lucuik for field assistance, D. Wallace, J. Cunningham, B. Tomkins and A. Obarymskyj for the use of equipment, G. Harvey, C. Ellis, A. Retnakaran and several anonymous reviewers for editorial suggestions, and the National Sciences and Engineering Research Council of Canada for financial support to SMS. This research was supported by contracts from Fossil flower to M.H.

References

Abbasi, S.A., P.C. Nipaney and R. Soni. 1984. Soap solution as an environmentally safe pesticide: for household insects - a preliminary investigation. Comparative Physiology and Ecology, 9:46-48.

Alford, A.R. and J.A. Holmes. 1986. Sublethal effects of carbaryl, aminocarb, fenitrothion, and *Bacillus thuringiensis* on the development and fecundity of spruce budworm (Lepidoptera: Tortricidae). Journal of Economic Entomology, 79:31-34.

Andrews, T.L. and R.P. Miskus. 1972. Some effects of fatty acids and oils on western spruce budworm larvae and pupae. Pesticide Biochemistry and Physiology, 2:257-261.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics, 11:1-41.

Grannett, J. and R.M. Weseloh. 1975. Dimilin toxicity to the gypsy moth larval parasitoid, *Apanteles melanoscelus*. Journal of Economic Entomology, 68:577-580.

Grisdale, D. 1970. An improved laboratory method of rearing large numbers of spruce budworm, *Choristoneura fumiferana* (Lepidoptera: Tortricidae). Canadian Entomologist, 102:1111-1117.

Howse, G.M. and M.J. Applejohn. 1986. Forest Insect and Disease Conditions in Ontario, Fall 1986. Department of Environment, Canadian Forestry Services, Sault Ste. Marie, Ontario. Survey Bulletin. 32pp.

Madore, C.D., D.G. Boucias and J.B. Dimond. 1983. Reduction of reproductive potential in spruce budworm (Lepidoptera: Tortricidae) by a chitin-inhibiting insect growth regulator. Journal of Economic Entomology, 76:708-710.

McFarlane, J.E. and G.O. Henneberry. 1965. Inhibition of the growth of an insect by fatty acids. Journal of Insect Physiology, 11:1247-1252.

McGugan, B.M. 1954. Needle-mining habits and larval instars of the spruce budworm. Canadian Entomologist, 86:439-454.

Osborne, L.S. and F.L. Petitt. 1985. Insecticidal soap and the predatory mite, *Phytoseiulus persimilis* (Acari: Phytoseiidae), used in management of the twospotted spider mite (Acari: Tetranychidae) on greenhouse grown foliage plants. Journal of Economic Entomology, 78:687-691.

Ostle, B. and R.W. Mensing. 1975. Statistics in Research. Iowa State University Press. 595 pp.

Pinnock, D.E., R.J. Brand, J.E. Milstead and N.F. Coe. 1974., Suppression of populations of *Aphis gossypii* and *A. spiraecola* by soap sprays. Journal of Economic Entomology, 67:783-784.

Puritch, G.S. 1975. The toxic effects of fatty acids and their salts on the balsam woolly aphid, *Adelges piceae* (Ratz.). Canadian Journal of Forest Research, 5:515-522.

Puritch, G.S. 1978. Biological effects of fatty acid salts on various forest pests. Symposium on Pharmacological Effects of Lipids. American Oil Chemist's Society Monograph. No. 5:105-112.

Puritch, G.S., N. Tonks and P. Downey. 1982. Effect of a commercial insecticidal soap on green house whitefly (Homoptera: Aleyrodidae) and its parasitoid, *Encarsia formosa* (Hymenoptera: Eulophidae). Journal of Entomological Society of British Columbia, 79:25-28.

Retnakaran, A. 1980. Effect of 3 new moult-inhibiting insect growth regulators on the spruce budworm, *Choristoneura fumiferana* (Clemens). Journal of Economic Entomology, 73:520-524.

Retnakaran, A. 1982. Laboratory and field evaluation of a fast-acting insect growth regulator against the spruce budworm, *Choristoneura fumiferana* (Lepidoptera: Tortricidae). Canadian Entomologist, 114:523-530.

Retnakaran, A., J. Granett and T. Ennis. 1985. Insect growth regulators. pp. 529-601 in G.S. Kerkut and L.I. Gilbert, *Ed.* Comprehensive Insect Physiology, Biochemistry and Pharmacology. Pergamon Press, Oxford.

Sanders, C.J. 1980. A summary of current techniques used for sampling spruce budworm populations and estimating defoliation in Eastern Canada. Department of Environment, Canadian Forestry Services, Sault Ste. Marie, Ontario. Report 0-X-306. 33 pp.

Thomas, E.M. and T.F. Watson. 1986. Effect of Dipel (*Bacillus thuringiensis*) on the survival of immature and adult *Hyposter exiguae* (Hymenoptera: Ichneumonidae). Journal of Invertebrate Pathology, 47:178-183.

Tilles, D.A. and N.E. Woodley. 1984. Spruce budworm parasites in Maine: A reference manual for collection and identification of common species. United States Department of Agriculture,

Forestry Service, Agriculture Handbook. No. 616. 35 pp.
Wilson, L.F. and L.M. Moore. 1986. Preference for some nursery-grown hybrid *Populus* trees by the spotted poplar aphid and its suppression by insecticidal soaps (Homoptera: Aphididae). Great Lakes Entomologist, 19:21-26.

(Received 26 August 1987; accepted 4 November, 1988)

EFFECT OF APPLICATION EQUIPMENT ON THE DISTRIBUTION OF CHLORPYRIFOS APPLIED FOR DUTCH ELM DISEASE VECTOR CONTROL

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Abstract *Proc. ent. Soc. Ont.* 119:63-68

Chlorpyrifos (0.5%) was applied to mature elm trees with either a hydraulic sprayer or a mist blower, and the deposition of chlorpyrifos on bark samples measured by high performance liquid chromatography (HPLC). Neither apparatus provided uniform deposition, and the upper crowns, trunks and major branches of most of the trees were poorly covered. The mist blower and hydraulic sprayer both oversprayed portions of the lower and middle crowns. Our results indicate that improvements in application equipment and technique are needed, and that chlorpyrifos concentration should be independently evaluated with each type of application equipment to achieve an effective deposit.

Introduction

The objective of modern management programs for Dutch elm disease (DED), *Ceratocystis ulmi* (Buisman) C. Moreau (Ascomycetes: Ophiostomataceae), is to prevent infection of high-valued individual elm trees, with control efforts directed and timed according to the activities of the bark beetle vectors (Euale *et al.* 1978, 1980; Peace 1954). In Ottawa, both the native elm bark beetle, *Hylurgopinus rufipes* (Eichhoff), and the smaller European elm bark beetle, *Scolytus multistriatus* (Marsham) (Coleoptera: Scolytidae) are vectors of DED. The insect activities of importance in DED control are the overwintering of adult beetles on the rough lower bark of the trunk, followed by upward migration on the bark in the spring, and feeding on twig crotches in the upper crown.

Chlorpyrifos has been recommended for use against elm bark beetles as part of an integrated program to control DED (Euale *et al.* 1980). Label specifications on a formulation of chlorpyrifos approved for this use, Dursban 4E, state that an aqueous dilution of 0.48% chlorpyrifos should be applied to the bottom 2.5 m of the trunk to prevent overwintering, and/or to the crown of the tree to prevent branch and twig feeding. The applicator is instructed to use a sprayer which will "give thorough coverage to the tree crown", and to "wet the trunk thoroughly, but do not spray to run off" with either a mist blower or hydraulic pressure sprayer.

The operating principles of these two types of application equipment are quite different. The mist blower applies a concentrated pesticide solution dispersed as fine droplets in a broad column of high velocity air, while the pressure sprayer applies a dilute formulation in a compact stream of large droplets. To compensate for these differences in pesticide deposition, Johnson and Zepp (1979) recommended that methoxychlor be applied in different dilutions depending upon the type of application equipment.

At a range of 15-20 metres or more, it is difficult for the spray operator to judge coverage visually. Although anecdotal, observations by the National Capital Commission, Ottawa, (Perumal, unpublished) and the Parks Department in Fredericton, New Brunswick, (O. Urquhart, personal communication 1978) indicate that an experienced operator applies as much as 10-fold more solution per elm tree with an hydraulic sprayer than with a mist blower. Thus, if label instructions for chlopyrifos dilution are followed, either the hydraulic sprayer may apply an excess of material or the mist blower may provide inadequate coverage.

The purpose of our study was to compare the two methods of application by examining the distribution of chlorpyrifos and uniformity of dosage obtained on mature elm trees. A chemical assay for chlorpyrifos was employed. This is faster and less expensive than a bioassay, but can be correlated with bioassay results against the target insects (Barger *et al.* 1973). It was also possible to compare the insecticide coverage, or the percentage of samples bearing a dosage at or above the label-specified effective dosage.

Materials and Methods

Insecticide application

Six healthy mid-sized elm trees, *Ulmus americana* L. (Ulmaceae), 10-20 metres high and of roughly equal bulk and age were selected from among trees growing along the Eastern Parkway in Ottawa, Ontario. The trees were in a park-like setting, readily accessible on all sides, and were subject to routine low-priority maintenance. Two ball-shaped, two cone-shaped and two umbrella-shaped trees were selected. The mist blower was an FMC Model 100 (trailer) (FMC of Canada Ltd., Burlington, Ontario) and the hydraulic sprayer was an FMC Model 2020MT with a Spray Master Deluxe Model 785 gun and a No. 12 disc, operated at 450 psi. Insecticide applications were made by trained operators on a clear day in July, with winds less than 10 km/h. The operators were given no special instructions on application technique and applied the material from all sides of the trees, as permitted by the maneuverability of the equipment. Chlopyrifos was applied as an 0.5% aqueous dilution of Dursban 4E (Dow Chemical Canada Inc., Sarnia, Ontario, PCP No. 10637).

Sample collection

The sampling design was adapted from one used by Barger *et al.* (1973). Each of the six trees in the study was divided into ten sample zones according to height and wind direction (Fig. 1), and two types of bark samples were distinguished: the thin, young bark in the crotches of 2-3 year old twigs in the crown exterior (zones 1-2A, 1-2B, 1-2C), and the mature, rough bark of the major interior branches (zones 1-2D) and lower trunk (zones 1-2E). The saddle-shaped portion of bark in the twig crotch was excised with a specially fabricated hand-operated punch (similar to a hand-operated paper punch), and bark disks (ca. 3 mm thick) from the major branches and trunk were removed with an 11.1 mm diameter brass cork borer. To control for any previous insecticide applications, a pooled sample of ten twig crotches or ten bark disks was collected from each sample zone before spray application. As soon as the bark appeared dry following the spray application, three pooled samples were again collected from each zone.

HPLC assay

Acetonitrile was added to each sample of 10 twig crotches (1.0 ml) and 10 bark disks (2.0 ml) in polypropylene-capped vials. The free acetonitrile in each sample was withdrawn after 48 hours and filtered through a 0.5 µmillipore filter. An aliquot of 20 µl was injected onto a high performance liquid chromatography (HPLC) column (Altex, 10 µLichrosorb C-10, 250 x 4.6 mm ID, temperature: ambient, flow rate: 1 ml/minute, detector: 254 nm UV) and eluted with acetonitrile:water, 3:1. Chlorpyrifos concentration was quantified by comparison of the peak height at the appropriate retention time to the values obtained using technical chlorpyrifos (Dow Chemical Canada Inc.).

The surface area of the saddle-shaped samples of bark from the twig crotches was difficult to determine, and chlorpyrifos yield was expressed on a weight/weight basis in µg/g dry weight after solvent extraction. Because bark disks of uniform surface area were obtained from the major branches and trunk, pesticide dosage on these samples was expressed in µg/cm.

Correlation of chlorpyrifos deposition to label specifications

Pesticide label specifications are written under the direction of Agriculture Canada, and describe the necessary concentration in solution of the active ingredient and the appropriate application method to control the target insects. In order to compare the deposition of chlorpyrifos with the two application methods, we assumed that the dosage of chlopyrifos needed for DED vector control was that obtained by precisely following label directions. Our operational definition of the label-specified effective dosage was the surface concentration of chlorpyrifos achieved by applying a 0.5% mixture of chlorpyrifos in water until the bark was thoroughly soaked, but not draining.

To correlate field deposition of chlopyrifos with the label-specified dosage, short sections of elm branches, having either mature rough bark or 2 to 3-year old twig crotches, were sprayed with Dursban 4E in water (0.5% chlorpyrifos in solution). A small air-powered sprayer normally used to spray chromatography plates was used, and spray was applied in a crossed pattern of parallel strokes from a range of approximately 15 cm until the bark surface was thoroughly soaked, but not draining.

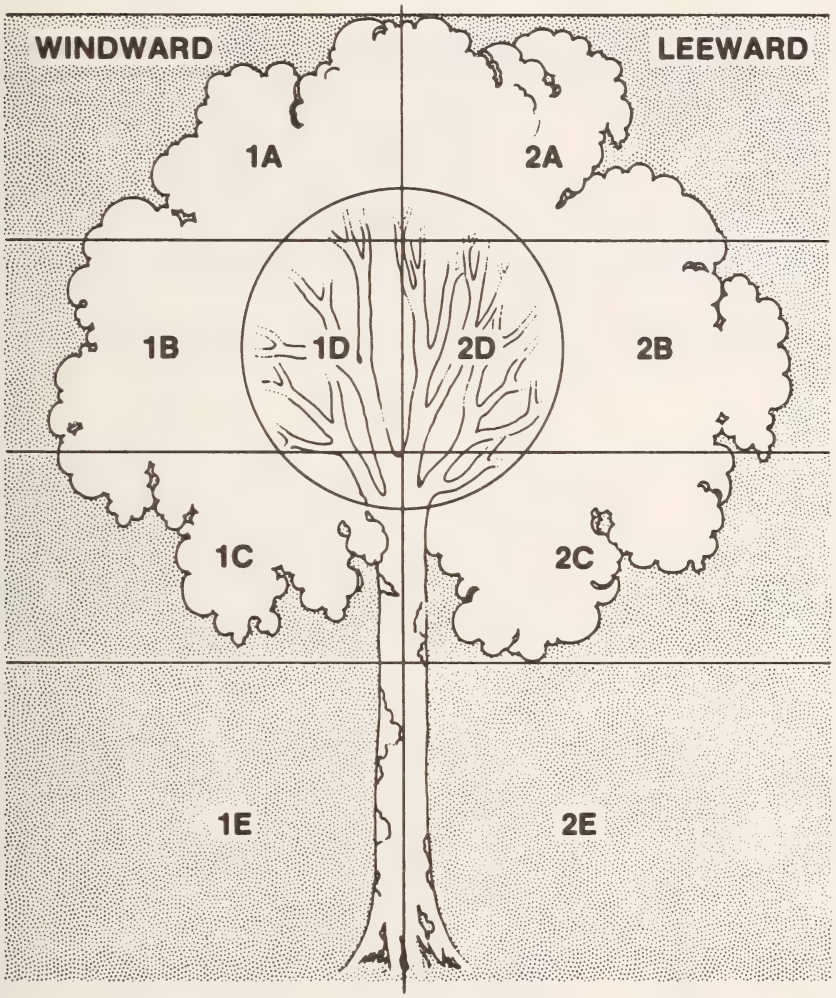

FIGURE 1. Location of chlorpyrifos sample zones on elm trees. Trees were divided into windward (1) and leeward (2) sides. Bark samples were excised from twig crotches in the upper (A), middle (B), and lower crown (C). Samples of rough bark were taken from the major branches (D), and lower trunk (E).

The branches were allowed to dry for 1 hour, then sampled and analyzed as described above. Measured chlorpyrifos dosages on five replicates agreed within 10%, with an average value of 30 µg/g dry weight for the twigs and 60 µg/cm^2 for rough bark. These mean values were considered to represent the label-specified effective dosage.

Quantitative accuracy of HPLC assay

A fortification study was conducted to determine the actual recovery of chlorpyrifos with the analytical method. Twig samples and bark disks were collected as described above from unsprayed elm trees. A series of five standard chlorpyrifos solutions ranging in concentration from 0.29 mg/ml to 4.85 mg/ml in acetonitrile was prepared. Rough bark samples were covered with 2.0 ml of each of the

five standard solutions, and twig crotch samples were covered with 1.0 ml. After 48 hours, the remaining free acetonitrile was analyzed by HPLC and the concentration of chlorpyrifos compared to that of the standards. The mean yield of chlorpyrifos, measured at 254 nm UV, was 85 ± 10%.

Data analysis

Data were subjected to analysis of variance (ANOVA) (Nie *et al.* 1975). In our primary model, crown shape, orientation to the wind, sample zone, and sprayer type were independent variables and measured chlorpyrifos deposition the dependant variable. With the twigs from the exterior crown, a revised model was developed to reclassify the factors related to tree size and crown shape in terms of the spray operation. In this revised model, the area of each zone as seen by the operator was classified in one of three size catagories ($<100m^2$, $100\text{-}200m^2$, $>200m^2$), and the square of the distance from the sprayer nozzle to the midpoint of the sample zone (assuming a nozzle position of *ca.* 1.75 m above the ground and 8 m from the trunk) was included in the analysis.

Results and Discussion

The advantages of our HPLC method over other chemical assays for chlorpyrifos are simplicity, speed, and use of the commonly available 254 nm UV detector. With this method, we determined the label-specified effective dosage of chlorpyrifos to be 30 µg/g for bark samples from the twig crotches and 60 $\mu g/cm^2$ for samples of rough bark from the trunk and major branches. The dosage on rough bark, when corrected by the 85% yield factor, is close to the chlorpyrifos concentration of 85 $\mu g/cm^2$ for rough bark obtained with a standard gas chromatography method (Euale *et al.* 1980). Although not addressed in our study, where efficacy data is required chemical assays can be correlated with bioassays to relate insecticide application rate and deposition to insect mortality (Barger *et al.* 1973).

TABLE I. Chlorpyrifos deposits on twigs and rough bark from elms treated with either a mist blower or hydraulic sprayer.*

Application Method	Crown Shape	Twig Crotches (mg/g)			Rough Bark (mg/cm2)	
		Zone A	Zone B	Zone C	Zone D	Zone E
Mist Blower	Ball	0 ± 0	72 ± 135	273 ± 292	22 ± 25	59 ± 31
	Cone	284 ± 169	317 ± 250	563 ± 257	38 ± 30	43 ± 38
	Umbrella	15 ± 24	114 ± 159	394 ± 296	27 ± 23	37 ± 27
Hydraulic Sprayer	Ball	2 ± 5	214 ± 309	526 ± 238	38 ± 21	74 ± 17
	Cone	234 ± 342	463 ± 309	763 ± 238	69 ± 38	96 ± 19
	Umbrella	19 ± 46	240 ± 170	605 ± 241	69 ± 28	76 ± 45

* Mean (± SD) of 6 samples from each zone, each sample containing ten pieces of bark.

With both types of application equipment, there was a great deal of variation in the deposition of chlorpyrifos on twig crotches from the outer crown, and on the rough bark (Table I). The lowest dosages were found on the twig crotches from the upper third of the crown (zone A). With the rough bark, chlorpyrifos dosage was lowest on the major branches (zone D), generally with the mist blower application.

Deposition of chlorpyrifos on bark in the twig crotches was significantly ($P \leq 0.01$) affected by crown shape, the sample zone on the tree, and the type of application equipment (Table II). The revised ANOVA model indicated that the area of the sample zone and the distance from the applicator to the sample zone were also significant factors. Orientation with respect to the direction of the wind, minimal during the insecticide application, had no significant effect on chlorpyrifos dosage.

The significance of distance to the spray zone and zone area indicates that operators of the hydraulic sprayer and the mist blower did not successfully compensate for these factors. As a result, higher zones were poorly covered, as were trees with bulkier crowns, and lower zones were often

oversprayed relative to the specified effective dosage. We observed that operators of both types of equipment could not judge from a distance when the bark was thoroughly soaked, but not draining. Operators also tended to aim toward the bulk of the crown, and were reluctant to spray the trunk down to the groundline. Scattering, foliage density, spray obstruction, and angular orientation to the target could also be expected to affect insecticide deposition.

TABLE II. Analysis of variance (ANOVA) of factors affecting chlorpyrifos dosages on elm twigs and rough bark.

		F-ratio	
	Variables	**Twig Crotch Samples**	**Rough Bark Samples**
Primary Model	Crown Shape	15.367*	0.245
	Sample Zone	40.381*	8.127*
	Wind Direction	0.177	1.960
	Sprayer Type	7.886*	24.588*
	4-way interaction	3.497	11.901*
Revised Model	Distance to Zone	6.457*	—
	Area of Zone	8.501*	—
	Sprayer Type	17.842*	—
	Wind Direction	0.005	—

*Significant at $P \leq 0.01$ level.

There were significant differences in the chlorpyrifos dosages obtained with the two types of equipment (Table II). In terms of coverage, or the percentage of samples bearing doses equal to or above the label-specified effective dosage, there was greater variation between twigs from different trees treated with the mist blower, and poorer coverage of the trunk and major branches, than was the case with the hydraulic sprayer application (Table III).

TABLE III. Measured coverage (C) on elm trees treated with 0.5% chlorpyrifos in solution, and estimated coverage with 0.25% ($C^{0.5}$), 1.0% (C^2), and 1.5% (C^3) chlorpyrifos. Coverage is expressed as the percentage of samples bearing deposits equal to or greater than the label-specified effective dosage.

		Twig Crotches			Rough Bark		
Application Method	**Crown Shape**	**C**	**$C^{0.5}$**	**C^2**	**C**	**$C^{0.5}$**	**C^3**
Mist Blower	Ball	35%	29%	35%	25%	0%	67%
	Cone	100	94	100	27	0	73
	Umbrella	67	50	72	27	0	73
Hydraulic Sprayer	Ball	50	50	56	58	0	83
	Cone	81	75	81	80	0	100
	Umbrella	63	63	69	58	8	100

Assuming the same spray deposition, we can estimate the effects on coverage of increasing or reducing chlorpyrifos concentration in solution (Table III). With both types of application equipment, doubling the chlorpyrifos concentration should only slightly improve twig coverage in the crown. Thus, modifications of the equipment or technique which would compensate for the effects of dis-

tance and zone area are more likely to produce significant improvements in crown coverage. Alternatively, a reduction in the concentration of active ingredient should be associated with a drastic reduction in coverage of the rough bark on the trunk and major branches. Theoretically, the concentration of chlorpyrifos used in the mist blower would have to be tripled to 1.5% to provide coverage roughly equivalent to that produced by an 0.5% chlopyrifos solution with the hydraulic sprayer. At the label-specified rate, it appears that a hydraulic sprayer should be used for applications to rough bark.

We noted several operational factors that affected the spray applications. The trailer mist blower was less maneuverable than the hydraulic sprayer, and two operators, a driver and a sprayer, must coordinate their efforts. The mist blower operator tended to direct the spray in a vertically oscillating pattern from the top to the bottom of the tree, making it difficult to compensate for distance or to recognize sprayed and unsprayed areas. It would be preferable for the operator to avoid rapid movements and work in a systematic spiral pattern down the tree. The towing vehicle should be light and fitted with broad tires to minimize soil compaction. These improvements in technique may allow the potential advantage of higher efficiency of the mist blower to be achieved. It is also possible to use a small hydraulic sprayer in conjunction with a mist blower to cover the trunk and major branches. With respect to these lower portions of the tree, the Dursban 4E label addresses the maneuverability issue by specifying use of a back pack mist blower, rather than a trailer, for trunk applications.

With the hydraulic sprayer, improvements are required in coverage of the upper crown and in reducing the amount of excessive spray. Reducing the operating distance by working from an elevating device, such as a bucket truck, should improve performance.

With both types of application equipment, success depends on the skill and diligence of the operator. Both supervisory and analytical spot checks may be required to ensure that the best techniques are employed. HPLC analysis offers a simple and inexpensive means of evaluating insecticide deposition in relation to label specifications.

Acknowledgements

We thank the National Capital Commission for cooperation and financial support and V.G. Smith for statistical advice. W.L. Chen (Dow Chemical Canada Inc.), D. Naffziger (Dow Chemical USA), S.M. Smith, two anonymous reviewers, and the editor made valuable suggestions on early drafts of the manuscript. Commercial sources appearing in this publication are for identification purposes only, and mention of a commercial source does not constitute an endorsement or warranty of products available, nor does it signify approval of any product to the exclusion of other comparable products.

References

Barger, J.H., R.A. Cuthbert, and D.G. Seegrist. 1973. Statistical correlation between GLC assay and smaller European elm bark beetle bioassay. Journal of Economic Entomology, 66:79-81.

Euale, L.R., L.M. Gardiner, G.E. Huntley, L.G. Jago, and E.S. Kondo. 1978. An integrated Dutch elm disease control program for Sault Ste. Marie: Part II. Canadian Forestry Service, Department of the Environment Information Report No. 0-X-283, 29 pp.

Euale, L.R., L.M. Gardiner, G.E. Huntley, L.G. Jago, and E.S. Kondo. 1980. An integrated Dutch elm disease control program for Sault Ste. Marie: Part III. Canadian Forestry Service, Department of the Environment Information Report No. 0-X-307, 38 pp.

Johnson, W.T., and D.B. Zepp. 1979. Insect control on trees and shrubs. Cornell recommendations for pest control for commercial production and maintenance of trees and shrubs. Cornell University, Ithica, New York, 63 pp.

Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bent. 1975. Statistical package for the social sciences (SPSS). McGraw-Hill, New York. 675 pp.

Peace, T.R. 1954. Experiments on spraying with DDT to prevent the feeding of *Scolytus* beetles on elm and consequent infection with *Ceratostomella ulmi*. Annals of Applied Biology, 41:155-164.

Zweig, G., and J. Sherma. 1972. Gas chromatographic analysis. Analytical Methods: Pesticides and Plant Growth Regulators, 6:191-233.

(Received 30 May 1988; accepted 24 October 1988)

SOIL INCORPORATION OF CARBOFURAN FOR PROTECTING BLACK SPRUCE SEED TREES FROM INSECTS

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Abstract *Proc. ent. Soc. Ont.* 119: 69-78

Carbofuran was applied to black spruce, *Picea mariana* (Mill.) B.S.P., seed trees by soil incorporation of granular and liquid formulations at rates of 5 or 10 g of active ingredient per cm diameter at breast height (AI/cm DBH). Numbers of spruce budworm, *Choristoneura fumiferana* (Clem), and spruce coneworm, *Dioryctria reniculelloides* Mutuura and Munro, degree of defoliation, cone production, percentage of cones damaged by seed and cone insects, numbers of sound seeds per cone slice, numbers of female buds per branch from the cone-bearing portion of the tree, and phytotoxicity were assessed in the year of treatment and one year later. The liquid formulation effectively controlled budworm in the year of treatment and the year after; granular carbofuran was not effective in the year of treatment, but it was effective the following year. Treatments were effective at upper, middle, and lower crown positions. They had no detectable influence on cone yields or cone damage by insects but cone seed counts were increased by the liquid formulation at 5 g AI/cm DBH in the year after treatment. Treatments did not influence initiation of female cone buds. Phytotoxic stress was evident at the 10 g AI/cm DBH liquid formulation in the second year of assessment but not at the 5 g AI/cm DBH.

Introduction

Black spruce, *Picea mariana* (Mill) BSP (Coniferae: Pinaceae), is widely used in reforestation programs in Canada. Seed collection areas have been set aside in some provinces to ensure that source-identified seed is available for reforestation, and seed production areas are being established to maximize production of high-quality seed through intensive stand management (Lamontagne 1979). Seed orchards for production of genetically improved seed are also being developed (Morgenstern and Carlson 1979). In spite of these developments, current requirements for seed cannot always be met because of poor seed yields caused by natural periodicity of cone crops and destruction by insects (McPherson *et al.* 1982). A survey of black spruce seed stands in Ontario in 1980 revealed that insects responsible for losses of cones and seeds include spruce budworm *Choristoneura fumiferana* Clem. (Lepidoptera: Tortricidae), spruce coneworm *Dioryctria reniculelloides* Mutuura and Munroe (Lepidoptera: Pyralidae), cone maggot *Lasiomma anthracina* Czerny, (Diptera: Anthomyiidae), and a cone midge *Dasineura rachiphaga* Tripp. (Diptera: Cecidomyiidae) (Sterner and Davidson 1981).

In spite of the known destructiveness of cone and seed-feeding insects on spruces (Tripp and Hedlin 1956) only one insecticide, dimethoate (Cygon®), is registered for use as a foliar spray (Fogal and Lopushanski 1985); others are needed. Carbofuran (Furadan 10G®) is registered and used by means of soil incorporation for control of cone and seed insects in southern pine seed orchards (DeBarr 1978) and has recently been registered for use in northern pine seed orchards (Rush and Overton 1987) in the United States. A liquid formulation appeared to be more effective than a granular formulation for control of cone-damaging insects in a seed orchard of red pine *Pinus resinosa* Ait. (Coniferae: Pinaceae) (Rush and Overton 1987) and irrigation improved the efficacy of granular carbofuran in a seed orchard of loblolly pine *P. taeda* L. (Coniferae: Pinaceae) (Hertel and Barber 1978).

Carbofuran has been tested for control of a variety of insect pests of coniferous trees (Cerezke and Holmes 1986) but there is little information to support its use for control of cone- and seed-feeding insects in spruce orchards. There is evidence that it does reduce insect damage to foliage (Fogal *et*

al. 1981) and to cones (Cerezke and Holmes 1986) of white spruce seed trees; however, phytotoxic effects were noted in both studies. In this report we describe results of an experiment on black spruce trees in a seed production area that had been heavily-defoliated by spruce budworm. The experiment was conducted to compare granular and liquid formulations of carbofuran for protecting trees from defoliating and cone- and seed-damaging insects, for possible effects on cone and seed yields, and for physiological responses including production of seed-cone buds and needle browning as measures of possible phytotoxic stress. We also wanted to know if the insecticide is equally effective at upper, middle, and lower crown positions for control of defoliation by budworm and if it persists in a toxic form in tree tissues one year after treatment.

Materials and Methods

1. **Study Site**

The experiment was conducted in a black spruce seed production plantation located at the Bonner Tree Improvement Centre of the Ontario Ministry of Natural Resources, Kapuskasing, Ontario (49° 21′N, 82°10′W). The plantation was on a flat 0.4-ha site of acidic (pH 5.9-6.2 in H_2O slurry and 4.9-5.3 in 0.1N KCl slurry) clay loam. It was surrounded by windbreaks of Scots pine *Pinus sylvestris* L. (Coniferae: Pinaceae) to the east and west, and natural mixed-wood stands to the north. Trees were planted at a spacing of 1.8 x 1.8 m in 1951 and thinned to 1.8 x 3.7 m in 1978 by removing every other row. In 1980, their mean diameter and standard error at breast height (DBH) was 9.7 ± 0.3 cm. Eighteen treatment plots were established in the plantation. Each plot contained five trees in a row (1.8 m spacing), with plot perimeters extending 2.4 m at the sides and ends of the rows. Plot edges were separated by at least 2.6 m to avoid the effect of one treatment on another. Rainfall records were obtained from Agriculture Canada, Research Branch, Experimental Farm, Kapuskasing, Ontario.

2. **Treatments**

Six treatments included the following combinations of formulation and rate of application: liquid or granular carbofuran at rates of 0 g (controls), 5 g, or 10 g AI/cm DBH. Three replicates of each treatment were assigned to plots in a completely randomized design on May 14, 1980, prior to budbreak.

The granular formulation of carbofuran (Furadan 10 G®: 10 per cent active ingredient) was applied by three passes with a hoe-drill (two furrows 60-cm apart) (Fogal and Lopushanski 1988) on each side of the row of trees. One pass covered the outer portion of the plot with the outermost furrow 10 to 20 cm from the plot edge; a second pass was made near the row of trees with the innermost furrow 40 to 50 cm from the row of trees. The third pass overlapped the first, so that 5 furrows from the outer edge of the plot were 30 cm apart and the 2 inner furrows were 60 cm apart. Granule delivery was adjusted to ensure that all of the active ingredient required for final rates of 5 g or 10 g AI/cm DBH per tree was applied in each plot. Chisels on the hoe-drill were allowed to penetrate 6 to 8 cm into the soil and any furrows that remained open following a pass were closed with a hand rake. Control plots receiving no insecticide were treated with an empty hoe-drill.

The liquid formulation of carbofuran (Furadan 4.8 F®: 49 per cent active ingredient was applied by means of a boom sprayer (1.2-m boom with 4 spray nozzles) (Fogal and Lopushanski 1988). The flowable product was made up to a volume of 50 L with water to provide final rates of 5 g or 10 g AI/cm DBH per tree in each plot. The 50 L volume of insecticide mixture was applied by making three passes on each side of the row of five trees within a plot. One pass covered the outside edge of the plot with the outer nozzle approximately 20 cm from the outside edge of the plot; a second pass was made with the inside nozzle as close as possible to the row of trees; the third pass equally overlapped the first and second. Controls included three undisturbed plots.

3. **Response variables**

The response of budworms and coneworms to treatments was assessed by taking a 46-cm branch sample from the lower, middle and upper crown of each of the five trees in each plot by means of a pruning pole equipped with a collecting basket. Samples were taken on 29 June, 1980, and 9 July, 1981. Budworm and coneworm larvae and pupae were counted. Defoliation of current-year needles

was estimated subjectively by ranking each branch tip into one of the following defoliation classes: 0, 5, 15, 25 ... 85, 95, or 100% defoliation. In 1980, most of the new flush of foliage had been killed by a late spring frost, so budworm defoliation on each sample was determined by subtracting the per cent defoliation definitely attributed to freezing from the total caused by budworm and frost.

All cones from each tree were counted and collected on 20 August, 1980, and 18 August, 1981 to assess cone yields. Subsamples of 20 cones, or all cones collected if less than 20, were assessed for insect damage (Tripp and Hedlin 1956). Budworm-damaged cones were curled and distorted; cones damaged by coneworm had excavations and were filled with frass and silk. After slicing each cone in half longitudinally, damage by internal feeders was identified and assessed as follows: spruce seed moth *Cydia youngana* (Kearfott) (Lepidoptera: Olethreutidae) was identified by the presence of seeds filled with fine granular frass and the presence of one or more larvae in a cone-axis gallery; spruce cone maggot was characterized by the presence of reddish-brown resin-filled feeding tunnels around the cone axis; cone-axis midge was identified by the presence of a gallery in the cone axis where one or more larvae overwinter in silken cocoons. The number of sound seeds on the cut face of one slice was then counted to assess seed yield.

The physiological response of trees to treatments was assessed by counting the number of seed-cone buds on a branch from the third whorl below the leader and by rating each tree for possible phytotoxic stress. Stress was subjectively rated by degree of needle browning as follows: 1, no browning; 2, 1-25 per cent; 3, 26-50 per cent; 4, 51-75 per cent; 5, 76-99 per cent; 6, 100 per cent. Phytotoxicity ratings and branch collections were made on 5 November, 1980, and 3 November, 1981.

4. **Statistical analyses**

To equalize variances, the numbers of budworms, coneworms, cones, seeds, and female flower buds were transformed to $y = \log_e (x + 1)$; per cent defoliation and per cent cones damaged by insects were transformed to y = arc sine $\sqrt{x}$; phytotoxicity ratings were not transformed. Separate analyses of variance were run for the results form 1980 and 1981. Preliminary analysis revealed significant plot-to-plot variation for all variables and, as a result, all analyses were done on a plot basis using mean values per plot. A second preliminary analysis revealed no significant difference in plot-to-plot variation between cultivated and sprayed plots, so the two application methods were combined in the same analysis of variance. For each year's data, the six combinations of formulation and rate of application were compared as if they were six independent treatments. Where data were taken from branches sampled at three crown positions (budworm counts, coneworm counts, and per cent defoliation), a randomized split-plot analysis of variance was applied to test for effect of treatment, effect of branch position, and treatment – position interaction. A simple one-way analysis of variance was applied to all other data. When F-tests indicated significant differences ($P < 0.05$) among treatments, means were then compared using Duncan's multiple range test (Steel and Torrie 1960). Data are presented as plot means with standard errors.

Results

1. Numbers of budworm, coneworm and defoliation in relation to treatments and crown position.

Budworm densities were lower in 1981 than 1980, corresponding to a widespread decrease of budworm populations throughout northeastern Ontario and northwestern Quebec (Sterner and Davidson 1982) (Table I). Analyses of variance revealed significant effects of treatment on per cent defoliation and numbers of budworm per branch for both assessment years, but treatments had no effect on numbers of coneworms per branch. Differences were also detected for numbers of budworms per branch at different crown positions for both assessment years, and per cent defoliation in 1980 but not in 1981, whereas there were no differences in numbers of coneworms per branch in either year. No interaction between treatments and crown position were evident except for numbers of budworms per branch in 1981.

In 1980, budworm numbers and defoliation decreased progressively from upper crown to lower crown in most treatments (Table I). In 1981, budworm numbers appeared to be greatest at the mid-crown position in control treatments; however, the pattern was not so obvious in the insecticide treatments, perhaps because the numbers of budworm were so low. That may have contributed to the

TABLE I. Effects of treatments (carbofuran applied as a granular or liquid formulation at rates of 0, 5, or 10 g AI/cm DBH) and crown position of branch sample on number of budworms and coneworms and per cent defoliation per branch. Means are presented with standard errors.

Treatments (Carbofuran formulation and application rate, g AI/cm DBH)	Crown position of branch	Assessment years and branch variables					
		1980			1981		
		Budworms per branch	Coneworms per branch	Per cent defoliation	Budworms per branch	Coneworms per branch	Per cent defoliation
Granules, 0	Upper	11.2 ± 1.3	0.8 ± 0.3	12.8 ± 2.2	1.1 ± 0.4	0.1 ± 0.1	7.5 ± 1.7
	Middle	8.0 ± 0.7	0.2 ± 0.1	10.7 ± 1.4	2.6 ± 0.6	0.1 ± 0.1	7.5 ± 1.6
	Bottom	8.0 ± 1.9	0.1 ± 0.1	8.9 ± 1.6	0.7 ± 0.2	0	3.3 ± 1.4
	Average	9.1 ± 0.7[a]	0.4 ± 0.1	10.8 ± 1.3[a]	1.4 ± 0.3[a]	0	6.1 ± 1.1[a]
Granules, 5	Upper	14.2 ± 2.5	0.3 ± 0.2	12.1 ± 1.3	0.4 ± 0.1	0	1.4 ± 0.5
	Middle	9.6 ± 2.8	0.3 ± 0.1	10.5 ± 1.9	0.7 ± 0.4	0	3.4 ± 1.6
	Bottom	6.8 ± 1.7	0.2 ± 0.1	9.5 ± 1.6	0.6 ± 0.2	0	0.7 ± 0.4
	Average	10.2 ± 0.9[a]	0.2 ± 0.1	10.7 ± 0.9[a]	0.6 ± 0.2[b]	0	1.8 ± 0.6[b]
Granules, 10	Upper	8.8 ± 1.9	0.2 ± 0.1	13.3 ± 2.3	0.2 ± 0.1	0	0.9 ± 0.4
	Middle	7.1 ± 1.4	0.3 ± 0.2	9.1 ± 1.2	0.3 ± 0.1	0	1.3 ± 0.6
	Bottom	5.0 ± 0.9	0.1 ± 0.1	6.9 ± 1.2	0	0	0.1 ± 0.1
	Average	7.0 ± 0.8[a]	0.2 ± 0.1	9.8 ± 1.3[ab]	0.2 ± 0.1[b]	0	0.8 ± 0.3[b]
Liquid, 0	Upper	13.9 ± 1.7	0.5 ± 0.1	16.3 ± 1.7	0.8 ± 0.2	0.2 ± 0.1	3.6 ± 0.7
	Middle	10.3 ± 1.3	0.3 ± 0.1	13.7 ± 3.0	3.0 ± 0.6	0	8.1 ± 2.6
	Bottom	7.0 ± 1.1	0.1 ± 0.1	8.3 ± 1.2	1.7 ± 0.6	0.1 ± 0.1	8.7 ± 2.1
	Average	10.4 ± 0.8[a]	0.3 ± 0.1	12.8 ± 1.4[a]	1.8 ± 0.3[a]	0.1 ± 0.0	6.8 ± 1.4[a]
Liquid, 5	Upper	4.3 ± 1.5	0.2 ± 0.2	7.8 ± 2.1	0.4 ± 0.2	0.1 ± 0.1	1.8 ± 0.6
	Middle	1.5 ± 0.7	0.1 ± 0.1	5.3 ± 1.1	0.5 ± 0.3	0	2.1 ± 0.8
	Bottom	0.8 ± 0.4	0.1 ± 0.1	6.8 ± 1.5	0.5 ± 0.2	0	0.9 ± 0.4
	Average	2.2 ± 0.6[b]	0.1 ± 0.1	6.7 ± 1.2[b]	0.5 ± 0.2[b]	0	1.6 ± 0.3[b]
Liquid, 10	Upper	0.8 ± 0.3	0.1 ± 0.1	4.3 ± 1.2	0.1 ± 0.1	0	0.7 ± 0.4
	Middle	0.4 ± 0.2	0.1 ± 0.1	4.3 ± 1.3	0.2 ± 0.1	0	0.9 ± 0.4
	Bottom	0.1 ± 0.1	0	2.3 ± 0.7	0	0.1 ± 0.1	1.2 ± 1.0
	Average	0.4 ± 0.2[c]	0	3.7 ± 0.9[c]	0.1 ± 0.1[b]	0	1.0 ± 0.4[b]
ANOVA F Values							
Treatment		10.17**	2.52	9.03**	12.17**	1.36	4.84*
Crown position		32.00**	4.44	11.82**	10.12**	1.86	2.87
Treatment X Crown position		1.97	1.08	1.16	2.87*	1.34	2.04

Significance of ANOVA F-values: * ($P<0.05$); ** ($P<0.01$).
Averages that bear the same letter are not significantly different ($P<0.05$) as judged by Duncan's multiple range test.

significant interaction effect.

In 1980, there were 9.1 budworms per branch on control plots for the granular formulation and 10.4 on control plots for the liquid formulation; levels of defoliation were 10.8 per cent and 12.8 per cent respectively. The figures for defoliation do not include shoots that may have been partially destroyed by feeding and then completely destroyed by heavy frost damage, so they may appear relatively low. The analysis of variance revealed that budworm numbers were significantly reduced and in spite of frost damage, defoliation was also significantly reduced on trees in plots that were treated with the liquid formulation of carbofuran. No control or protection was provided by the granular formulation.

Lack of control with granular carbofuran in 1980 may have been caused by low rainfall up to the time of assessment for budworm control. There was no rain for 16 days after treatment and the total rainfall up to 29 June, 1980, when budworm larvae were counted, was only 74 mm. Thus, although granules had been incorporated into the soil, there may have been insufficient soil moisture to dissolve them for diffusion through soil and uptake by roots.

2. Cones per tree, cone damage by insects, and cone seed counts.

Cone yields on the trees were low in 1980, ranging from an average of 2.6 to 13.9 over all treatments (Table II). No differences among treatments were evident. About half of the cones had been damaged by budworm and almost half by cone maggot; few cones were damaged by the seed moth or coneworm and none by the cone axis midge. Treatments had no effects on proportion of cones damaged by those insects. The number of sound seeds per 10 cone slices ranged from 5.6 to 19.0 and treatments caused neither an increase nor reduction in counts.

In 1981, there were a few more cone-bearing trees and more cones per tree but, again, treatments had no discernible effect on numbers of cones. The change (from 1980) in the proportion of cones damaged by insects is likely related to change in the size of the cone crop, the insects' population levels, and competitive advantage among the insects (Tripp and Hedlin 1956): reduced damage by budworm is likely related to the drop in the budworm population; coneworm damage may have increased because of reduced competition from budworm; reduced damage by cone maggot and seedmoth may have been related to the increase in size of the cone crop; and, increased levels of damage by the cone-axis midge could have resulted from lower competition from the cone maggot and seed moth. None of the treatments provided protection of cones against insect feeding damage. The number of sound seeds per 10 cone slices tended to be lower than counts from 1980, and there was a significant increase in seed counts with the liquid formulation of insecticide at the 5 g AI/cm DBH level, but not at the higher level.

3. Seed-cone buds and phytotoxicity.

Treatments with insecticides did not induce an increase in numbers of seed cone buds in either year (Table III). In an experiment on white spruce we did note an increase in numbers of seed cone buds on trees treated with carbofuran at a rate of 21.6 g AI/cm DBH (Fogal *et al.* 1981). Although phytotoxicity ratings were not influenced by the treatments in 1980, in 1981 the rating was significantly higher for trees treated with 10 g AI/cm DBH of the liquid formulation than it was for the other treatments. Although statistically significant, this rating of 2.5 was only marginally greater than ratings for other treatments (1.7 to 2.0) and considerably less than the maximum possible rating of 6.0. Nonetheless, there appears to have been a slight, detectable level of stress associated with the highest rate of the liquid formulation but not with the lower rate or with either rate of the granular formulation.

TABLE II. Effects of treatments (carbofuran applied as a granular or liquid formulation at rates of 0, 5, or 10 g AI/cm DBH) on number of cones per tree, per cent cones damaged by insects, and number of filled seeds per 10 cone slices. Means are presented with standard errors.

Year of assessment and variable	Treatments (formulation and application rates, g AI/cm DBH)						ANOVA F-values
	Granules			Liquid			
	0	5	10	0	5	10	
1980							
Number of plots with cone-bearing trees	3	3	3	2	2	2	
Total number of cone-bearing trees	4	5	6	4	3	4	
Average number of cones per tree[1]	5.2 ± 3.2	2.6 ± 1.6	4.7 ± 2.1	7.7 ± 5.0	3.5 ± 1.9	13.9 ± 7.7	0.07
Per cent cones damaged by:							
Budworm	52.5 ± 18.9	72.2 ± 19.1	48.3 ± 16.9	74.3 ± 11.6	56.9 ± 6.4	28.8 ± 15.3	0.15
Coneworm	0.0	2.2 ± 2.2	0.0	0.0	0.0	0.0	0.72
Seedmoth	5.0 ± 5.0	33.2 ± 13.9	8.3 ± 8.3	0.0	0.0	0.0	1.43
Cone maggot	30.0 ± 16.7	63.2 ± 15.3	36.8 ± 14.1	48.0 ± 14.7	32.7 ± 27.4	42.5 ± 22.2	0.46
Cone-axis midge	0.0	0.0	0.0	0.0	0.0	0.0	—
Number of seeds per 10 cone slices	20.3 ± 6.2	7.5 ± 1.9	6.9 ± 3.9	10.2 ± 5.7	13.4 ± 1.2	15.6 ± 3.7	0.69
1981							
Number of plots with cone-bearing trees	3	3	3	3	2	3	
Total number of cone-bearing trees	8	8	8	5	6	8	
Number of cones per tree[1]	42.6 ± 29.6	2.7 ± 1.1	4.6 ± 2.2	4.9 ± 4.1	31.1 ± 11.5	23.9 ± 16.3	0.98
Per cent cones damaged by:							
Budworm	32.9 ± 8.2	10.4 ± 6.3	15.4 ± 6.8	13.0 ± 8.9	5.0 ± 1.8	6.8 ± 4.1	0.48
Coneworm	10.3 ± 6.3	3.6 ± 2.6	10.0 ± 7.6	10.6 ± 6.8	2.5 ± 1.7	12.5 ± 12.5	0.70
Seedmoth	0.0	0.0	0.0	0.0	5.0 ± 5.0	0.0	1.94
Cone maggot	25.0 ± 13.5	4.5 ± 17.3	0.6 ± 0.6	37.2 ± 19.8	6.7 ± 4.0	35.3 ± 12.0	0.94
Cone-axis midge	1.3 ± 1.3	0.0	2.5 ± 1.8	0.0	1.7 ± 1.1	0.6 ± 0.6	0.91
Number of seeds per 10 cone slices	6.9 ± 2.2[b]	3.5 ± 1.7[b]	8.6 ± 2.3[b]	8.7 ± 3.5[b]	22.0 ± 4.8[a]	12.0 ± 2.3[ab]	3.32*

[1]Average includes cone-bearing plus non-cone-bearing trees.
Significance of ANOVA F-values: *(P<0.05).
Averages that bear the same letter are not significantly different (P<0.05) as judged by Duncan's multiple range test.

TABLE III. Effects of treatments (carbofuran applied as a granular or liquid formulation at rates of 0, 5, or 10 g AI/cm DBH) on number of female buds per sample branch and on phytotoxicity rating. Means are presented with standard errors.

Year of assessment and variable	Treatments (formulation and application rates, g AI/cm DBH)						ANOVA F-values
	Granules			Liquid			
	0	5	10	0	5	10	
1980							
Female buds per sample branch	0.5 ± 0.2	0.9 ± 0.9	0.2 ± 0.2	0.1 ± 0.1	0.4 ± 0.3	0.3 ± 0.3	0.38
Phytotoxicity rating	1.7 ± 0.3	1.5 ± 0.3	1.6 ± 0.2	1.5 ± 0.3	1.4 ± 0.2	2.1 ± 0.6	0.55
1981							
Female buds per sample branch	2.1 ± 0.5	7.6 ± 3.6	4.5 ± 1.8	3.9 ± 1.5	3.4 ± 2.6	6.6 ± 4.0	0.47
Phytotoxity rating	1.7 ± 0.2^{b}	2.0 ± 0.1^{b}	1.9 ± 0.1^{b}	1.9 ± 0.1^{b}	1.9 ± 0.1^{b}	2.5 ± 0.3^{a}	3.28*

Significance of ANOVA F-values: *(P<0.05).
Averages that bear the same letter are not significantly different (P<0.05) as judged by Duncan's multiple range test.

Discussion

Adults and larvae of the spruce budworm are photopositive. Thus, there is a tendency for larvae to be found at the top of the crowns in a dense stand where lower levels of the crown are shaded. High temperature, absence of food, and direct incidence of strong sunlight cause late stage larvae to reduce their phototropic behavior and move down the tree. Other factors, such as strong winds and heavy rainshowers, also cause them to move to lower levels (Wellington 1948). In the year of treatment in this experiment, conditions were apparently favorable at the top of the trees because larger numbers of budworms and greater defoliation were found at the top of the crown. The plantation was relatively dense so that lower levels of the crown were shaded, wind was likely moderated by windbreaks, and there was little rainfall (46 cm) from June 1 to 30 when late-instar larvae were actively feeding. In addition, population densities were probably too low to cause forced downward movement because of starvation. When budworm counts were made, 52.8% of foliage had been lost to frost and an additional 11.8% lost to feeding by budworm, leaving an untouched excess of 35.4%. In 1981, budworm counts and defoliation were highest at mid-crown. The downward shift in distribution of larvae by comparison with 1980 may have been influenced by heavier rainfall in 1981 (100 mm from June 1 to 30) and exposure to intense sunlight as a result of heavy loss of foliage to frost in 1980.

Interaction of branch position with treatment for budworm counts and defoliation estimates was not evident, except for budworm counts in 1981 when overall densities were low. Absence of interaction for budworm counts suggests that insecticide treatments do not alter the insects' response to factors that modify intra-tree distribution; for defoliation, no interactions imply that treatments are equally effective at all levels of the tree crown, and that the toxicant is evenly distributed to all crown positions. Hence, the potential for preventing damage to seed cones, which are usually concentrated in the upper crown, and to pollen cones usually borne on the crown, should be similar. Another practical consequence of an absence of interaction is that valid comparisons among treatments can likely be made by sampling consistently at just one vertical position on the crown.

The insecticide was applied before budbreak, so control of budworm defoliation with the liquid formulation in the year of treatment may have resulted from rapid uptake and accumulation of carbofuran in the needles in large enough quantities to kill second-instar larvae following emergence from hibernacula. Emerging larvae are known to feed by mining previous-year needles. Toxicant absorbed by roots will likely be translocated in the transpiration stream and appear first in transpiring leaf tissue rather than in buds and reproductive structures (Kozlowski and Winget 1963). Thus, budworm larvae that feed on previous-year needles early in spring would more likely encounter toxicant than would later larvae feeding on developing shoots and strobili. Such a situation has been demonstrated for the European pine shoot moth *Rhyacionia buoliana* (Schiffermuller) (Lepidoptera:

Olethreutidae) feeding on mugho pine *P. mugho* Turra (Coniferae: Pinaceae); carbofuran accumulates in leaves but not buds and control of the shoot moth is most effective on needle-feeding stages as opposed to the bud-mining stage (Pree and Saunders 1972, 1973). In 1981, budworm counts were much lower and foliage was protected on trees receiving both formulations. Thus, the toxicant persisted in foliage of trees for at least one year. However, there was a lag in the uptake and distribution of toxicant when applied as a granular formulation.

No cone protection or increase in seed counts was evident in 1980, whereas treatment with the low rate (5 g AI/cm DBH) of the liquid formulation did provide an increase in seed counts in 1981. This suggests that toxicant was not incorporated into reproductive structures early enough in the year of treatment to effect any increase in number of seed, whereas sufficient levels were accumulated by 1981 to effect an increase in seed counts but not enough to prevent invasion and signs of feeding by insects. Failure to obtain significant increases at the higher level may be explained by some physiological aberration; these trees displayed small but significantly elevated levels of needle browning as a result of treatments. That is consistent with reports of reduced seed yields in white spruce trees treated with 4.5 to 8.9 g AI/cm DBH of granular carbofuran (Cerezke and Holmes 1986).

The occurrence of toxicant in trees one year after treatment may result from persistence in the soil, the trees, or both. Carbofuran can persist in soil. Harris (1969) found that carbofuran residues were biologically active in sandy-loam soils for up to 16 weeks and Read (1969) detected activity in acid soils for up to 150 days. Felsot *et al.* (1982) have shown that carbofuran dissipates at a slower rate in acid soils not previously treated with insecticides, than it does in fields with a history of carbofuran use. Carbofuran appears to be a moderately persistent insecticide in soil, particularly in acidic clay-loam soils (Read 1986) like those associated with trees in this experiment. However, storage and retranslocation in the tree may also be responsible for persistent toxicity because carbofuran is metabolized very slowly over a period of years in coniferous trees (Pree and Saunders 1973, 1974). Persistence and control of insects for more than a single year in trees is common with systemic insecticides. For example, the introduced pine sawfly *Diprion similis* Hartig (Hymenoptera: Diprionidae) was controlled for two years with a single injection of systemic insecticide into white pine *Pinus strobus* L. (Coniferae: Pinaceae) and large quantities of toxicant were found in newly-formed needles in the spring of the second year (Norris and Coppel 1961). Implants of the same toxicant into American elm *Ulmus americana* L. (Urticales: Ulmaceae), controlled elm bark beetles *Scolytus multistriatus* (Marsh) (Coleoptera: Scolytidae) for two seasons (Al-Azawi and Norris 1959), and injections of either oxydemetonmethyl or dicrotophos provided two years' protection of white spruce cones from seed and cone insects (Fogal and Lopushanski 1984).

At a rate of 5 g AI/cm DBH, the liquid formulation effectively controlled budworm and provided increased cone seed counts in our experiment on black spruce seed trees. That rate is similar to those used for control of cone and seed insects on other pinaceae, including slash pine *P. elliottii* Engelm and loblolly pine *P. taeda* L. (DeBarr 1978, Barber 1979), white pine *P. strobus* L. (DeBarr *et al.* 1982), red pine *P. resinosa* Ait. (Rush and Overton 1987), tamarack *Larix laricin*a (Du Roi) K. Koch (Amirault and Brown 1986), and white spruce *P. glauca* (Moench) Voss (Cerezke and Holmes 1986). While the use of a liquid formulation improved efficacy over a granular formulation for controlling budworm and enhancing cone-seed counts, the latter effect did not occur until the year after treatment. In addition, cone-seed counts were not increased by the higher level of 10 g AI/cm DBH, suggesting a possible phytotoxic effect on seed development. The lag in effectiveness and potential phytotoxicity of carbofuran may limit its usefulness for control of cone-feeding insects in black spruce. However, other insecticides can be applied as a soil drench for control of insects on conifers and hardwoods (Drouin and Kusch 1977, Dutcher and Harrison 1984). Some, including dimethoate and oxydemetonmethyl, are effective in white spruce as foliar sprays or stem injections (Fogal and Lopushanski 1984, 1985) and might also be effective in black spruce. In addition, alternative application times in late summer or autumn might overcome the apparent lag in effectiveness of carbofuran. Clearly, further studies are requried to find minimum effective rates, effective application times for carbofuran and alternative insecticides and to assess the benefits of insecticide application relative to potential increases in seed yields.

Acknowledgments

We gratefully acknowledge the cooperation and assistance of personnel at the Bonner Tree Improvement Centre, Moonbeam, Ontario and the Ontario Ministry of Natural Resources, Kapuskasing District. We also thank Miss M. Autayo and Mrs. E. Trottier for collating and entering data into the computer and Mr. J. Christie who programmed the data for easy access and calculation. Mrs. F. Christie-Boyle and Mr. D. McKenna assisted with data analysis and the manuscript was improved by suggestions from Drs. B.L. Cadogan, G.T. Harvey, and O. Hendrickson. Carbofuran was supplied through the courtesy of Chemagro Limited, 1355 Aerowood Drive, Mississauga, Ontario, L4W 1C2.

References

Al-Azawi, A.F., and D.M. Norris. 1959. Experimental prevention of bark beetle transmission of *Ceratosystis ulmi* (Buis) Moreau with the systemic insecticide Chipman R-6199. Journal of Economic Entomology, 52: 902-904.

Amirault, P.A. and N.R. Brown. 1986. Cone and seed insects of Tamarack, *Larix laricina* (Du Roi) K. Koch, and attempts to control damage using chemical insecticides. Canadian Entomologist, 118: 589-596.

Barber, L.R. 1979. Evaluation of two carbofuran soil incorporating systems. Southeastern Area, State and Private Forestry, United States Department of Agriculture, Forest Service. Forest Insect and Disease Management Report Number 79-1-17, 14 pp.

Cerezke, H.F. and R.E. Holmes. 1986. Control studies with carbofuran on seed and cone insects of white spruce. Canadian Forestry Service, Information Report, NOR-X-280, 10 pp.

DeBarr, G.L. 1978. Southwide tests of carbofuran for seedbug control in pine seed orchards. United States Department of Agriculture Forest Service Research Paper, SE-185, 24 pp.

DeBarr, G.L., L.R. Barber, and A.H. Maxwell. 1982. Use of carbofuran for control of eastern white pine cone and seed insects. Forest Ecology and Management, 4: 1-18.

Drouin, J.A. and D.S. Kusch. 1978. Pesticide field trials on shade and shelterbelt trees in Alberta, 1977. Canadian Forestry Service Information Report, NOR-X-205, 16 pp.

Dutcher, J.D. and K. Harrison. 1984. Application of reduced rates of systemic insecticides for control of foliar pecan arthropods. Journal of Economic Entomology, 77: 1037-1040.

Felsot, A., J.G. Wilson, D.E. Kuhlman, and K.L. Steffey. 1982. Rapid dissipation of carbofuran as a limiting factor in corn rootworm (Coleoptera: Chrysomelidae) control in fields with histories of continuous carbofuran use. Journal of Economic Entomology, 7: 1098-1103.

Fogal, W.H., D.A. Winston, S.M. Lopushanski, D.A. MacLeod, and A.J. Willcocks. 1981. Soil application of carbofuran to control spruce budworm *Choristoneura fumiferana* (Lepidoptera: Tortricidae) in a managed white spruce seed production area. Canadian Entomologist, 113: 949-951.

Fogal, W.H., and S.M. Lopushanski. 1984. Stem injection of insecticides for control of white spruce seed and cone insects *In*, Yates, H.O. III (ed.). Proceedings of the International Union of Forest Research Organizations Cone and Seed Insects Working Party Conference, Athens, Georgia. July 31 – August 3, 1983. pp. 157-167.

Fogal, W.H., and S.M. Lopushanski. 1985. A test of foliar-applied insecticides to prevent damage to white spruce cones by insects. Forestry Chronicle, 61: 499-502.

Fogal, W.H., and S.M. Lopushanski. 1988. Prototype equipment for soil-incorporating granular and liquid formulations of insecticides in seed stands. Proceedings of the Entomological Society of Ontario, 119: 79-81.

Harris, C.R. 1969. Laboratory studies on the persistence of biological activity of some insecticides in soils. Journal of Economic Entomology, 62: 1437-1441.

Hertel, G.D., and L.R. Barber. 1978. Bird mortality and insect control when using Furadan on Catawba Timber Company's irrigated pine seed orchard, Catawba, S.C. Southeastern Area, State and Private Forestry, USDA Forest Service. Forest Insect and Disease Management Report No. 78-2-10, 14 pp.

Kozlowski, T.T. and C.H. Winget. 1963. Patterns of water movement in forest trees. Botanical Gazette, 124: 301-311.

Lamontagne, Y. 1979. Seed collection and production areas. *In*, Morgenstern, E.K. and Carlson, L.W. (eds.) Tree seed production and tree improvement in Canada – research and development needs 1977-1987. Environment Canada, Canadian Forestry Service, Information Report PS-X-74, pp. 64-72.

McPherson, J.A., E.K. Morgenstern, and B.S.P. Wang. 1982. Seed production in grafted clonal orchards at Longlac, Ontario. Forestry Chronicle, 58: 31-34.

Morgenstern, E.K., and L.W. Carlson. 1979. Tree seed production and tree improvement in Canada. Research and development needs 1977-1987. Environment Canada, Canadian Forestry Service, Petawawa Forest Experiment Station Information Report, PS-X-74. 98 pp. plus appendices.

Norris, D.M. and H.C. Coppel. 1961. Translocation and stability of Chipman R-6199 in *Pinus strobus* as related to its control of the introduced pine sawfly, *Diprion similis*. Journal of Economic Entomology, 54: 159-161.

Pree, D.J. and J.L. Saunders. 1972. Chemical control of the European Pine Shoot Moth. Journal of Economic Entomology, 65:1081-1085.

Pree, D.J. and J.L. Saunders. 1973. Bioactivity and translocation of carbofuran residues in Mugho pine. Environmental Entomology, 2: 262-267.

Pree, D.J., and J.L. Saunders. 1974. Metabolism of carbofuran in mugho pine. Agriculture and Food Chemistry, 22: 620-625.

Read, D.C. 1969. Persistence of some newer insecticides in mineral soils measured by bioassay. Journal of Economic Entomology, 62: 338-342.

Read, D.C. 1986. Accelerated microbial breakdown of carbofuran in soil from previously treated fields. Agriculture, Ecosystems and Environment 15: 51-61.

Rush. P.A., and R.P. Overton. 1987. Carbofuran trials in a red pine seed orchard. Northern Journal of Applied Forestry 4: 177-180.

Steel, R.G.D., and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York. 481 pp.

Sterner, T.E., and A.G. Davidson. 1981. Forest Insect and Disease Survey Conditions in Canada 1980. Forest Insect and Disease Survey, Can. For. Serv., Ottawa. 43 pp.

Sterner, T.E., and A.G. Davidson. 1982. Forest Insect and Disease Survey Conditions in Canada 1981. Forest Insect and Disease Survey, Can. For. Serv., Ottawa. 46 pp.

Tripp, H.A. and A.F. Hedlin. 1956. An ecological study and damage appraisal of white spruce cone insects. Forestry Chronicle, 32: 400-410.

Wellington, W.G. 1948. The light reactions of the spruce budworm, *Choristoneura fumiferana* Clemens (Lepidoptera, Tortricidae). Canadian Entomologist, 80: 56-82A.

(Received 2 July 1987; accepted 1 February 1988)

PROTOTYPE EQUIPMENT FOR SOIL INCORPORATING GRANULAR AND LIQUID FORMULATIONS OF INSECTICIDES IN CONIFER SEED STANDS

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In a previous report (Fogal *et al.* 1981) we presented evidence that broadcast application of a granular formulation of carbofuran could successfully control spruce budworm on seed trees of white spruce *Picea glauca* (Moench) Voss (Coniferae: Pinaceae). However, carbofuran granules left on the surface of soil are attractive and toxic to birds (Barber 1979). Incorporation of a granular formulation of the insecticide into soil can significantly reduce bird mortality but trials in several orchards of the southeastern U.S.A. did not provide consistent control of target pests or increases in cone and seed yields (Barber 1979, Overgaard *et al.* 1983). Application of water by sprinkler irrigation to help dissolve granules enhanced insect control and further reduced the risk to birds (Hertel and Barber 1978), and sprinkling a liquid formulation was better than a granular formulation for control of cone insects on red pine *P. resinosa* Ait. (Coniferae: Pinaceae) (Rush and Overton 1987). Herein, we describe equipment that we have used to compare incorporation of granular and liquid formulations of carbofuran into soil for control of insects on seed trees of black spruce *Picea mariana* (Mill.) B.S.P. (Coniferae: Pinaceae) in small experimental plots (Fogal *et al.* 1988).

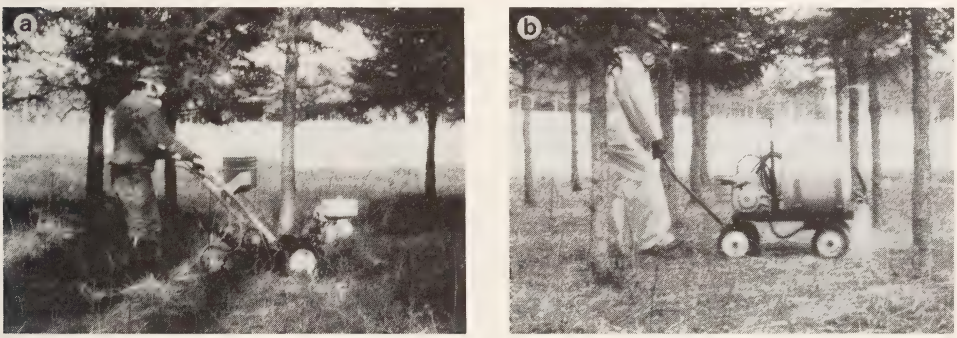

FIGURE 1. (a) Hoe drill and (b) sprayer in operation in a black spruce seed stand.

To apply the granular insecticide, a hoe-drill was constructed by modifying a 6 h.p. Rocket VI rototiller manufactured by Ariens Co., Brillion, Wisconsin (Figs 1a and 2a). Parts, denoted by letters, are shown on the line drawing (Fig. 1a). The rototiller attachment was removed and two Massey-Ferguson cultivator tines (part no. 1716448-MI) (L) and chisels (part no. 1903259-MI) (K) were mounted 60 cm apart on the rear of the tractor unit. This was accomplished by bolting a flat iron plate 1 cm x 15 cm x 75 cm across the end of the gear box to serve as a mounting plate (O). A second flat iron plate, of the same dimensions, was welded in a flat position parallel to the first mounting plate across the two angle irons to provide a mounting plate for the two cultivator tines (M). Chisels were welded to the cultivator tines (K, L). A hopper (A) from a fertilizer spreader (Imperial Roto Spread, Mark IV; manufactured by Erie Iron Works Co. Ltd., St. Thomas, Ontario) was mounted on the handles of the tractor after modifying the fertilizer release gate. The original control gate was removed. A copper pipe 10 cm long and 4 cm in diameter (o.d.) was cut in half longitudinally and one half soldered to the

Disclaimer: *This paper reports research involving pesticides. Pesticides must be handled and applied properly. All uses of pesticides must be registered by federal and provincial authorities before they can be recommended. The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by the Canadian Forestry Service.*

bottom of the hopper to create a trough (B). Two 1-cm diameter holes, 4 cm apart and 1 cm from the ends, were drilled through the bottom of the trough. The end of a 1-cm diameter (i.d.) polypropylene tube 35 cm in length was slipped over the copper tubes and extended to the upper part of the cultivator tines (F). Then, a copper tube 35 cm long and 1 cm in diameter (o.d.) was inserted into the bottom end of each polypropylene tube (H) and clamped onto the back of the cultivator tines so that it extended to 2 cm below the top of the chisel. Rubber tubing (1 cm, i.d.) (J) extending to the tip of the chisel was slipped over the end of the copper tubing; the lower end was cut at an angle, with the open side away from the chisel to prevent clogging of the tube with soil.

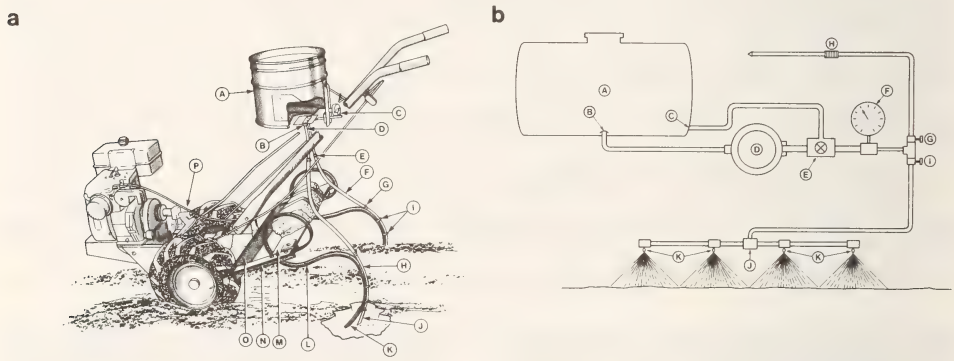

FIGURE 2. (a) Line drawing and cut-away of hoe drill: A, Hopper from a fertilizer spreader; B, modified gate, 4 cm copper pipe, cut laterally; C, control for opening gate; D, soldered copper tubing x 2; E, hose clamp; F, 1 cm (i.d.) polypropylene tubing; G, hose clamp; H, 1 cm O.D. copper tubing; I, large hose clamps for holding tubing; J, 1 cm (i.d.) rubber tubing, lower end cut to wedge; K, welded cultivator chisel; L, cultivator 'S' tine (Massey Ferguson); M, 1 cm x 15 cm x 75 cm iron plate for mounting tines; N, 5 cm x 5 cm angle iron; O, 1 cm x 15 cm x 75 cm mounting plate; P, garden tractor (Ariens, Rocket VI)). (b) Line drawing of sprayer: A, 85 litre polypropylene tank; B, outlet to pump, with screen; C, return to tank for agitating liquid; D, pump; E, control and bypass valve; F, Ashcroft pressure gauge; G, control valve to hand wand; H, hand wand; I, control valve to spray boom; J, t-fitting; K, nozzles with flat spray tips.

The gate control on the hopper of the hoe-drill permitted release rate adjustment by volume (100 mL was equivalent to 139 g of 10G Furadan). The two delivery tubes released equal volumes of granules and granule release volume was related to ground speed and gate setting in calibration trials under operating conditions. Thus, uniform application of insecticide was possible with varying treatment areas and insecticide application rates. The drill had adequate power to maintain a relatively uniform depth of 6 to 8 cm. Some damage to feeder roots occurred when they were snagged and broken or pulled to the surface by the cultivator chisels. That caused some impediment to forward motion, but the bouncing motion and vibration of the gasoline engine helped maintain a continuous flow of granules into the furrows. Low gear (23 m/min = 1.4 km/h) was found to be superior to the higher gear (42 m/min = 2.5 km/h) as better control of the machine could be maintained and fewer roots were brought to the surface. Furrows did not close completely following each pass so raking was required to cover any exposed granules.

A liquid formulation of carbofuran was applied as a soil drench with a modified motor-powered (3 h.p.) sprayer and tank mounted on a hand-pull wagon (Mighty Mac Sprayer, manufactured by Ameund Mackissic Co., Parker Ford, Pennsylvania) (Figure 1b and 2b). In addition to the original equipment, a 1.2 m boom was attached 20 cm above ground across the rear of the wagon. The boom was fitted with four shank nozzles (K) (two No. 9191A-531TD and two No. 9192A-531TD, TeeJet Spraying Systems Co., Wheaton, Ill.) for 12.7 mm (i.d.) hose. Nozzles were equipped with 65° flat

spray tips (no. 6503, TeeJet). The 15.9 mm (i.d.) feeder hose from the pump was joined to the 12.7 mm nozzle hoses by a reducing T-connector. Valves (E, G, I) were added to direct flow to the hand wand or boom, and to facilitate continuous mixing of the solution within the tank. A fine brass screen (B) was placed over the outlet in the tank to prevent clogging of the spray tips by dirt particles in the spray mixture. A pressure gauge (Ashcroft, No. J7363-5, J. Instruments and Specialty Co., Elk Grove Village, Ill.) (F) was placed between the multiflow valve (E) and the on-off spray control valves (G, I).

The sprayer was easily moved over most terrain. Rates of application were governed by the concentration of the solution, operating pressure, and forward speed. At a pressure of 276 kPa each nozzle delivered 1 litre of spray per minute. A boom height of 20 cm provided uniform distribution of spray mixture over the surface of the root-bearing soil and good penetration into the duff with minimum spray drift. Higher boom heights would have required higher pressures and resulted in greater drift, whereas a lower boom would have resulted in snags on stumps and debris. Speed was calibrated with a stopwatch held by a second person. With practice, a slow walk of approximately 33 m/min (2 km/h) could be maintained and delivery rates calibrated by varying the concentration of solution or by number of passes over a specified area.

The two units are easy to construct by modifications to available equipment and could be adapted for operational use in small orchards. The hoe-drill could be modified to reduce root snags by using chisels designed to cut through smaller roots and to ride over larger diameter roots. It could also be modified to deliver liquid rather than granules into furrows by utilizing components of the sprayer. Injection of liquid into the soil would likely improve uptake and efficacy of insecticide by comparison with granule incorporation (Fogal *et al.* 1988) and would also reduce deposits of insecticide on the surface of soil, litter, and vegetation that occur with a sprayer.

Acknowledgments

We are grateful to Mr. L. Lussier and Mr. K. Stewart of the Mechanical Workshop at Petawawa National Forestry Institute for making modifications to equipment and to Mr. P.K. Gregory of the Drafting Division, Environmental Conservation Service, Environment Canada, Hull, Quebec for line drawings.

References

Barber, L.R. 1979. Evaluation of two carbofuran soil-incorporating systems. Southeastern Area, State and Private Forestry, United States Department of Agriculture Forest Service. Forest Insect and Disease Management Report No. 79-1-17, 14 pp.

Fogal, W.H., D.A. Winston, S.M. Lopushanski, D.A. MacLeod, & A.J. Willcocks. 1981. Soil application of carbofuran to control spruce budworm *Choristoneura fumiferana* (Lepidoptera: Tortricidae) in a managed white spruce seed production area. Canadian Entomologist, 113: 949-951.

Fogal, W.H., S.M. Lopushanski, D.A. MacLeod & D.A. Winston, 1988. Soil-incorporation of carbofuran for protecting black spruce seed trees from insects. Proceedings of trhe Entomological Society of Ontario, 119: 69-78.

Hertel, G.D. & L.R. Barber. 1978. Bird mortality and insect control when using Furadan® on Catawba Timber Company's irrigated pine seed orchard, Catawba, S.C. Southeastern Area, State and Private Forestry, United States Department of Agriculture, Forest Service. Forest Insect and Disease Management Report No. 78-2-10, 14 pp.

Overgaard, N.A., L.R. Barber, D.F. Walsh, R.E. Major, G.D. Hertel & J.E. Gates. 1983. Evaluation of modified Power-Till seeder for soil incorporation of carbofuran to provide insect control and minimize bird mortality in pine seed orchards. United States Department of Agriculture, Forest Service, Technical Publication R8-TP3, 35 pp.

Rush, P.A. & R.P. Overton. 1987. Carbofuran trials in a red pine seed orchard. Northern Journal of Applied Forestry, 4: 177-180.

(Received 17 June 1987; accepted 1 February 1988)

TOXICITY AND REPELLENCY OF THE FUNGICIDE TCMTB TO THE EASTERN SUBTERRANEAN TERMITE (ISOPTERA: RHINOTERMITIDAE)

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Prophylactic preservative treatments are important means of protecting wood in service from infection by mold, stain, and decay fungi, and infestation by wood-boring insects. The search for new wood preservatives has been stimulated by concerns over possible ill effects on human health of the most commonly used materials: creosote, pentachlorophenol, and inorganic arsenicals (Brooks 1983). One compound of current interest is the fungicide 2-(thiocyanomethylthio)benzothiazole (TCMTB), which has a mammalian oral LD_{50} of 1590 mg/kg (Thomson 1985). This compound is an effective antisapstain agent (i.e., inhibiting growth of wood-staining fungi) (Drysdale 1987; Oteng-Amoako 1988), and has low leachability in soil (Duguet and Dartigues 1988; Konabe 1987). TCMTB is used agriculturally as a seed treatment, is available in several formulations as an antisapstain agent and wood preservative, and is marketed for incorporation into paints, caulking compounds, sealants, adhesives, and particle board resin. Although it has been combined with the insecticide deltamethrin (Duguet and Dartigues 1988), little information is available on the insecticidal properties of TCMTB alone.

Along with those of other candidate wood preservatives, the toxicity and behavioural effects of TCMTB on the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), were recently evaluated using Busan 1030 (Buckman Laboratories of Canada, Ltd., 613 Orly Avenue, Dorval, Quebec H9P 1G1), a 30% active formulation of TCMTB (Buckman Laboratories 1985). This formulation was diluted in methanol and applied uniformly by pipet to each side of individually weighed oven-dried filter papers (9 cm Whatman No. 1) to obtain precise percentage (weight of solute / weight of substrate) deposits of the active ingredient (TCMTB). Papers containing weight/weight percentages of 0.1%, 1.0%, and 5.0% TCMTB, and a methanol-treated control paper, were cut into strips ca. 2 x 6 cm (ca. 69 mg), oven-dried (2 hours, 75°C), and placed along one side of polystyrene snap-cap vials (Canlab No. V3001-212, 44.8 ml, 60 x 35 mm diameter) containing 10 g oven-dried brick sand and 1 ml deionized water. Thirty *R. flavipes* workers (externally undifferentiated individuals older than the third instar as determined by size) were placed in each vial, which was then capped and placed in an unlighted temperature (27 ± 0.5°C) and humidity (90 ± 5% RH) controlled cabinet. The termites were collected from Scarborough, Ontario, in a trap consisting of corrugated cardboard rolled within a capped ABS pipe (ca. 10 cm ID x 15 cm L) (LaFage *et al.* 1983) placed on top of an infested maple stump. They were held in the temperature cabinet in plastic containers containing moist cardboard, and used within 30 days of collection.

Immediate mortality following a 24 hour and a 7 day exposure to TCMTB, and feeding during the 7 day exposure were respectively evaluated by counting surviving termites and weighing the oven-dried papers at a precision of 0.01 mg. To evaluate delayed post-exposure mortality, termites were removed from the original vials after the 24 hour and 7 day exposure periods, placed in new vials containing the same amount of sand and water and untreated filter paper strips, and recounted after an additional 9 days. Each treatment was replicated three times and results subjected to analysis of variance (ANOVA) and the Ryan-Einot-Gabriel-Welsch (REGW) Multiple F Test (SAS Institute Inc. 1987). Proportions were compared with multiple Z tests using Bonferroni's inequality to maintain $\alpha \leq 0.05$ (Dixon and Massey 1983).

During both the 24 hour and the 7 day exposure periods, the termite workers clustered on the opposite side of the vials from the Busan 1030 treated papers, although tunneling in the sand adjacent to the papers indicated that exploration occurred. Repellency was confirmed by the absence of any detectable feeding on the TCMTB treated papers (no weight loss, independent of TCMTB concentration) during the 7 day exposure, although the control papers averaged a weight loss of 8.8 ± 0.5 µg (ca. 13% of their original weight).

No significant immediate or post-exposure mortality occurred as a result of the 24 hour exposure

TABLE I. Percentage mortality of *Reticulitermes flavipes* workers immediately after exposure to various concentrations of TCMTB, and 9 days post-exposure.*

	24 Hour Exposure		7 Day Exposure	
Dosage	**Immediate**	**Post-Exposure**	**Immediate**	**Post-Exposure****
5.0 %	1 ± 2a	22 ± 2ab	48 ± 10a	100a
1.0	2 ± 2a	26 ± 2a	38 ± 13a	97ab
0.1	3 ± 3a	20 ± 3b	37 ± 10ab	67b
Control	1 ± 2a	23 ± 3ab	17 ± 0b	24c

*Mean± standard deviation. N = 3 groups of 30 workers. Means in each column followed by different letters are significantly different (ANOVA, REGW Multiple F Test, $\alpha \leq 0.05$).

**Survivors from 7 day exposure were pooled. Percentages followed by different letters are significantly different (Z test of proportions, $\alpha \leq 0.05$).

period (Table I). However, significant mortality, increasing with TCMTB concentration, during and after the 7 day exposure suggests that prolonged confinement with a treated substrate exposes the insects to either contact toxicity or fumigant action despite their behavioural avoidance response.

Compounds modifying subterranean termite behaviour may play an important role in future pest control strategies (Grace 1987; Rust *et al.* 1988). Thus, candidate wood preservatives should be evaluated not only in terms of toxicity assays and field (stake) tests, but also in terms of their effects on insect behaviour. A low (0.1%) concentration of TCMTB, while showing limited toxicity to *R. flavipes*, may, by deterring feeding, provide protection equivalent to that of higher insecticidal concentrations or more active insecticidal agents.

I thank A. Abdallay and J. Iriah for technical assistance. Funding was provided in part by Canada Mortgage and Housing Corporation, Ontario Ministry of Housing, and the cities of Toronto, Scarborough, North York, Leamington, Hamilton, Guelph, Etobicoke, and East York. The Busan 1030 sample was a gift from Anchor Consultants (Concord, Ontario), and Buckman Laboratories of Canada, Ltd. (Dorval, Quebec). Mention of a commercial source does not constitute an endorsement or warranty of products available, nor does it signify approval of the product to the exclusion of other comparable products.

References

Brooks, D. 1983. Regulatory status of wood preservatives. pp. 70-72. *In:* Khasawinah, A.M. (Ed.), Termiticides in Building Protection, Proceedings of a Workshop September 22-23, 1982. National Institute of Building Sciences, Washington, D.C.

Buckman Laboratories. 1985. Busan 1030: a new microbicide for the paint industry. Buckman Laboratories of Canada, Ltd., Doval, Quebec. Bulletin No. B24W, 8 pp.

Dixon, W.J., and F.J. Massey. 1983. Introduction to Statistical Analysis. McGraw-Hill, New York. 678 pp.

Drysdale, J.A. 1987. Commercially available anti-sapstain chemicals in New Zealand - an update. International Research Group on Wood Preservation, Stockholm, Sweden. Document No. IRG/WP/3416, 13 pp.

Duguet, J.S., and V. Dartigues. 1988. Evaluating possibilites of leaching of deltamethrin and TCMTB (insecticide and fungicide for protecting wood) by rain water or by soaking in water. International Research Group on Wood Preservation, Stockholm, Sweden. Document No. IRG/WP/3464, 8 pp.

Grace, J.K. 1987. The challenge of wood destroying insects. Proceedings of the Canadian Wood Preservation Association, 7: 3-12.

Konabe, H.C. 1987. Effectiveness of Busan 30 in a soil medium. International Research Group on Wood Preservation, Stockholm, Sweden. Document No. IRG/WP/3409, 7 pp.

LaFage, J.P., N.-Y. Su, M.J. Jones, and G.R. Esenther. 1983. A rapid method for collecting large numbers of subterranean termites from wood. Sociobiology, 7: 305-309.

Oteng-Amoako, A. 1988. In search of alternative antisapstain chemicals for use in Papua, New Guinea. International Research Group on Wood Preservation, Stockholm, Sweden. Document No. IRG/WP/3472, 15 pp.

Rust, M.K., J.K. Grace, D.L. Wood, and D.A. Reierson. 1988. The search for new termite control strategies. California Agriculture, 42(5): 15-18.

Thomson, W.T. 1985. Agricultural Chemicals, Book IV - Fungicides. Thomson Publications, Fresno, California, pp. 119-120.

SAS Institute Inc. 1987. SAS/STAT Guide for Personal Computers, Version 6 Edition. SAS Institute, Inc., Cary, North Carolina, pp.125-154.

(Received 7 September 1988; accepted 31 October 1988)

GYNANDROMORPHS IN CANADIAN SIMULIIDAE (DIPTERA)

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Several authors have reported on gynandromorphs in Simuliidae from different parts of the world (Edwards 1931, Puri 1933, Grenier and Bertrand 1949, Rubtzov 1958, Wolfe and Peterson 1959, Fredeen 1970, Crosby 1973, Hunter and Moorhouse 1976, Dang and Peterson 1979, Elsen 1981, Cheke and Garms 1985). While identifying daily collections of black flies that emerged into a cubic-yard (0.8 m^3) screen cage placed over the rapids of Costello Creek, Algonquin Park, Ontario (45°40′N, 78°20′W) during the spring and early summer of 1946 and 1947 (Davies 1950), I found nine adult gynandromorphs (Table I). Five other gynandromorphs were collected in Ontario, three in the North Madawaska River above and below Lake Sasajewun, Algonquin Park (45°40′N, 78°30′W) and two from streams flowing into Big Trout Lake, Patricia District (53°51′N, 89°53′W and 53°45′N, 90°10′W) (Table I). One gynandromorph occurred among simuliids which emerged into a cubic-yard screen cage from 6-19 August 1949 from a stream at Baker Lake, Northwest Territories (64°N, 95°W) (my 1950 identification of material collected by Biting Fly Survey, Department of Agriculture) (Table I).

The ratio of gynandromorph simuliids in the "normal" population is low; in Ontario it was 1/2000 for *Simulium decorum* Walker, 1/4500-22,000 for *S. venustum* Say/*verecundum* Stone and Jamnback complex and 1/1000-8000 for *S. vittatum* Zetterstedt and at Baker Lake, NWT 1/1319 for *Metacnephia borealis* (Malloch). This compares with a ratio of 1/ca 50,000 for netted *C. venustum* (mainly females) in the region of Shefferville, Quebec (Wolfe and Peterson 1959) and of 1/2600 for *Simulium arcticum* Malloch females either netted or collected from cows in the Athabasca River region, 144 km north of Edmonton, Alberta (Fredeen 1970). Fredeen (1970) also netted a gynandromorph of *S. vittatum* from a swarm (including also *S. arcticum*) around a horse at Kinistino, Saskatchewan. Rubtzov (1958) records finding 10 gynandromorphs (real hermaphroditism) among 100,000 simuliids examined over a 25-year period (1/10,000); the gynandromorphs were of two species: *Simulium (Wilhelmia) pseudoequinum* Seguy (as *mediterraneum* Puri) from central Asia and *S. (W.) equinum* L. from the Leningrad district of USSR.

The appearance of each of my gynandromorphs is described in Table I. None of the specimens had deformed eyes. Eight of these had male eyes (1 *S. decorum*, 5 *S. venustum/verecundum*, 2 *S. vittatum*). Three had female eyes (2 *S. decorum*, 1 *S. venustum*), three had a male right eye and a female left eye (1 *S. venustum/verecundum*, 2 *S. vittatum*), and *M. borealis* had a male left eye and female right eye. Of the eight with male eyes, all, but two, had male thoraces, six had female abdomens; five of the eight had female genitalia, one had a mainly female genitalia with a small male component and two had largely male genitalia with a small female component. Of those with female heads, two had the rest of the body male and one had the forlegs male and other legs female and the genitalia mainly male with a small female component on each side. Of those with a male right eye, two had male thoraces and one had four male and two female legs with male/female genitalia. In *M. borealis* with a male left eye, two of the right legs are female and the rest male and the genitalia are mainly male with a small left female component.

Since these collections were made, cytotaxonomy has shown that *S. decorum*, *S. venustum*, *S. verecundum* and *S. vittatum* are all complexes of sibling species (Rothfels 1981) and Rothfels (1981) has made preliminary broad geographic distributions of each cytotype. At present, however, it is not possible to be certain which cytotypes are represented here.

Mermithid parasitism causes changes in the expression of genitalia producing intersexes in simuliids (Hunter and Moorhouse 1976). No evidence of mermithid parasitism was found in the present gynandromorphs.

TABLE I. Descriptions of 15 gynandromorphs of Simuliidae collected from Algonquin Park (Nipissing District), Big Trout Lake (Patricia District) in Ontario and Baker Lake, Northwest Territories

Species	Place and Date	Gyn/Total Catch	Head (eyes)		Thorax		Legs (fore-hind)		Abdomen		Genitalia	
			Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Metacnephia borealis	Baker L., NWT 15 VIII 1949	1/1319	M	F	?	?	MMM	FMF	?	?	M/Fr	M
Simulium (Simulium) decorum	Costello Ck Algonquin Pk 28 VI 1946	1/2051	M	M	M	M	MMM	MMM	F	F	F	F
	L. Sasajewun Algonquin Pk 2 VIII 1950	unknown	F	F	M	M	MMM	MMM	M	M	M	M
	L. Sasajewun 10 VI 1955	unknown	F	F	?	?	M/FFF	MFF	M	M	M/Fr	M/Fr
Simulium (Simulium) venustum/ verecundum complex	Costello Ck Algonquin Pk 26 VI 1946	2/9179	F	M	F	M	FFM	MMM	F	M	F	M
	Costello Ck 5 VII 1946		M	M	M	M	?MM	MM?	F	F	F	F
	Costello Ck 15 VI 1947	2/44616	M	M	?	?	???	M??	?	?	F	F
	Costello Ck 19 VII 1947		M	M	?	?	MMM	MMM	M	M	F/M	M
	L. Sasajewun 23 V 1955	unknown	M F_P	M F_P	?	?	FFF	FFF	F	F	F	F
	Mukata Ck Big Trout L. 22 VI 1961	unknown	M	M	F	F	FFF	FFF	F	F	F/Mr	F
	Big Trout L. 25 VI 1961	unknown	F	F	M	M	MMM	MMM	M?	M?	M/Fr	M/Fm
Simulium (Psilozia) vittatum	Costello Ck Algonquin Pk 7 VII 1946	1/8289	M	M	M	M	MFM	MFF	F	F	F	F
	Costello Ck 18 VII 1947	3/3476	F	M	?	?	MMM	MMM	M/F	F	M	F
	Costello Ck 19 VII 1947		M	M	M	M	FMM	MMF	F	?	M/Fr	F
	Costello Ck 28 VII 1947		F	M	M	M	MMM	MMM	?	?	F?	M

L = lake, Ck = creek, Pk = park, Gyn = gynandromorph(s), M = male, F = female, r = reduced, m = modified, p = palp, ? = part missing or difficult to distinguish

Acknowledgements

I wish to thank Mrs. H. Györkös for expert assistance in the laboratory, Professor Emeritus A.M. Fallis who encouraged me in my early years in the Department of Parasitology, Ontario Research Foundation, Toronto and Dr. D.M. Wood for assistance at Big Trout Lake. A grant from the Natural Science and Engineering Research Council of Canada was appreciated.

References

Cheke, R.A. and R. Garms 1985. Sexual mosaics in the *Simulium damnosum* species complex (Dipt., Simuliidae) in West Africa. Entomologist's Monthly Magazine, 121: 137-141.

Crosby, T.K. 1973. A gynandromorph of *Austrosimulium (Austrosimulium) australense* (Schiner) from New Zealand (Diptera: Simuliidae). Journal of Natural History, 7: 629-631.

Dang, P.T. and B.V. Peterson 1979. A case of bilateral gynandromorphism in *Simulium soubrense* Vajime and Dunbar (Diptera: Simuliidae). Tropenmedizin und Parasitologie, 30: 548-550.

Davies, D.M. 1950. A study of the black fly population of a stream in Algonquin Park, Ontario. Transactions of the Royal Canadian Institute, 28: 121-159.

Edwards, F.W. 1931. Simuliidae *in* "Diptera of Patagonia and South Chile" Part II, Fasc. 4: 121-154. British Museum (Natural History), London.

Elsen, P. 1981. Note sur un cas de gynandromorphisme chez *Simulium* (*Metomphalus*) *wellmani* Roubaud, 1906 (Diptera; Simuliidae) en provenance du Burundi. Revue Zoologique Africaine, 95: 843-847.

Fredeen, F.J.H. 1970. Sexual mosaics in the black fly *Simulium arcticum* (Diptera: Simuliidae). The Canadian Entomologist, 102: 1585-1592.

Grenier P. and H. Bertrand 1949. Un cas d'intersexualité chez *Simulium auricoma* Mg., (Dipt.). Remarques comcernant la question des mâles dichoptiques chez les Simuliidae. Bulletin Biologique de la France et de la Belgique, 83(4): 1-5.

Hunter, D.M. and D.E. Moorhouse 1976. Sexual mosaics and mermithid parasitism in *Austrosimulium bancrofti* (Tayl.) (Diptera: Simuliidae). Bulletin of Entomological Research, 65: 549-553.

Puri, I.M. 1933. A case of gynandromorphism in *Simulium*. Indian Journal of Medical Research, 20: 801-802.

Rothfels, K. 1981. Cylotaxonomy: principles and their application to some northern species-complexes in *Simulium* (pp. 19-29). *In* M. Laird (Ed.). Blackflies: the Future for Biological Methods in Integrated Control. Academic Press, New York and London. 399 p.

Rubtzov, I.A. 1958. On the gynandromorphs and intersexes in black flies (Simuliidae, Diptera). Zoological Journal, 37: 458-461. (In Russian)

Wolfe, L.S. and D.G. Peterson 1959. Black flies (Diptera: Simuliidae) of the forests of Quebec. Canadian Journal of Zoology, 37: 137-159.

(Received 31 May 1988; accepted 31 October 1988)

A PROGRAM FOR THE PROTECTION OF THE EASTERN POPULATION OF THE MONARCH BUTTERFLY, *DANAUS PLEXIPPUS PLEXIPPUS*, (LEPIDOPTERA: DANAIDAE)

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Following his discovery of the overwintering sites of the eastern population of the monarch butterfly, *Danaus plexippus plexippus* (L.), F.A. Urquhart (1979) reported that initial steps had been taken by Mexican authorities to protect them from lumbering operations and hazards which could be created by visitors to the areas. After several years of perseverence with the Mexican government, Dr. Urquhart's labours have now been rewarded with the implementation of a program for the protection of the monarch butterfly.

Six areas on the Neovolcanic Plateau in the states of Mexico and Michoacan have been declared the Monarch Butterfly Preserve by the Mexican government. The establishment of this reserve was an arduous process which required the coordination of various federal government agencies, the state governments of Mexico and Michoacan, seven municipal governments, and the cooperation of farmers, local residents and a wide variety of social and conservation groups. The reserve is composed of core areas where the monarchs actually overwinter and is closed to all unnecessary human activity. In the buffer zones, existing farms and villages are allowed to remain and forestry is allowed to continue, but an agreement was reached with land-owners which requires the responsible use of the land and its resources.

To insure the continued success of this project, various federal and state government agencies have the responsibility to promote projects which improve the quality of life for the local people, preserve the beauty of the region, increase and diversify local industry while protecting the ecosystem, and enforce the vigorous application of the law should violation to the regulations occur. In order to develop the knowledge to better manage the natural resources, a research centre located at Sierra Chincua will be available for the use of all authorized universities and reaseach institutions. As a result of the publicity sirrounding the discovery of the monarch's overwintering site, thousands of tourists now come to see the monarch every year. It is the duty of the Tourist Department of the Mexican government to guide and assist them and to prevent them from disturbing the monarch. Shelters and lodges have been built, responsible guides have been employed, and authorized viewing areas designated. The monarch has proven to be an economic blessing to the local area.

Without the dedication and hard work of Dr. and Mrs. Urquhart, this important program may never have been eventuated. They are both to be congratulated.

References

Urquhart, F.A. 1979. Conservation areas for the eastern population of the monarch butterfly. Proceedings of the Entomological Society of Ontario, 110: 109.

PRESIDENT'S PRIZES, 1988

The society congratulates Ian MacKay and David McCorquodale for their exemplary presentations at the 125th Annual Meeting, held in Guelph on 14-16 October, 1988 which resulted in their both being awarded the President's Prize at the banquet. Abstracts of their presentations are given below.

OVIPOSITION BEHAVIOUR OF THE GALL INDUCER *HEMADAS NUBILIPENNIS* (HYMENOPTERA: PTEROMALIDAE)

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Proc. ent. Soc. Ont. 119:93

Hemadas nubilipennis (Ashmead), a tiny (4mm) chalcid wasp, induces a gall on the vegetative shoots of the common lowbush blueberry *Vaccinium angustifolium* Aiton. This study examined the ovipositor complex of the insect in an attempt to correlate anatomical features with the behaviour exhibited during oviposition. Light and scanning electron microscopy were used to study the ultrastructure of the ovipositor and associated structures. Micro-video recording and monitoring were utilized to study the oviposition behaviour under laboratory conditions.

Adaptive features of the ovipositor complex include: a denticulate ovipositor which is used to ream out an egg chamber within the plant tissue prior to egg deposition and well developed bulbous articulations which permit rotary and ventral extensions of the ovipositor. Other features include a small notch on the posterior edge of the terminal sternum which provides structural support to the ovipositor during extension. A petiolate waist gives the insect the ability to manipulate and accurately position the abdomen during oviposition.

Three phases of oviposition were recognized: 1. Pre-oviposition behaviour; involves foraging activities during which the insect searches for appropriate shoots on which to induce a gall. 2. Egg deposition; phase during which the clutch is laid. 3. Post-oviposition behaviour; involves repeated stabbing of the shoot's apical meristem with the ovipositor. This action reportedly destroys the apical growth of the shoot and nutrients are redirected toward the developing gall.

WHY DO "SOLITARY" WASPS SHARE NESTS?

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Proc. ent. Soc. Ont. 119:93-94

The nests of most sphecid wasps, including the vast majority of species in the large genus *Cerceris*, are occupied by one female. These species are solitary. The nests of *Cerceris antipodes* are regularly shared by 2 to 8 females at two nesting aggregations in New South Wales, Australia (McCorquodale 1988a). This study considered the importance of three factors. 1) relatedness among nestmates, 2) nest defense and 3) soil conditions, that have been suggested to promote nest sharing in sphecid wasps (Alcock 1980; Evans and Hook 1986).

Average relatedness among nestmates was estimated from allele frequencies derived from protein electrophoresis (McCorquodale 1988b). Average relatedness among nestmates was greater then 0.50 at one aggregation during two consecutive years. Relatedness was lower, (point estimates of about 0.30), at three other aggregations. The highest values are consistent with relatedness having a major effect on the costs and benefits leading to kin selection. Nest defense improved as the number of

females occupying a nest increased (McCorquodale 1989a). The greatest increase was evident between nests with 1 and 2 females. An increase in frequency of defense was observed for each additional female up to 5. As the number of females increased, and overall frequency of defense increased, the average number of responses per female decreased. New nests could only be excavated when soil was softened after rains (McCorquodale 1989b). Experimental watering resulted in new nests only in the water softened plots.

Soil hardness limiting nest initiation is hypothesized to be the initiator of nest sharing. When nests could not be dug, females stayed in their natal nests or joined an occupied nest. Females in these shared nests enjoyed the advantages of lower nest construction costs, improved nest defense and the potential to assist close relatives. The combination of these three factors presumably maintain nest sharing as a viable alternative in *Cerceris antipodes*.

References

Alcock, J. 1980. Communal nesting in an Australian solitary wasp, *Cerceris antipodes*. Journal of the Australian Entomological Society, 19: 223-228.

Evans, H. E. and A. W. Hook. 1986. Nesting behaviour of Australian *Cerceris* digger wasps, with special reference to nest reutilization and nest sharing. Sociobiology, 11: 275-302.

McCorquodale, D. B. 1988a. Nest sharing in the sphecid wasp, *Cerceris antipodes* Smith. Ph.D. Thesis, Department of Zoology, Australian National University, Canberra, Australia.

McCorquodale, D. B. 1988b. Relatedness among nestmates in the primitively social wasp, *Cerceris antipodes* (Hymenoptera: Sphecidae). Behavioral Ecology and Sociobiology, in press.

McCorquodale, D. B. 1989a. Nest defense in single and multi-female nests of *Cerceris antipodes* (Hymenoptera: Sphecidae). Journal of Insect Behavior, in press.

McCorquodale, D. B. 1989b. Soil softness, nest initiation and nest sharing in the wasp, *Cerceris antipodes* (Hymenoptera: Sphecidae). Ecological Entomology, in press.

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ENTOMOLOGICAL SOCIETY OF ONTARIO

Volume

One Hundred and Twenty-One

1990

Published December, 1990

ISSN 0071-0768

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of the
ENTOMOLOGICAL SOCIETY OF ONTARIO

Volume One Hundred and Twenty-One
1990
Published December, 1990

THE ENTOMOLOGICAL SOCIETY OF ONTARIO

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SUSTAINABLE AGRICULTURE AND FORESTRY: AN ENTOMOLOGICAL PERSPECTIVE

FORWARD

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Proc. ent. Soc. Ont. 121:1-3

The five papers following this introduction make up part of a symposium presented at the Entomological Society of Ontario's 126th Annual Meeting held October 27-29th 1989 in London, Ontario at Spencer Hall, Windermere Road and the new Agriculture Canada research laboratory at Sandford Street.

What does "sustainable" mean when applied to agriculture and forestry? I hope that this series of papers will help to answer this question, but first I think that it is necessary to understand the historical background that has brought this concept to the forefront of modern agricultural and forestry research.

Before World War II very few pesticides were available for use and, with few exceptions, farmers utilised methods of pest control that had been used for centuries. By the late 1950's, however, the availability and relatively low cost of the new generation of synthetic pesticides, such as the insecticide DDT, and inorganic fertilizers changed the way that farming was carried out. High-input systems became the norm, usually consisting of large-scale annual monocultures that were very susceptible to nutrient losses and pest outbreaks. The aim was to increase the yield as much as possible, even to the point of overproduction, with pesticides and fertilizers being applied as a matter of course. There was no concern for environmental degradation or the lack of economic stability facing the small farmer because of the capital costs of synthetic chemicals. The use of one input such as, soil cultivation, fertilization, pesticides or minimal crop rotation, frequently created the need for another. For example, nutrient cycling and soil fertility were often affected to such an extent, because heavy pesticide use depleted earthworms and soil insect populations, that synthetic fertilizers had to be added. Alternatively, a decline in the population of natural enemies, resulting from the depletion of habitat diversity caused by herbicide use, often led to an increase in insect pest populations which were then corrected by insecticide input, and so on. Governments actively encouraged this farming practice by providing incentives for farmers to increase production. This philosophy was taken into the Third World in the form of the "Green Revolution" in the early 1960's, and by the late 1960's and early 1970's it was apparent that all was not well with 'spaceship earth'. Pests, especially insects, were becoming resistant, pesticides were appearing in the food chain, nutrients from synthetic fertilizers were accumulating in streams and underground aquifers, soil erosion was widespread and wildlife habitats were being destroyed.

In the early 1970's integrated pest management (IPM) was introduced for certain crops. Biological and cultural control measures were used as much as possible with chemical controls being utilized only when needed. The population density of potential pests were monitored and compared to "economic threshold" values to determine whether or not pesticide applications were economically justified. IPM has been successful in certain situations; in Ontario for example, there was a 36% decrease in the frequency of insecticide application on onions between 1972 and 1980. However, many IPM extension programmes were, and still are, based on data that may have little to do with the specific conditions existing in the geographical region in which the programme was undertaken. A far more complex model, that includes all the available local information, might allow predictions to

be made with greater accuracy, particularly at pest populations approaching threshold levels. Alternatively, it may be that this is as far as we can go toward reducing pesticide use within the framework of the high-input farming system used today, as suggested by Dr. Hill in his following paper. Unfortunately, with time, the original idea of using alternative methods of pest control such as biological and cultural methods has been forgotten in many cases, and IPM has become pesticide rather than pest management.

It is from this background that "sustainable agriculture" has evolved. There are many philosophies of "sustainable agriculture" but they all seem to have one important feature in common and that is that they promote the drastic reduction, even elimination, of synthetic pesticides and inorganic fertilizers, main elements of conventional farming practices.

Madden ("Can sustainable agriculture be profitable?", Environment 29(4):19-34 1987) prefers the term "regenerative agriculture" to sustainable agriculture and defines it as "**a farming system in which an abundance of safe, nutritious food and fibre is produced using farming methods that are ecologically harmless, sustainable and profitable. Following an initial transition phase, chemical insecticides and other toxic compounds are replaced by a reliance on natural biological controls to the maximum extent feasible. Renewable sources of soil nutrients are largely or totally substituted for chemical fertilizers.... Regenerative agriculture also incorporates profitability as part of the norm or goal; if farmers must commit financial suicide in quest of ecological harmlessness, their form of agriculture is neither sustainable nor regenerative.**"

Agriculture Canada has reacted to enormous pressure from an environmentally conscious public by introducing the concept of environmental sustainability as one of its major goals, or "pillars". It defines sustainable agricultural systems as "**those that are economically viable, and meet society's needs for safe and nutritious food, while conserving or enhancing Canada's natural resources and the quality of the environment for future generations**". It encourages the use of an IPM system that includes cultural and biological control methods and considers farms as total "managed systems". Like most definitions of this complex subject, this is a goal oriented definition and emphasizes what it seeks to achieve and not how to achieve it.

The Ontario Ministry of Agriculture and Food (OMAF) introduced an initiative in 1988 called "Foodsystems 2002" which supplements the IPM programmes that are already in place. Dr. Surgeoner (Dept. of Environmental Biology, University of Guelph) presented a paper at the symposium (not included in this collection) on "Foodsystems 2002", which is a programme that aims to assists growers in reducing their pesticide use by 50% over a 15 year period. Thus, it can be seen that both levels of government have taken steps toward improving the *status quo*. In addition, many chemical companies, that have been almost entirely involved in the production of synthetic insecticides in the past, are now investigating alternative methods of insect control. Mr. Bushell (Ciba-Geigy, Toronto) presented a paper on this subject as part of the symposium (not included in this collection).

Organic farming systems, those that avoid the use of synthetic fertilizers, pesticides, growth regulators etc. entirely, were represented at the symposium by Mr. Van Diepan (Farmer Jack's Orchard, Lambeth). He presented a very interesting paper (not included in this collection) entitled "The Challenge of Growing Organic Food" in which he described some of the successes and problems facing a certified organic farmer. He pointed out that the codling moth, *Laspryresia pomonella* (L.), (Lepidoptera: Tortricidae) a pest on apples, was the bane of his life and expressed regret that the codling moth virus (*Granulosis* sp.) was not registered in Canada. He strongly encouraged research into alternative methods of controlling this pest.

Dr. Hill began the symposium with an enlightening if somewhat controversial view of sustainable agriculture. He feels that even biological control is simply a "substitution" approach, used in a curative way, the actual cause of the pest problem remaining unchanged. Dr. Hill is a strong believer in a return to cultural farming practices which represent a "deep" ecological solution, tackling the problem at its source. Dr. Harmsen approaches

sustainable agriculture from a very different perspective, using the biological equilibrium theory. He uses mite/leaf-miner interactions in apple orchards to exemplify some of the problems associated with establishing sustainable management practices. Drs. Tomlin and Protz discuss the components of the soil fauna and their invaluable contribution to soil structure and microfabric. They explain how disruptive pesticides and conventional tillage practices are to soil faunal activity and describe the changes that must occur for a system to be "sustainable". Drs. Kevan, Clark and Thomas stress the importance of pollination in both agriculture and nature, pointing out that chemicals and habitat destruction resulting from conventional farming practices have had a profoundly detrimental effect on pollinators. They believe that sustainable agricultural practices and agroforestry could be the answer to the serious problems of decreased pollinator diversity.

Finally, Dr. Smith discusses insect pest management as it pertains to the forest ecosystem. I feel that it is important to consider the problems of sustainable forest pest management in conjunction with those facing proponents of a sustainable agricultural system. The goals of forest production are basically the same as those in agriculture except that the time scale is much longer in forest management. The forest has to be kept healthy for many years before it is eventually harvested. The concept of "sustained yield" is central to the maintenance of a continuous supply of wood. Dr. Smith describes several insect pest species that are of importance in Canadian forests. She goes on to explain forest pest management (FPM) in the context of insect pests and the biological and cultural methods employed to keep their populations at acceptable levels.

I hope that you will find this group of papers as interesting as I did and I also hope that they will leave you with a better idea of the meaning of "sustainable" in the context of agriculture and forestry, the importance of achieving "sustainability" and what must done in order to reach this goal.

PEST CONTROL IN SUSTAINABLE AGRICULTURE

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Proc. ent. Soc. Ont. 121:5-12

Today, pests are usually seen as enemies and pest control as the use of science and technology to repress them. While great successes have been achieved by following this approach, there have also been numerous disbenefits including damage to human health, to non-target species including beneficial organisms, and the development of additional pest problems. Recognition of this situation has led to the development of integrated pest management (IPM), an approach designed to retain the benefits of the previous methods of control and to minimize the disbenefits. Although progress has been made in this direction there remain inherent problems, particularly because of the continued dependence of IPM on curative solutions. The alternative approach is to develop preventative solutions. Whereas curative approaches tend to be generated within disciplines, preventative solutions are transdisciplinary and involve the redesign of whole systems.

To understand this clearly I believe it is necessary to take an evolutionary approach towards the development of pest control. Indeed, the nature of the relationship between people and pests may be seen as an indicator of the level we have reached in the evolution of our own species. In this paper I will develop this argument and share with you the way in which my approach towards pest control has changed over the past ten years.

The importance of pest definitions

Pests comprise competitors of humans for resources, enemies, including those that transmit diseases, and nuisance organisms.

The pest status of competitors is usually defined in terms of economics. Thus, they are considered to be pests when it is economic to control them. This may reflect both rational and irrational criteria, such as cosmetic standards for the appearance of food. Enemies and nuisance organisms may also be controlled in response to both rational and irrational criteria. Weed free lawns and insect free recreational areas exemplify the latter. As such definitions reflect our values, it is likely that by developing more rational values we will also generate a more rational definition of pests, and more rational approaches to their control or prevention. For example, by defining pests as indicator organisms of maldesigned and malfunctioning ecosystems, in our response to them we would be more likely to focus our attention on redesign and improved management than on the enemy, the pest, and its elimination or control.

History of our relationship with agricultural pests

Moore (1967) has divided our past relationships with potential crop pests into four stages (Fig. 1): pre-agriculture, when pests rarely caused significant damage because of the ecosystem's natural complexity; pre-pesticide agriculture, when, with the simplification of ecosystems, pests followed cycles of outbreak and repression by natural controls; pesticide agriculture, when pesticide use was followed by pest resurgence and the development of secondary pests as a result of the repression of natural controls; and pesticide resistance

agriculture, when pesticides became less effective because of their selection of resistant individuals within pest populations.

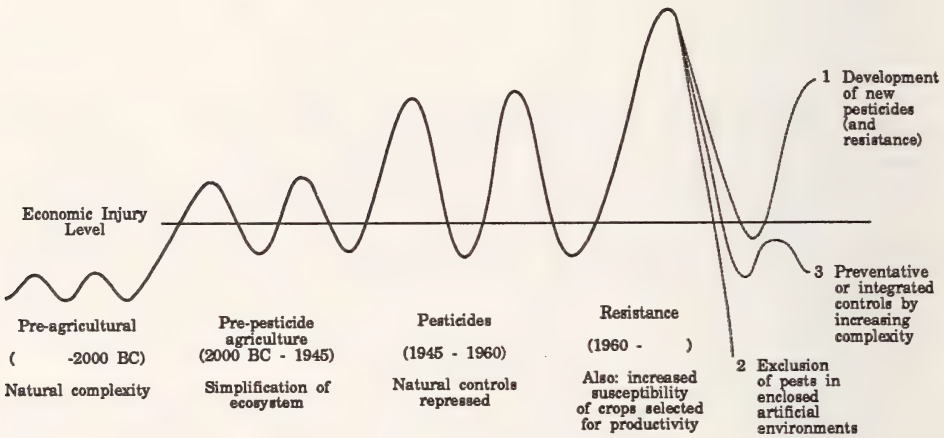

FIGURE 1. Changes in pest density in response to agriculture (modified from Moore 1967).

With respect to the future, Moore argues that we have three alternatives: continue to develop new pesticides (and therefore also new resistances); grow crops in enclosed artificial environments designed to exclude pests; and redesign agroecosystems to incorporate enough characteristics of pre-agriculture ecosystems to keep pest population densities below economic thresholds.

My own perception is somewhat similar to Moore's and is show in Figure 2. It describes what has happened and what I hope will happen in the future. Thus, the major development that is still taking place is an evolution from a control to a management philosophy, and from reliance on one or a few pest control strategies to the integration of many approaches into a system usually referred to as integrated pest management or IPM. At the present time efforts to introduce alternatives may be conveniently grouped into three approaches: "efficiency", "substitution", and "redesign". Integrated pest management (IPM) combines techniques that largely fall within the first two approaches together with the use of pesticides. IPM's first requirement is access to accurate techniques for monitoring pests (and, ideally, also their natural controls). Monitoring techniques include routine examination of the crop and the crop environment, simply methods such as 'jarring', sweeping with a net, interception traps, and traps that incorporate attractants, such as pheromones or sex attractants. These latter are also sometimes used as control measures, particularly to disrupt the normal mating behaviour of certain pests. Other ways to increase the "efficiency" with

which pesticides are used include better formulation and methods of application (e.g. electrostatic applicators), and access to economic threshold data for each of the pests. The requirement for pesticides can also be reduced by using resistant crop varieties, and by trapping the pests.

Pests as omens & punishments for evil acts	→ Control of pests	→ Elimination of pests	→ Management of pests	→ Pests as indicators of maldesigned and malfunctioning systems	→ Pests as indicators of unsustainable systems	→ ?
↓	↓	↓	↓	↓	↓	↓
Prayer, sacrifices, good behaviour	Increasingly powerful curative solutions	Massive application of curative solutions	Monitor pests, economic thresholds, integration of less environmentally disruptive but still largely curative solutions	Redesign & refined management of systems that meet demand (preventative control)	Design & management of systems that meet real needs (integrated, balanced, responsive to feedback)	?
↓	↓	↓	↓	↓	↓	↓
Frustration, oppression, disillusion, continued pest	Resurgence, resistance, secondary pests, disbenefits	Massive disbenefits	Team work systems approach, less disbenefits	Unexpected benefits, but still resource consuming	Clarification of priorities, values development, resource conservation, increased production	?

FIGURE 2. Evolution in our relationship with pests.

The "substitution" approach involves the replacement of highly toxic, persistent, non-specific pesticides with less harmful products or, more preferably, with biological controls (parasites, predators, and pathogens of the pests). Parasites include parasitic wasps, and certain flies and nematodes. Examples of predators are ladybird, ground and rove beetles, lacewing larvae, certain wasps, flies, spiders and their relatives, birds, and many others. Pathogens include bacteria, fundi, viruses, and protozoa.

Flooding pest populations with sterile or genetically incompatible males has proved effective for controlling certain pest species, particularly for isolated populations. Efforts to

find more specific and safer pesticides has led to the investigation of new botanical pesticides, hormones, sterilants and contraceptives, and also the re-examination of abrasive and sorbative dusts, such as diatomaceous earth, particularly for insects in stored grain and in buildings.

Alternatives mentioned up to this point, although potentially superior to non-specific toxic chemicals, share one important flaw with the latter. As they are primarily used in a curative way (see upper part of Fig. 3), the more effective they are, the more they will protect and perpetuate those features of the agricultural system that are the underlying causes of pest problems (Fig. 4). Because of this, I regard them as "shallow" ecological approaches. They are external solutions to internal problems.

The main advantage of IPM is that it has made the practice of pest control more "scientific" and more precise. In its refined form, it is based on a systems approach and is administered by a team of specialists from a diversity of disciplines. It has been particularly helpful in answering the following five questions: Is control warranted, when should it be applied, where should controls be applied, what mix of controls are appropriate, and how successful was the intervention? In addition, although it claims to be integrated, IPM still tends to take a linear approach, and it fails to deal with the extremely complex interrelationship between influencing variable. Another view of IPM is that it largely represents an effort to use pesticides more efficiently and, where economic, substitute less environmentally disruptive approaches, such as biological controls.

It is apparent then that all IPM programs are severely limited by the designs and management strategies of present food and fibre production systems, particularly their uniformity, reliance on susceptive crop varieties, and tendency to cause stress to crops during the growing process, thus making them more attractive to pests and susceptive to damage.

Evolution of a preventative approach to pest outbreaks

If IPM is limited in its development, as I believe it is, then it is necessary to take a different approach before agriculture can become "sustainable". Such an approach was implied in the discussion of the definition of pest above (see also Fig. 2). thus, if pests are viewed as indicators of maldesigned and malfunctioning systems, the requirement is to understand the causes of pest outbreaks and to modify the design and management of systems to prevent them.

In plant production the causes of pest outbreaks are associated with the main stages of production (left hand side of Fig. 4): plan selection, site selection and preparation, planting design, site maintenance, harvesting, distribution, storage and the timing of all operations.

Just as these practices are responsible for pest damage by influencing the properties of pests, their dispersal, availability of suitable food and space and by limiting the presence and effectiveness of natural controls (central part of Fig. 4), it is by the integration of changes in these practices that effective preventative methods of pest control are likely to be found (see also lower part of Fig. 3).

These "deep" ecological solutions comprise the components of the "redesign" approach - the only approach that I advocate for the future. This is because it incorporates the kind of value change referred to earlier; it pictures humans within, rather than on the outside, of the food system; and it seeks to solve problems internally by accommodating and supporting the system's natural homeostatic processes, rather than relying on the repeated application of increasingly ineffective cures to inappropriately designed, malfunctioning systems.

The roots of this "redesign" strategy are to be found in "cultural" methods of pest control (Table I). Cultural controls are the oldest methods that have been used to manage pest populations, and because they are preventative rather than curative they are dependent on long-range planning. They also depend on a detailed knowledge of the bio-ecology of

the natural control agents and their environment. These relationships were poorly understood in the past, the results of cultural control were very variable, and it was often difficult to evaluate their effectiveness. It is understandable that most farmers were eventually won over to the, at first, more reliable and less knowledge- and skill-dependent toxic chemical solutions to pest problems.

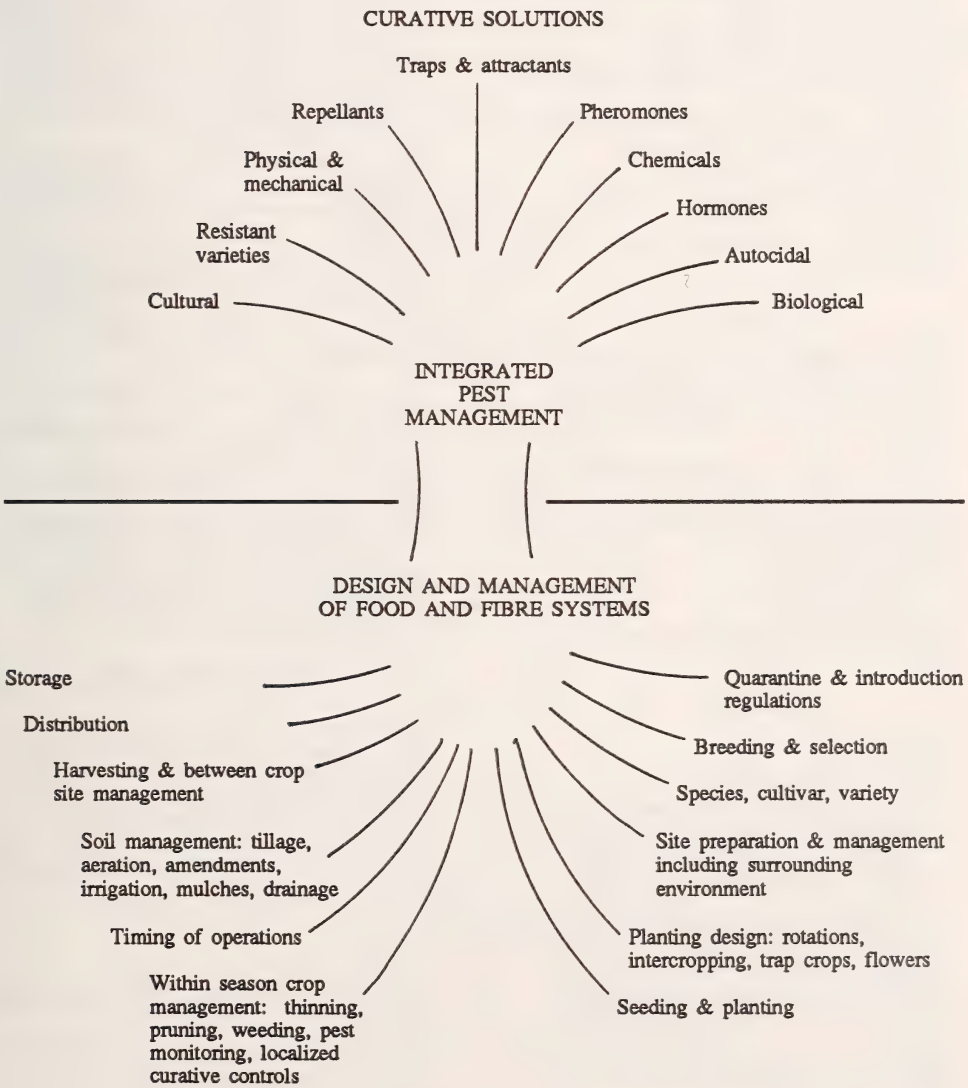

FIGURE 3. Curative and preventative approaches to pest control.

TABLE I. Ecological strategies for pest control.

Selection of plant

Stricter limits on plant introduction.
More thorough quarantine procedures for introduced plant materials.
Increase genetic diversity.
Develop and use resistant varieties.
Only use healthy seeds and plants, e.g. certified disease-free and from reliable dealers.
Use varieties suited to your soil and climate.
Use seeds inoculated with beneficial microorganisms.
Develop and use varieties able to compete with weeds.
Develop and use varieties able to grow in mixed culture.

Selection of site

Select site, particulary the soil, for its ability to satisfy all the needs of the plant and to avoid pest damage. This requires detailed knowledge of plants, soil, and pests.
Consider:
- soil type, fertility, structure, and drainage;
- elevation, slope, aspect;
- location in relation to other features of the landscape;
- climate;
- previous history of site, i.e. crop, tillage, chemicals, pests.

Modify site, if necessary, to meet needs of crop.

Planting

Include in planting design:
- crop rotation;
- mixed or companion planting;
- management of field borders and other adjacent environments to favour natural controls, e.g. by provision of nursery or trap crops, nesting, and overwintering sites;

Plant at the best time and in the best way for the plant and the worst time and way for the pest.
Introduce preventive pest control devices, e.g. tree bands, barriers, pheromone, or other traps.
Design size and shape of plots to discourage pests.

Maintenance of site

General:

Create and maintain optimum soil conditions for the plant and for beneficial soil and above-ground organisms, and unfavourable conditions for pests, e.g. through appropriate tillage, irrigation, drainage, and application of organic and inorganic amendments and mulches; inoculation of plant and/or soil with beneficial organisms.
Avoid damaging the plant or stressing it with growth stimulants or toxins, e.g. unbalanced fertilizers, hormones, herbicides, and pesticides.
Practice good sanitation.
Prune and thin where and when necessary.
Monitor pest populations.

If pest outbreak occurs:

Remove and destroy pest and/or plant, e.g. picking, jarring.
Cultivate to destroy pests or expose them to predators and sunlight.
Introduce traps and attractants or repellents.
Encourage and/or introduce predators, parasites, pathogens, sterile or genetically incompatible pests (biological controls).
Spray or dust with naturally occurring materials that are: effective, specific, and safe; degradable; economic; easy to apply.

Harvesting, distribution, storage, and end-of-season chores

Time harvesting to avoid late pest attack.
Store only healthy, pest-free produce in optimal conditions for crop and unfavourable conditions for pests.
Destroy crop residues and potential over-wintering sites of pests.
Manage soil during winter to reduce pests and encourage natural controls.

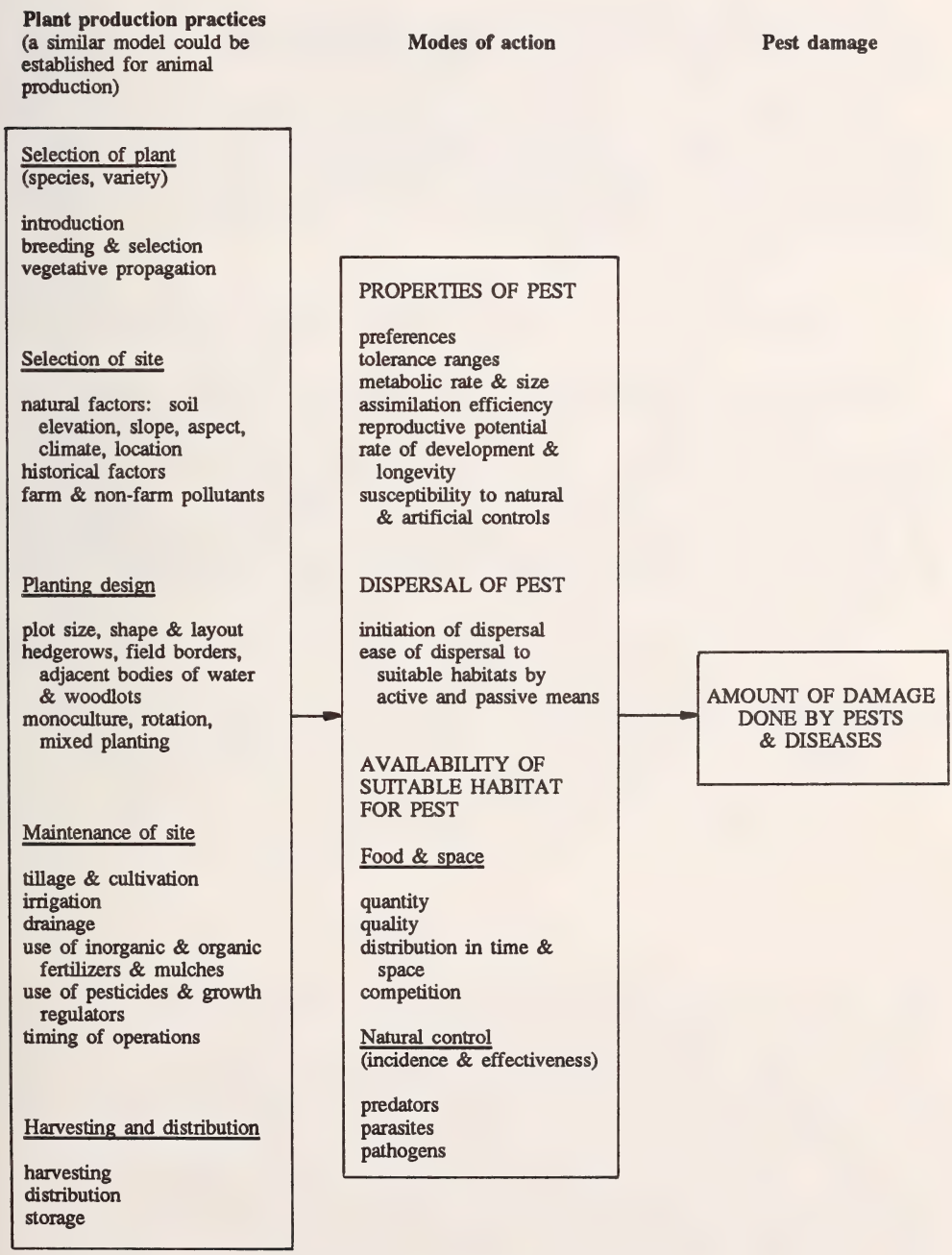

FIGURE 4. Relationships between plant production and pest damage.

Today the situation is very different from those early days of pest control. We have a much better understanding of the bio-ecological relationships within crop systems and predictive computer models are available for some pests.

For this approach to be successful the barriers to the development and implementation of cultural methods of pest control (and their integration with other agricultural goals and practices) must be identified. Foremost among these are the lack of appropriate research, training, services, equipment, and crop species and cultivars. In addition to responding to these deficiencies, changes in human values and attitudes will also be required: a shift in emphasis from cosmetic to nutritional quality; and from pest elimination to management below thresholds related to our values.

Conclusion

The development of "deep" ecological approaches require us to start to identify the driving and restraining forces that are operating, and to work towards strengthening the former and weakening the latter. On a personal level this transformational process involves developing a sense of integration with the earth, and paying attention to the processes of balance and feedback. It involves studying how natural systems function, spending time with them and learning how to imitate them. The development of this approach will not only affect the future of pest control but, more importantly, the evolution of our species; and by supporting such developments it is likely that the "deep" approach advocated here will, in their turn, become the "shallow" approach of some future generation.

Reference

Moore, N. 1967. A synopsis of the pesticide problem. Advances in Ecological Research, 4: 75-129.

THE THEORY OF SUSTAINABLE AGRICULTURE: OPPORTUNITIES AND PROBLEMS

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Abstract. *Proc. ent. Soc. Ont.* 121:13-24

The concept of sustainable agriculture is approached using the tenets of biological equilibrium theory as illustrated by the process of ecological succession. Modern agricultural systems are recognized as man-made early successional ecosystems, maintained in a state of severe disequilibrium by continuous input of energy and chemicals that cannot continue in perpetuity. An argument is made for the development of agricultural management practices and protocols using higher informational content in lieu of increasing energy inputs. The identification and manipulation of domains of local equilibrium in agricultural systems may allow for the development of localized sustainability. Such development depends on three separate approaches: 1) biological research and education; 2) rapid, high-tech manipulation and feedback; 3) altered (reduced?) yield objectives. Both opportunities and problems are illustrated with an example of integrated pest management research dealing with one subsystem of orchard management: tentiform leafminer and mites. Current leafminer control is exclusively chemical, and creates as a byproduct a serious mite problem. However, apparently stable interactive states have been identified between the leafminer, its parasites, the phytophagous mites and their predators. Experimental management protocols appear to be capable of managing the orchard system at or near these stable states, and operate at sustained productivity without large pesticide inputs, and with comparable yields to conventional control methods. Problems such as high research and monitoring costs are identified and discussed.

Introduction

In the Art Gallery of Ontario hangs a picture by Pieter Breughel the Younger dating from the late sixteenth century in the Low Countries which consists of a panel with nine individually painted scenes, each depicting an old European proverb carrying a message to a presumed naive public. One of these messages, which mankind has chosen to ignore, is labelled "Do not piss against the moon" (Fig. 1). The real message to 16th century society was to point out the futility of attempting an activity to eliminate some condition (eg. the reflection of the moon) that is bound to recur the moment you stop the activity. I can rephrase this warning into a more appropriate, 20th Century form as follows: "Those who create non-equilibrium systems will pay a price". The price, of course, can be in one of two forms: the system will sooner or later collapse, or the cost of maintaining it in its disequilibrium state in perpetuity will be paid. It would be more useful to phrase the message as: "To be sure of achieving one's objectives, one should if at all possible, avoid a dependence on systems that are in a state of disequilibrium".

FIGURE 1. The foolishness of attempting to maintain a system in a perpetual state of disequilibrium was illustrated by Pieter Breughel the Younger in the late 16th Century in his painting of a then current proverb: "He pisses against the moon". The painting is of a man attempting to keep the reflection of the moon off the water's surface. The original painting hangs in the Art Gallery of Ontario in Toronto.

Unfortunately, agricultural systems are usually in a state of severe disequilibrium, and the expanding worldwide agricultural industry, feeding an expanding human population, has been paying a growing price for this condition - a price future generations may not be willing or able to pay. The desire to develop agricultural methods that do not depend on the maintenance of disequilibrium systems is being expressed with increasing urgency. Agricultural methods that carry neither the high price of energy consumption and attendant chemical pollution, nor the risk of system collapse are expected to change the industry into what has become known as a "sustainable agriculture" (MacRae *et al.* 1989).

In this paper I will explore the theoretical problems and opportunities that I foresee in our search for a truly sustainable agriculture. I will illustrate these ideas with the results

from a specific set of experiments in integrated pest management which were aimed at sustainability, but also illustrate the kinds of problems and limitations one can expect to encounter.

Equilibrium theory

Ecologists have had a long standing interest in the concept of equilibrium (e.g. Levin 1989), which is illustrated clearly in the study of community succession. In its basic form, succession theory explains the processes that result in the sequence of plant assemblages that succeed one another after a certain area is severely disturbed or denuded (see Horn 1981). The rate of change in such a system tends to be initially high, but gradually declines until an equilibrium condition, known as "climax" becomes established; this climax condition is self-perpetuating. In contrast, the earlier stages of the successional sequence are in disequilibrium (see Fig. 2). Two comments are called for at this point. Firstly, various successional plant communities (including the climax one) carry their own specific animal assemblages, and secondly, in the real world, successional processes and patterns are much more complex than presented here (McBrien *et al.* 1983). In essence, however, the above concept of a series of disequilibrium communities following the establishment of an initial assemblage of invaders and resulting in some final equilibrium state, is a realistic approximation.

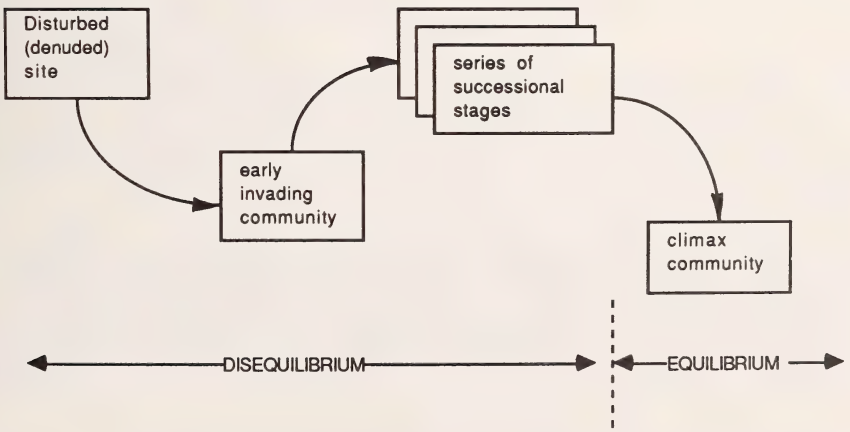

FIGURE 2. A schematic representation of a typical successional sequence, from a disturbed or denuded site which is being invaded by an assemblage of early invader species, via a series of non-equilibrium, transient "communities" to a steady state equilibrium community known as the "climax".

The most precise ways of expressing equilibrium are mathematical, but diagrammatic representations can be more convincing than equations. The concept of a stable equilibrium for instance, can be illustrated as a marble lying at the bottom of a parabolic pit (Fig 3a):

no amount of disturbance will be able to displace that marble permanently, and no matter where the marble is placed in the pit, it will always return to the bottom. Another important aspect of the bottom equilibrium location is that it is the only location in the pit where the marble can be maintained without constant expenditure of work. On the other hand, to maintain the marble part way up some slope, in a permanent state of disequilibrium (Fig. 3c), is obviously costly in terms of energy expenditure. Finally, there are states of a system that may be represented by "shoulders" and "local dips" on a slope (Fig. 3d). A shoulder in a section of slope is isomorphic with a local or temporary state of a system which is close to an equilibrium condition. Even more significant is the local dip or depression in a contoured landscape. Such a local dip is isomorphic with a system that is at a stable equilibrium point within a localized or neighbourhood stabilizing region. Keeping the marble in such areas would only occasionally need external manipulation.

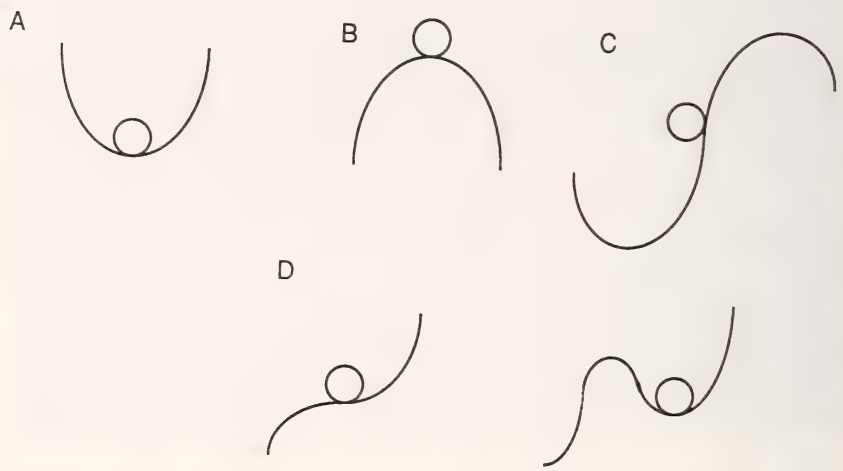

FIGURE 3. A graphic representation of some essential equilibrium theory concepts: **A.** A ball inside a pit represents a universal, stable equilibrium. **B.** A ball on top of an inverted pit represents a labile equilibrium. **C.** A ball on a sloping surface represents a state of disequilibrium; the slope of the incline is a measure of the degree of disequilibrium. **D.** Shoulders or dips are local, or regional conditions of near equilibrium or equilibrium respectively.

Whether real world ecosystems have shoulders and dips is not an easy question to answer, but some evidence suggests that they do. For instance, an abandoned agricultural field in Ontario tends to go through a rapid successional sequence of plant communities until a dense stand, mainly of the goldenrod *Solidago canadensis* L. establishes itself. The system then enters a period of very slow change for some ten to fifteen years, and eventually other species, mostly shrubs and tree saplings, overgrow the goldenrod, causing its rapid demise. In terms of equilibrium theory, one sees a system which begins in a state of severe disequilibrium, then spends some time in a state near or even at equilibrium, but sooner or later disequilibrium returns as the community develops into mixed broadleaf woodland. For

illustrative purposes it is that goldenrod-dominated pseudoequilibrium that is the important phenomenon. No one is interested in farming goldenrod, and consequently this particular near-equilibrium state is of no practical interest, but the phenomenon indicates that time is not wasted searching for similar near-equilibria in systems that are of economic importance.

Agricultural ecosystems

All agricultural systems are aimed at maximizing either productivity or profit through the manipulation of ecosystems by:

1. creating a major disturbance (site preparation such as slash and burn, bulldozing, tilling, fertilizing, etc.),
2. establishing an assemblage of primary invaders (planting specific species of desired crop plants), and
3. preventing succession (weeding and herbicides to eliminate competition by secondary invaders, insecticides to eliminate grazers on the crop plants, and/or reploughing, etc.).

In terms of equilibrium theory, agriculture tries to minimize, to the point of elimination, the various processes that "seek" community equilibrium, such as grazing, and plant competitive interactions. This means, agro-ecosystems are maintained at the early, severe state of disequilibrium, which requires a massive input of energy (and more recently also of pesticides). Figure 4 shows the above argument in the form of a flow diagram. The problems posed by competitors and grazers are at their most worrisome in crops such as orchards, that are both perennial systems, and simultaneously in a severe state of disequilibrium. This implies that the advantages of retilling and crop rotation are not available to the manager, so that all aspects of pest and weed control must be part of an ongoing maintenance protocol.

The main developments of modern agriculture have been the breeding of high yield crop species, use of chemical fertilizers, input of mechanical equipment powered by fossil fuels, use of irrigation, and application of synthetic pesticides. These developments have led to large yield increases and major reductions of labour, but the costs have been higher energy input, and unacceptably high levels of pollution and eutrophication of adjacent waterbodies. A slower development, but probably of more long term significance, is the growing emphasis on research, and resultant growth in managerial complexity of agro-ecosystems with the accompanying need for education. In most technologically advanced nations this process has been accelerating in recent decades, and is starting to open the door to a more sophisticated level of agricultural management based more on information and less on energy. It is to be hoped that this development is pointing the way to a sustainable agriculture for the 21st century.

Management based on information

The research-based revolution in agricultural management practices has already produced some spectacular results such as animal and crop varieties that have been bred for specific purposes, highly specific synthetic pesticides or application methods, sterile male release, the implementation of biologically based timing and feedback in various management practices, and more recently the highly promising application of molecular biology and genetic engineering (Allen and Rajotte 1990). The most successful research and information-based agricultural practices are those in the areas of biological control and integrated pest management (Murdoch *et al.* 1985). However, despite obvious successes, we are still a long

way from replacing all possible energy consuming and polluting management practices with management based on biological information.

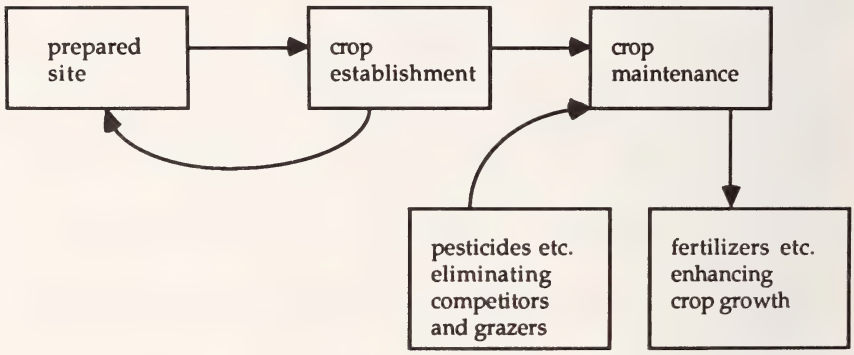

FIGURE 4. A typical agricultural system, viewed within the paradigm of ecological succession. The prepared site is artificially "invaded" by a crop, which represents the early assemblage. Any further succession through transient stages is prevented by chemical or mechanical management. Sooner or later (usually annually) the system is destroyed and reinitiated. Consequently, the system is maintained in a perpetual state of disequilibrium.

Most research aimed at providing the necessary information for the development of sustainable agricultural practices has been poorly funded and poorly integrated, and, as a result, of short term (but see Gruys 1982). Such research has not become a well established part of agricultural science policy. It has proven very difficult to convince governments of the need to bring together theoretical ecological research with laboratory and field entomology and botany, and coordinate this research effort with biotechnological developments and government policy. It seems clear to me that a rapid approach to a high degree of sustainability in modern agriculture depends on three separate but integrated developments:

1. **Biological Research and Education**

Research, using all possible approaches, is the only tool which can supply the necessary information to develop an adequate understanding of the interactive functioning of agro-ecosystems. Before development of reliable agricultural practices based on an understanding of the various systems can proceed, the necessary information must be available. Whether it is canola production in Manitoba, or peaches in southern Ontario, the relevant biological information must be available. This means, not only that the necessary research must be done, but also that the research results and conclusions are available for rapid retrieval, integration and use.

Because much of the information available now (and that forthcoming in the future) is highly scientific or technical in nature, or both, the personnel involved in its management must attain levels of education that allow the utilization of the information in a meaningful way.

Translating a vast quantity of research information about a specific agro-ecosystem and system constituents into a heuristic model for the functioning of that system under various environmental conditions will be a major task. Yet, if location and identification of local stability or shoulder points in agrosystems, or restructuring systems so that they contain local stability points, is to be attained, that approach must be taken. It requires highly trained personnel and large monetary inputs, but is absolutely essential if sustainability is to be achieved.

2. **Rapid Manipulation and Feedback**

During the dynamic sequence from establishing a crop to its reaping, most ecological developments that threaten yields proceed at such high rates that corrective measures may have to be taken at short notice. This is especially true if some aspect of the system functions at a local equilibrium point. For instance, when a pest species is held in reasonable control by a predator, no yield damage is expected until some perturbation pushes the prey-predator relationship beyond some threshold. Immediately the system starts to move away from its previous equilibrium range, and damage to anticipated yield becomes a certainty unless corrective measures are taken. The sooner these corrective measures are taken the less costly they will be. This means, however, that the appropriate information-based management strategy must be applied quickly, which will be impossible without a management system in place. Computer access to all necessary information, a team of operators with the appropriate level of education to monitor feedbacks constantly, and a repertoire of corrective measures are essential components of such an approach. Some good pioneering work in this area has been done in Michigan showing the potential, but also identifying some serious difficulties (Croft *et al.* 1976). To a large degree, computers, automated data loggers, electronic communication links, selected laboratory reared predator populations, bio-engineered pathogens and bio-monitoring devices with back-up laboratories, run by trained technicians will have to replace spray and fogging equipment, and manual sampling.

3. **Altered Yield Objectives**

It would be overly optimistic to expect much progress towards a sustainable agriculture without having to accept some short term loss in productivity. The high yields of recent decades are, to a large degree, the direct result of massive energy input via fossil fuels, overuse of soils, fertilizer dependent plant varieties, and the use of chemical pesticides. To reduce energy inputs, stop soil deterioration and drastically reduce the use of synthetic pesticides some yield reductions must be accepted. At this stage, biology and even agriculture give way to economics and politics. If governments are willing to pay for the necessary research and for maintaining a management/extension infrastructure, the actual cost of producing harvestable crops may not be higher than it is now. However, growers will still have to be enticed into embracing the increased complexity of sustainable management and a lower yield. Agricultural producers will face a more sophisticated and complex world, which may, at first, appear less profitable. None of the efforts of researchers and management consultants will bear fruit unless governments are willing to structure the economics of fuel, pesticides and commodities more effectively than they do now, and establish a legal framework such that all those involved in the production process will be convinced of the desirability and potential of the new approach.

Below I will describe and analyze a system that illustrates both the potential and the limitations of the introduction of some aspects of sustainable, information-based management practices.

Apple orchard ecosystem and management

An apple orchard is a perennial agro-ecosystem with several unique characteristics, but it is generally representative of a typical agricultural system as illustrated in Figure 4, but without the annual return to a fallow starting point. Competition and grazing must therefore be minimized by a complex set of management procedures (see Fig. 5). Herbicides or mowing, or both, are used to control weeds, and various insecticides and acaricides provide adequate control of phytophagous insects and mites when applied frequently enough. Other chemical applications such as thinning agents, fungicides and fertilizers are intentionally left out of this discussion for simplicity's sake.

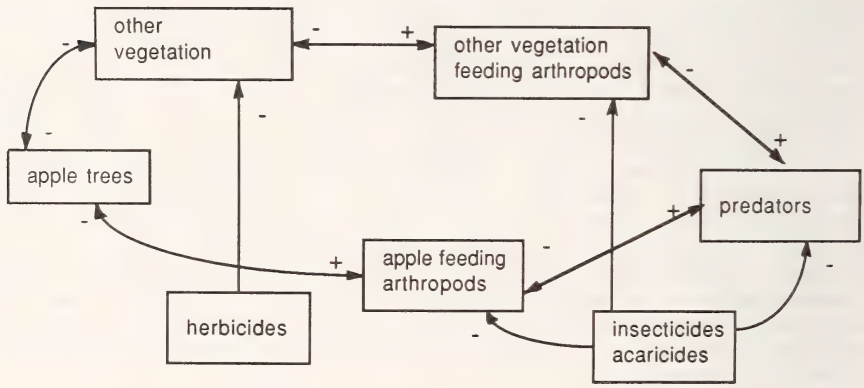

FIGURE 5. A schematic overview of the apple orchard system. This is a perennial agricultural system where the apple trees are the only desired crop plant. All essential interactions are represented by arrows. Positive and negative interactions are indicated by plus and minus signs respectively. The essence of this diagram is the secondary effect of biocides aimed at enhancing crop yield, that destabilize the system through the destruction of natural control factors such as predators.

One major problem becomes obvious from the analysis of the flow diagram of Figure 5. Insecticide and acaricide applications replace control functions of predators, but their negative effects on predators and weed-feeding arthropods as well, can make the task of chemical pest control more difficult with the following unfortunate result: by removing natural control agents, the system moves from partial disequilibrium into a state of more severe disequilibrium, forcing the manager to utilize yet more environmentally damaging pesticides. Figure 6 presents a more detailed illustration of a minor, but important subsystem: the mite complex and its interaction with the tentiform leafminer and current conventional management. Within this subsystem are a few other, less important species, but the simplified version presented in Figure 6 illustrates the relevant phenomena more clearly. In an orchard which has no tentiform leaf miner, *Phyllonorycter blancardella* F. (Lepidoptera: Gracillariidae), the European red mite, *Panonychus ulmi* Koch (Acari: Tetranychidae) is generally not a problem, because a stable, local equilibrium controls the relationship between the red mite and a number of predatory mites of the families Stigmaeidae and Phytoseiidae.

However, because leaf miners developed resistance to organophosphorous insecticides, orchard managers have switched to synthetic pyrethroids, such as permethrin, for leaf miner control (Li *et al.* 1990). These substances are very effective controls for the leaf miner, but also directly or indirectly reduce numbers of various parasites of the leafminer; worse, pyrethroid treatments destroy mite predators, but have little direct effect on the pestiferous red mite. These effects have an unwanted byproduct: the escape of the red mite from its previous stable equilibrium with its predators. Outbreaks of red mite can devastate the foliage of apple trees resulting in yield loss (Hardman *et al.* 1985). In response, the grower has to apply acaricides, adding to the already extensive load of pesticides applied to commercial orchards. These acaricides do reduce the red mite population, but directly or indirectly also reduce mite predators, thereby further moving the system out of equilibrium. High reproductive rates and levels of dispersal of red mites may require multiple acaricide applications during a season. If synthetic pyrethroid and acaricide combinations are used frequently enough, predatory mites may not be able to regain a foothold in the orchard, and this costly and environmentally damaging control protocol becomes a perpetual component of orchard management.

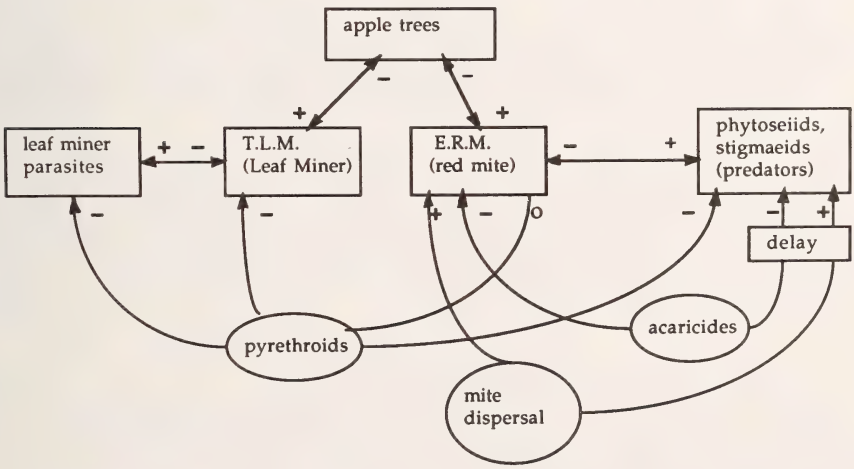

FIGURE 6. A schematic representation of the mite-leafminer subsystem of apple orchard management. All essential interactions are represented by arrows. Pyrethroids are the major destabilizing factor in this system. Used for leafminer, they also cause the destruction of leafminer parasites and mite predators. The resulting increases in mite populations are subsequently controlled with acaricides further destabilize the system. For a detailed discussion see the text.

Recent research

The orchard subsystem described above is one which is kept in a perpetual state of severe disequilibrium by the frequent application of non-specific pesticides. One can ask several questions that can only be answered by detailed and intensive long term research. The most relevant questions are ecological: "Why does the red mite - predatory mite equilibrium have at least some local stability, whereas the leafminer - parasite interaction has

no such stabilizing equilibrium?", and physiological: "What differences exist between red mites and predatory mites resulting in the former being resistant to synthetic pyrethroids while the latter are not?". Each of these questions immediately conjure up others, such as: "How extensive is the stabilizing domain for the mite equilibrium?" or rephrased as: "How much synthetic pyrethroid can be applied before some threshold is exceeded and the system switches into disequilibrium?" (Li *et al.* 1991), or "Can pyrethroid-resistant predators be produced using selection protocols (Roush and McKenzie 1987) or even genetic engineering methods?". Other questions of potential importance address the leaf miner component of the subsystem. For instance: "Can the leaf miner-parasite relationship be manipulated so as to create a locally stable equilibrium, or at least find a shoulder where the system can be maintained at less cost?".

Recent research has come close to answering many of these questions, and predatory mites have been extensively studied, so that their interactions with one another and their prey is much less of a mystery now (e.g. Clements and Harmsen 1990). Predatory mites, resistant to synthetic pyrethroids have been selected under laboratory conditions (e.g. Strickler and Croft 1982) and in the field (Suckling *et al.* 1988). However, techniques need to be refined, and adapted to local conditions. Attempts at producing pyrethroid-resistant predatory mites in Ontario using field selection are under way, and some initial results look very promising (Harmsen *et al.* 1989, 1990). Theoretical models and simulations (Woolhouse and Harmsen 1987) are producing predictions which are being followed up with experimental laboratory and field experiments. The leaf miner, together with its parasites has been the object of much recent research (Johnson *et al.* 1976; Pree *et al.* 1986; Trimble and Hagley 1988).

Progress, however, is slow. Reliable, sustainable management protocols for this small part of just one agricultural crop that is environmentally benign and not too costly is still years in the future. Organizations that fund agricultural research (industry, growers and government) usually seek short term approaches that favour conventional solutions and, despite a professed commitment to the development of sustainable agriculture, are not matching their words with the necessary backing to achieve the stated goals.

Summary and conclusions

"Sustainable Agriculture" is a fairly vague concept for most people, and more clearly defined in terms of its goals and objectives than in terms of system processes and structure (i.e. more in terms of what we want it to do than in terms of how to do it).

In this paper I have phrased agricultural systems in the conceptual terminology of ecological equilibrium theory. Current agro-ecosystems are often energetically costly ones in disequilibrium, whereas the drive towards sustainability is defined as managing existing systems more and more by recognizing and using local equilibrium points, or by restructuring systems so as to incorporate useable stabilizing domains. Three major developments are necessary if we seriously want to shift agriculture towards sustainability:

1) research and education must supply the information upon which to base our new approach,
2) fast information storage and retrieval, and an infrastructure of personnel and monitoring and communication systems must be developed to maximize the usefulness of the information supplied by the research, and most importantly
3) government must create an economic, political and legal framework that will entice or coerce growers into embracing the new technology despite an inevitable loss of yield.

The example of the mite-leaf-miner subsystem presented here clearly illustrates some tentative successes, but also points to the cost and other problems with successfully establishing sustainable management practices in even a minor subsystem of one crop in one area of Ontario. The main current problem is the unwillingness of the various funding agencies to provide adequate sustained funding for the necessary research. Everyone agrees that the goals of a sustainable agriculture are laudable, but at this time, no one is willing to pay the cost of reaching those goals.

Acknowledgements

I wish to acknowledge the research of, and the many discussions with my students, Dave Clements, Shiyou Li and Tina Roeder. I also wish to express my thanks to Howard Thistlewood and an anonymous reviewer for their critiques of this manuscript. Partial funding and facilities for the research referred to here were provided by the Ontario Pesticides Advisory Committee, Agriculture Canada, Queen's University and I.C.I. Chipman.

References

Allen, W.A. and E.J. Rajotte. 1990. The changing role of extension entomology in the IPM era. Annual Review of Entomology, 35: 379-397.

Clements D.R. and R. Harmsen. 1990. Predatory behavior and prey-stage preferences of stigmelid and phytoseiid mites and their potential compatibility in biological control. Canadian Entomologist, 122: 321-328.

Croft, B.A., J.L. Howes and S.M. Welch. 1976. A computer-based, extension pest management delivery system. Environmental Entomology, 5: 20-34.

Gruys, P. 1982. Hits and misses. The ecological approach to pest control in orchards. Entomologia Experimentalis et Applicata, 31: 71-87.

Hardman, J.M., H.J. Herbert and K.H. Sandford. 1985. Effect of populations of the European Red Mite, *Panonychus ulmi*, on the apple variety red delicious in Nova Scotia. Canadian Entomologist, 117: 1257-1265.

Harmsen, R., S. Li and J. Warner. 1989. Development of resistance to a synthetic pyrethroid in predatory mites in a mite infected apple orchard. Pesticides Research Report - 1988. Agriculture Canada Publication. p. 14

Harmsen, R., S. Li and J. Warner. 1990. Development of resistance to a synthetic pyrethroid in predatory mites under apple orchard conditions. Pesticides Research Report - 1988. Agriculture Canada Publication. p. 17

Horn, H.S. 1981. Succession. *In*: R.M. May (eds.). Theoretical Ecology. Blackwell Scientific, Oxford. pp. 253-271

Johnson, E.F., J.E. Laing and R. Trottier. 1976. The seasonal occurrence of *Lithocolletis blancardella* (Gracillariidae), and its major natural enemies in Ontario apple orchards. Proceedings of the Entomological Society of Ontario, 107: 31-45.

Levin, S.A. 1989. Challenges in the development of a theory of community and ecosystem structure and function. *In*: J. Roughgarden, R.M. May and S.A. Levin (eds.). Perspectives in Ecological Theory, Princeton U.P., Princeton, N.J.

Li, S., R. Harmsen, J.M. Cook and J. Warner. 1990. Evaluation of a synthetic pyrethroid for spotted tentiform leaf miner. Pesticides Research Report - 1989. Agriculture Canada Publication. p. 23

Li, S.Y., D.R. Clements and R. Harmsen. 1991. A new protocol for control of the spotted tentiform leafminer, *Phyllonorycter blancardella* (F.) (Lepidoptera: Gracillariidae) with pyrethroid insecticides. Submitted.

MacRae, R.J., S.B. Hill, J. Henning and G.R. Mehuys. 1989. Agricultural science and sustainable agriculture: a review of the existing scientific barriers to sustainable food production and potential solutions. Biological Agriculture and Horticulture, 6: 173-219.

McBrien, H.L., R. Harmsen and A. Crowder. 1983. A case of insect grazing affecting plant succession. Ecology, 64: 1034-1039.

Murdoch, W., J. Chesson and P. Chesson. 1985. Biological control in theory and practice. American Naturalist, 125: 344-366.

Pree, D.J., D.B. Marshall and E.E. Archibald. 1986. Resistance to pyrethroid insecticides in the spotted tentiform leafminer, *Phyllonorycter blancardella* (Lepidoptera: Gracillariidae) in southern Ontario. Journal of Economic Entomology, 79: 318-322.

Roush, R.T. and J.A. McKenzie. 1987. Ecological genetics of insecticide and acaricide resistance. Annual Review of Entomology, 32: 361-380.

Strickler, K. and B.A. Croft. 1982. Selection for permethrin resistance in the predatory mite *Amblyseius fallacis* Garman (Acarina: Phytoseiidae). Entomologia Experimentalis et Applicata, 31: 339-345.

Suckling, D.M., J.T.S. Walker, P.W. Shaw, N.P. Maskwick and C.H. Wearing. 1988. Management of resistance in horticultural pests and beneficial species in New Zealand. Pesticide Science, 23: 157-164.

Trimble, R.M. and E.A.C. Hagley. 1988. Evaluation of mass trapping for controlling the spotted tentiform leafminer, *Phyllonorycter blancardella* (Lepidoptera: Gracillariidae). Canadian Entomologist, 120: 101-108.

Woolhouse, M.E.J. and R. Harmsen. 1987. A transition matrix model of the population dynamics of a two-prey-two-predator acarid complex. Ecolological Modelling, 39: 307-323.

SOIL FAUNAL ACTIVITY AND SOIL MICROFABRICS IN SUSTAINABLE CROPPING SYSTEMS

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Abstract. *Proc. ent. Soc. Ont.* 121:25-41

The identity and relationships of various components of the soil fauna and their contribution to soil structure or microfabric are discussed within the context of recent Canadian glacial history and current agricultural practices. Methods of extracting fauna from the soil are reviewed. Direct imaging of soil biotic activity through the use of rhizotrons or microscopic analysis of intact soil is discussed.

Generally, the most widespread and disruptive agricultural practices to soil quality are deforestation and conventional tillage. Sustainable agricultural practices such as reduced tillage and pesticide inputs are less damaging to soil fauna. Cropping systems will have to be devised that balance optimum crop production with maintenance of sufficient organic matter in the soil to provide for soil faunal activity.

Introduction

Human activity is dependent upon food that is primarily obtained from cultivating the soil, and its conservation must be a central consideration for current and future generations if civilized societies expect to survive. Soil, or more precisely, the topsoil that supports plant growth, may require from centuries to millennia to restore following its exhaustion or loss to erosive processes (Winter *et al.* 1991).

Soil is a complex mixture of mineral, organic matter, water, and biotic components, composed of primary producers (plant roots and algae), microflora (bacteria, fungi, actinomycetes, yeasts), and microfauna (mainly invertebrates). Soil organisms, both floral and faunal, which together form the active fraction of soil organic matter, comprise less than 20% of all soil organic matter, but decompose more quickly than the more resistant humus fraction (Voroney 1988). The humus fraction is closely associated with the clay fraction, and is important to soil structure, cation exchange and water-holding capacity.

Bal (1982) pointed out that, in general, neither pedologists nor biologists realize how complex and abundant soil fauna is, and how intimate is its involvement in topsoil formation. The relationship between soil microfabric and soil fauna was first investigated by P.E. Muller in a series of papers published in the late 19th century (recently reviewed by Bal (1982)), and by Kubiena (1938). Soil ecology has attracted increasing interest from biologists (Kuhnelt 1976; Kevan 1955; Schaller 1968; Wallwork 1970), and was the subject of a widely circulated popular article (Edwards 1969). More recently, both pedologists and biologists have turned their attention to faunal influences on soil microfabric (Pawluk 1985; Rusek 1985; Shipitalo *et al.* 1988), and faunal interactions in the rhizosphere (Foster 1988). Soil scientists are

recognizing that topsoil is composed of organic matter and mineral particles that have passed through the gut of soil fauna and been excreted as fecal pellets (Bal 1982), and that the consequences of this passage for soil structure are immense.

Recent interest by growers, the public, and policymakers in "sustainable agriculture" as an alternative to "conventional agriculture" for providing foodstuffs, with less soil erosion and less dependence on fuel and chemical inputs, begs the question as to what constitutes soil quality. However, this question can only be answered by a comprehensive understanding of the biotic and abiotic processes involved in soil genesis and conservation.

We shall provide a brief outline of the analytical techniques for measuring soil fauna, its composition, contribution to soil microfabric, and its response to various agricultural and land use practices, within an Ontario setting.

Ontario soils

The deglaciation history, landform genesis and subsequent soil formation have been outlined in the classic work on the physiography of southern Ontario by Chapman and Putnam (1984). The classification of southern Ontario soils is in a continual state of revision since the summary publication, Soil Associations of Southern Ontario by Hoffman *et al.* (1964). The rate and sequence of vegetation has been summarized in a series of papers by Ruddiman and Wright (1987).

Most of Ontario's best agricultural soils (Classes I and II) lie in the southwestern corner of the province, south of a line running from Toronto to Sarnia.

Composition of the soil fauna

About 85% of the soil biomass (not including plant roots and algae) is composed of microflora: bacteria, actinomycetes, fungi, yeasts, Reichle (1977). The remaining 15% of the soil biomass is soil fauna (Fig. 1) comprising representatives (Table I) of most arthropod classes and orders, protozoans, nematodes, and annelid worms (Lumbricidae and Enchytraeidae), and vertebrates (Jeffrey 1987). Abundance and occurrence of all these animals vary with soil type and vegetation. There are few studies on the fauna of either Canadian or Ontario soils (Marshall *et al.* 1982; Tomlin and Miller 1987), a particular deficiency in light of Canada's huge land surface.

Distribution and biology of the soil fauna

Most soil animals are confined to the surficial layers of topsoil, but earthworms can reach a depth of 2.5 m (Edwards and Lofty 1977). Soil animal abundance has an inverse curvilinear relationship with depth (Fig. 2), probably as a function of nutrient and oxygen availability (Haarlov 1960); typically > 60% of the soil fauna occurs in the upper 10 cm of the soil horizon (Petersen and Luxton 1982; Holliday *et al.* 1982; Tomlin and Miller 1987).

Substantial proportions of organic matter of plant or animal origin eventually reach the soil, where they may remain for only a few hours or days if they are readily decomposable, or as long as several decades if they decay slowly (Oades, 1989). Soil animals contribute to the breakdown of organic matter in several ways (Edwards *et al.* 1970): they (1) disintegrate plant and animal tissues and make them more easily invaded by microorganisms, (2) selectively decompose and chemically change parts of organic residues, (3) transform plant residues into humic substances, (4) increase the surface area available for bacterial and fungal action, (5)

form complex aggregates of organic matter with the mineral part of soil, (6) mix the organic matter thoroughly into the upper layers of soil, and (7) disseminate fungal propagules and stimulate fungal growth beneficial to plants (Moore 1988). The presence of earthworms in the surficial layers, and large worm species that burrow to the surface increase air and moisture infiltration rates into soil (Edwards and Lofty 1977).

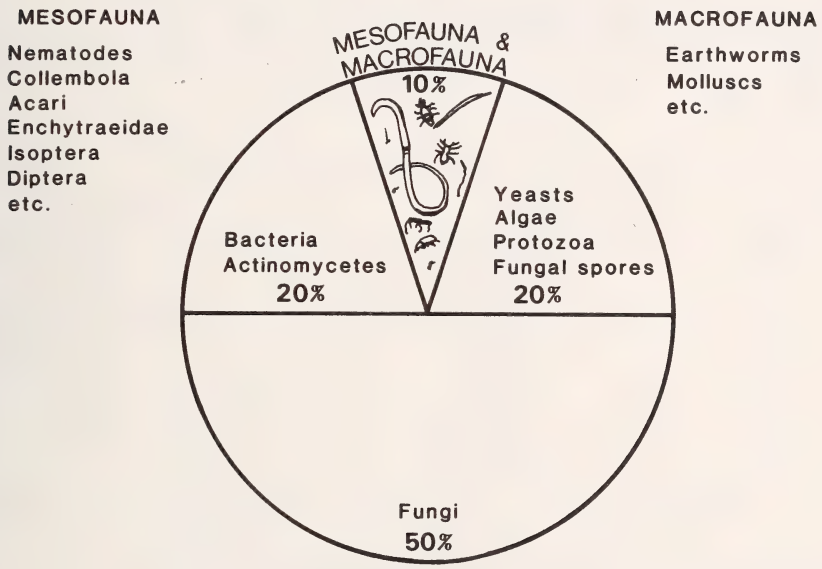

FIGURE 1. Approximate contribution of floral and faunal components to soil biota.

The key to understanding faunal effects on soil microfabric is to appreciate the vast numbers of animals that reside in soil. Table II provides comparative numbers of some faunal densities for fertile soils in temperate climates. Forest soils in temperate climates may have up to hundreds of millions or more of these animals for each square metre of surface (Table II), and scientists are only beginning to elucidate their biology and impact on soil structure and genesis. Tilled soils usually have much lower faunal densities and diversity than soils of stands of virgin woods on soils of the same textural series (Fig. 3) (Tomlin and Miller 1987).

Soil animals metabolize a large array of organic and inorganic compounds into materials that are exploited by other animals, plants, and microorganisms both in and above the soil (Russell 1950). Because animals are generally mobile, they are also capable of disseminating these compounds, and each other, throughout the soil, in symbiotic, commensal, or phoretic relationships (Tomlin and Miller 1981; Desender and Vaneeschoutte 1984). Soil animals are not evenly distributed throughout the soil, despite the fact that faunal densities are usually described as mean numbers/m^2. They may exhibit highly aggregated behaviour (Christiansen 1970; Joosse 1971; Price 1973; Usher 1976), and horizontally aggregated distributions (Mitchell 1978), as well as variations in seasonal distributions (Fig. 4) in the same soil profiles

(Lloyd 1963; Parr 1978; Tomlin and Miller 1987). Soil faunal densities are also highly correlated with organic matter, which is usually most concentrated at the soil surface as litter. This correlation can be seen between the various thicknesses of the LFH (litter:fermentation:humus) horizon from soil cores in the James Bay Lowlands and numbers of arthropods and cryptostigmatid mites (Table III).

TABLE I. Approximate soil biomass contributions of soil decomposers and other organisms (data compiled from several sources by Jeffrey 1987).

% Soil biomass	Organism group	% Decomposer biomass
66.0	Roots	Primary producers
17.1	Bacteria	55.5
13.1	Fungi	38.9
1.4	Actinomycetes	4.2
0.1	Algae	Primary producers
0.7	Protozoa	1.9
0.2	Nematoda	0.3
0.7	Annelida	2.0
0.6	Arthropoda	0.9
0.1	Vertebrata	0.4

TABLE II. Maximal densities of various soil animal taxa in different soils and state of scientific knowledge of these taxa (data from various sources).

Taxon	Importance	Max. Density/m2	Knowledge
Protozoa	Most soils	10^3	Little known
Nematoda	Sands or peats	10^7	Little known
Lumbricidae	Heavier soils	10^3	Some known
Enchytraeidae	Peats and mulls	10^4	Little known
Acari	Most soils	10^5	Little known
Collembola	Most soils	$<10^5$	Some known

TABLE III. Relationship between "LFH" thickness and soil faunal densities for a coastal transect in the James Bay Lowlands (n=6)

Sample ID code	"LFH" Thickness (cm)	Est. no arthropods/$m^2$2	Est. no. cryptostigmata/m^2
KJ-H+1	0	26,988	4,342
NPD-21	0	27,235	15,640
A	1	28,221	11,742
NPD-24	2	38,582	29,455
NPD-26	3	74,648	51,164
KJ-23	3	78,793	42,776
KJ-24	10	72,428	44,503

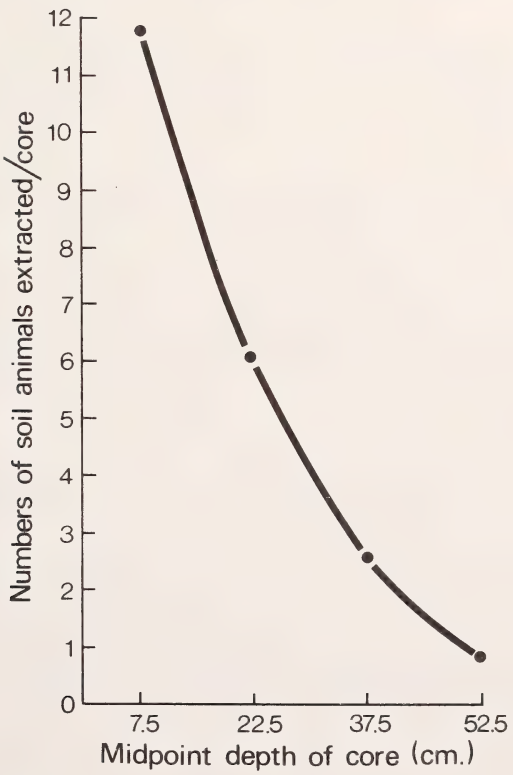

FIGURE 2. The relationship of soil animal abundance with depth (data from Holliday *et al.* 1982).

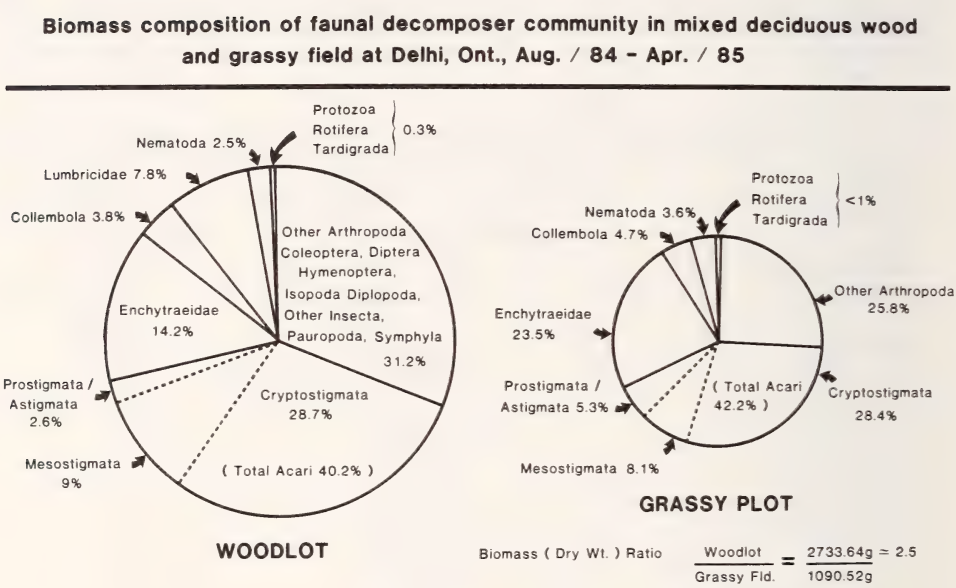

FIGURE 3. Comparative biomasses for different soil faunal taxa from forested and grassy plots at Delhi, Ontario. The areas of the circles are proportional to faunal biomass at each site (data from Tomlin and Miller 1987).

Soil fauna may also be active during winter under an insulating blanket of snow (Aitchison 1979). Litter comminution and mineralization of organic matter continues under these conditions, albeit at lower levels.

Little work has been done using soil fauna in models investigating stability-diversity relationships, and it could be a fruitful field for theoretical studies. Land use practices such as forest clearing and cultivation reduce the number of ecological niches in soil and, consequently, the variety of animal species that may live in such soils, because two different animal species may not occupy the same niche (Hardin 1960). Krebs (1978) summarizing Elton (1958) concluded that reductions in biotic diversity would result in less stable ecosystems. Conversely, May (1973) showed that increasing community complexity reduces stability in general mathematical models. However, May's models assumed random assemblages of interacting species, whereas natural communities, as products of evolution, may be non-random assemblages in which diversity and stability are related (Krebs 1978). Curry and Cunningham (1978), however, found no relation between faunal diversity and stability when comparing soils of permanent pastures and leys in Ireland.

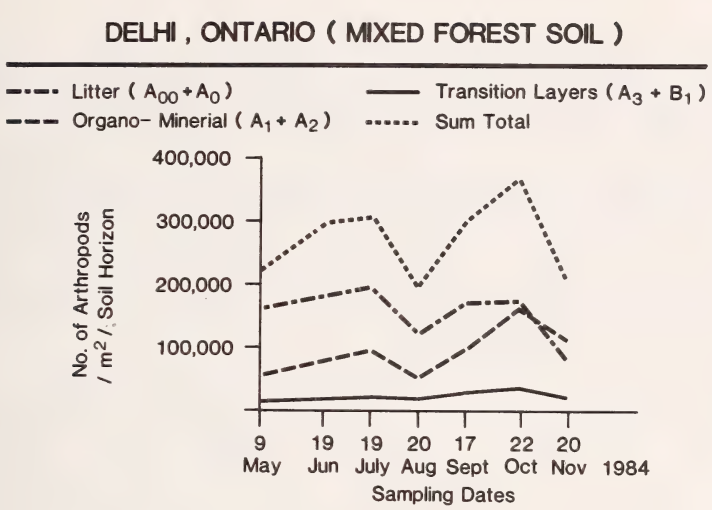

FIGURE 4. Seasonal abundance of soil arthropods in surface soil horizons at Delhi, Ontario; note the late spring and early autumn peaks.

Most Canadian soils are of relatively recent origin; the Laurentide ice sheet that overlaid most of Canada until about 12,000 years ago exterminated any indigenous soil fauna that existed here at the time the ice sheet last advanced, about 50,000 years ago. In fact, much of Canada has been glaciated for most of the Pleistocene (about 1,000,000 YBP). The presumption is that the fauna of Pleistocene-glaciated soils of Canada and Ontario followed the retreating glaciers northward from southern refugia in the lower 48 states of the present-day United States, and from the Beringian Refugium of present-day Alaska and Yukon (Matthews 1979). The mechanisms and rate of faunal reinvasion of soils following glacial retreat are not well understood, but should yield to analysis by laboratory and field experiments.

Recent Pleistocene glaciations exterminated most native earthworm populations in Canada (Reynolds 1977). Earthworms of Canadian soils are primarily exotic species that were imported either accidentally on plant rootstocks, or as soil ballast for wooden sailing ships, loaded in Europe and left on North American shores, in exchange for cargoes bound for Europe (Gates 1958). Settlers and farmers may have introduced worms intentionally, hoping to sustain or improve soil fertility. There is some evidence that greenhouse operations were a source of introduction and propagation of earthworms (Gates 1966), especially during the last century when there was little appreciation or control of soil and plant importations. We should also assume that a variety of other soil organisms such as arthropods, nematodes, fungi and bacteria also made their way from Old World biogeographic zones over the past few centuries by similar mechanisms. The invasion of the Americas by large epigeaic fauna was extensively reviewed by Crosby (1986), but the probable invasion of euedaphic fauna has usually passed without comment.

The dew worm (*Lumbricus terrestris* L.) has flourished over the last century or so, following its introduction into southwestern Ontario soils. Evidence of its increase is demonstrated by the fact that 1,000,000,000 or more worms (value about $50 million) are annually picked from Ontario soils between Oshawa and Windsor and exported to US bait

outlets to supply the sport fishing industry (Tomlin 1983). The effect of this earthworm species on soil structure and air and water infiltration is great because of its deep burrowing activity and mixing of soil horizons (Edwards and Lofty 1977).

Extraction methods and sampling considerations for soil fauna

The technical difficulties of working with the soil fauna involve the following: (1) most of its members are minute and require skilled microtechnique in order to view them efficiently, (2) soil is an opaque medium that does not usually allow direct viewing of animal and plant activity, and (3) both soil and its fauna are subject to great variability, even within small areas, that may confound analysis (Wallwork 1976).

Soil animals range in size from < .005 mm for the smallest protozoans to > 100 mm for the largest earthworms and molluscs (Fig. 5), and as a convenience, soil biologists frequently divide the soil fauna into three arbitrary size classes, microfauna (0.02 - 0.20 mm), mesofauna (0.20 - 10 mm), and macrofauna (> 10 mm) (Wallwork 1970).

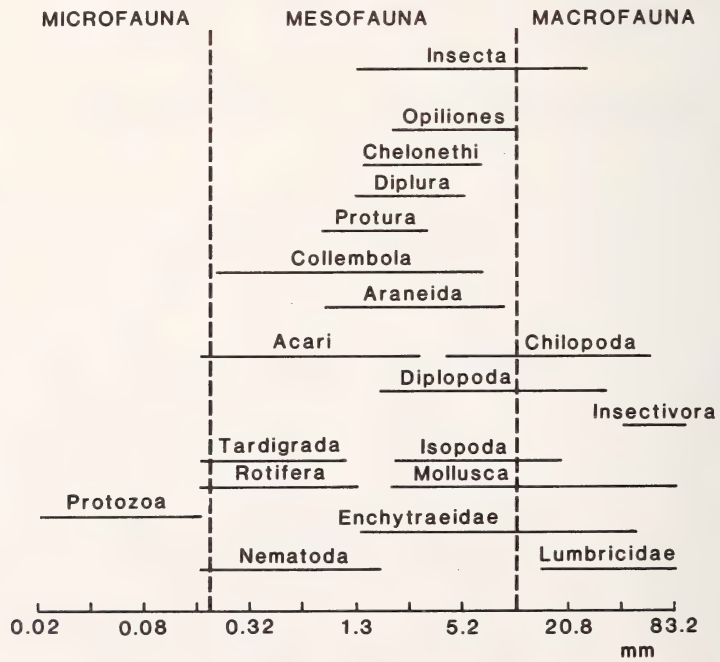

FIGURE 5. Size ranges of soil fauna in mm.; divisions into "micro", "meso", and "macro" are arbitrary (adapted from Wallwork 1970).

Adaptations of soil animals to dark, cool, moist conditions of the soil may be exploited to extract them from the soil by creating dry, bright, and hot conditions over a period of several days in a soil sample. This drives the ambulatory animals from the soil. Some of

these extraction systems are elaborate modifications of Berlese-Tullgren funnels (Edwards and Fletcher 1971), which are used for collecting large arrays of mites, springtails, centipedes, millipedes, pauropods, beetles, and other insects. In order to compare treatment effects with some degree of confidence, it is necessary to take at least 3 or 4 replicate soil samples from each treatment in order to obtain a measure of faunal variance. Soil fauna in temperate climates have pronounced activity maxima in spring and fall (Tomlin and Miller 1987); consequently, frequent sampling may be required during the course of a growing season to establish abundancy ranges for various taxa.

Wet funnel extractors (O'Connor 1971) collect soil animals such as Enchytraeidae, Nematoda, Tardigrada, and Rotifera from soil water films. Protozoa may be extracted by gently blending soil with water; their abundance may be estimated by counting numbers of protozoans from small volumes of the slurry smeared onto microscope slides (Smith *et al.* 1990).

Earthworms may be extracted by hand-sorting or use of a worm expellant such as formalin sprinkled onto the soil (Raw 1959).

Should a full survey of soil fauna be required for a particular site, all of these extraction techniques may have to be used concurrently, with sufficient soil samples taken from each site to provide enough material for all extractive methods. Faunal abundances of smaller animals may be converted to biomass by consulting tables collated from several sources and published by Petersen and Luxton (1982).

Effects of agricultural and land use practices

Cultivation

Agricultural practices that cause the greatest changes in soil faunal populations are deforestation followed by conventional tillage (Tomlin and Miller 1987; Winter *et al.* 1991). Ploughing on balance, has adverse effects (Wallwork 1976) that lead to reductions in population density and diversity by causing unstable microclimatic conditions and abrasive effects in the soil profile by removing protective leafy material and litter. Ploughing's beneficial effects on fauna derive from its mixing of mineral and surface organic matter, and improvement of aeration.

Continuous production of row crops using conventional tillage leads to a deterioration of soil structure that improves when forages are grown, but the rate of improvement under different crop rotations is unknown (Kay and Sheard 1988). Soil structure deterioration correlates with increases in continuous row cropping, and associated linear increases in use of nitrogen fertilizer. Soil in areas where small grains were cropped annually showed a loss of 38% of the organic matter in 40 years, and continuous corn cropping resulted in a loss of 25% of the organic matter after 20 years (Voroney 1988). Evidence exists that reduced tillage methods decrease the rate of organic matter mineralization and improves soil structure (Kay and Sheard 1988) caused, in part, by increased densities of soil fauna.

Shipitalo and Protz (1988) found that although soil macroporosity was greater in the Ap horizon (the plough layer) of conventionally-tilled plots than in the Ap horizon of a no-till soil, there were 2 to 9 times more biopores resulting from earthworm activity in the no-till soil. They found that the organic carbon content of the no-till soil was greater and distributed to a greater depth than in the conventionally ploughed soil after seven years, and that aged or dried earthworm casts (fecal pellets), under organic mulch, enhanced soil aggregate stability. Shipitalo *et al.* (1988) estimated that earthworms could ingest all the surface horizon within 3 to 4 years under optimal temperature, moisture and food conditions.

Agricultural chemicals

Fertilizer use on cultivated soils normally results in significantly higher densities of soil fauna especially with organic, but also with inorganic fertilizers (Edwards and Lofty 1969). Pesticides have measurable, but highly variable effects on soil faunal populations. Earthworms are highly susceptible to many insecticides (Thompson 1971), and even fungicides such as benomyl (Tomlin and Gore 1974). Insecticide applications can have detrimental effects on arthropod components of the soil fauna such as mites and springtails (Broadbent and Tomlin 1982). Extensive reviews of pesticidal effects on soil fauna are provided in Edwards and Thompson (1973), and Brown (1978).

Other land use effects on soil fauna

Large engineering projects involving earthmoving, paving, or flooding schemes presumably have catastrophic effects on soil biota. Compaction of soils by heavy machinery has detrimental effects on soil animal densities and diversity (Tomlin 1977), but the effect of one-time compaction is more pronounced in silt loam than clay soils in reducing faunal numbers (Aritajat *et al.* 1977a). However, faunal recovery was slower in clay soil than loam (Aritajat *et al.* 1977b).

Sustainable cropping systems

Earthworms and reduced tillage

Conventional agriculture is associated with over-production, decreased farm incomes, and increased costs of energy-based inputs. It has also produced ecological problems such as reduced diversity, soil and water pollution, and soil erosion (Edwards 1989). Integrated systems of lower input agriculture can alleviate these problems. Alternatives include conservation tillage, legume rotations, use of waste organic matter, integrated pest management (IPM), mulches, pest and disease forecasting, and biological and cultural pest control, intercropping, undersowing, trap crops, and double-row cropping. Earthworm densities are usually higher on no-till or reduced till systems than under conventional till (Ehlers 1975; St. Remy and Daynard 1982). The distribution of organic matter below the soil surface and soil aggregation are two processes that decrease the rate of mineralization of organic matter, and are enhanced by macrofaunal activity, especially earthworms (Oades 1989).

Doran (1980) concluded that the no-till soil ecosystem resembles that of undisturbed soil ecosystems. Surface levels of carbon, nitrogen and water are greater with no-till than with conventional till, but metabolic status is, on average, less oxidative. As in natural soil ecosystems, there is a gradual decomposition of plant residues controlled by soil fauna and microflora in no-till systems (House and Stinner 1987). Parmelee and Crossley (1988) showed that in no-till systems, 50% of harvested nitrogen has passed through an earthworm gut. Edwards and Fletcher (1988) adduced evidence that earthworms indirectly stimulate plant growth by interacting with microorganisms to provide available nutrients. Lavelle (1988) concluded that earthworm activity might be synchronized with other seasonal soil processes, such as plant growth and addition of organic matter to the soil, to influence soil microbial activity and soil physical structure.

Required research

An improvement in our ability to locate microorganisms and organic compounds *in situ* (Figs. 6-8) would make it possible to classify optimal microenvironments for specific soil processes even though technical difficulties remain (Foster, 1988). Coleman *et al.* (1988)

suggest that more basic research is needed to understand microfloral-microfaunal interactions within various soil ecosystems. Soil micromorphological methods using fluorescing dyes (Altemuller 1986) to identify soil organic matter have been refined to the point where these interactions could be observed and measured. Lysimeters and both conventional rhizotrons (Carpenter *et al.* 1985) and "mini-rhizotrons" (Upchurch and Ritchie 1984) could also be applied to study these interactions under field and laboratory conditions. It should be possible to manipulate soil faunal populations, especially earthworms, in order to manage critical soil processes such as air and water infiltration rates that strongly influence soil structure. Lynch (1988) suggests that in future we may wish to manage the flora and fauna of the rhizosphere to maximize crop production.

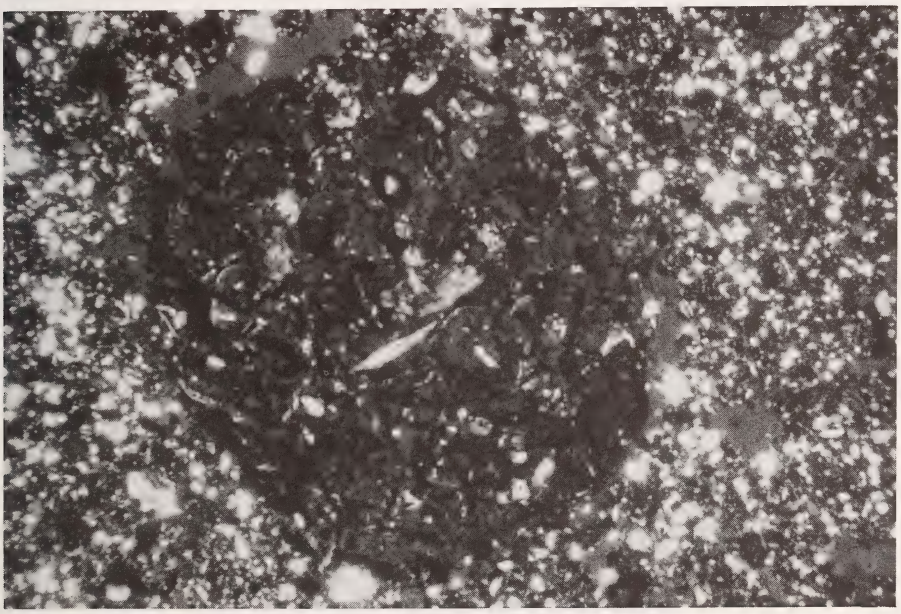

FIGURE 6. Resin-embedded soil thin section of organic fragments in earthworm fecal pellets within a subsurface soil horizon (Magnification: 40x).

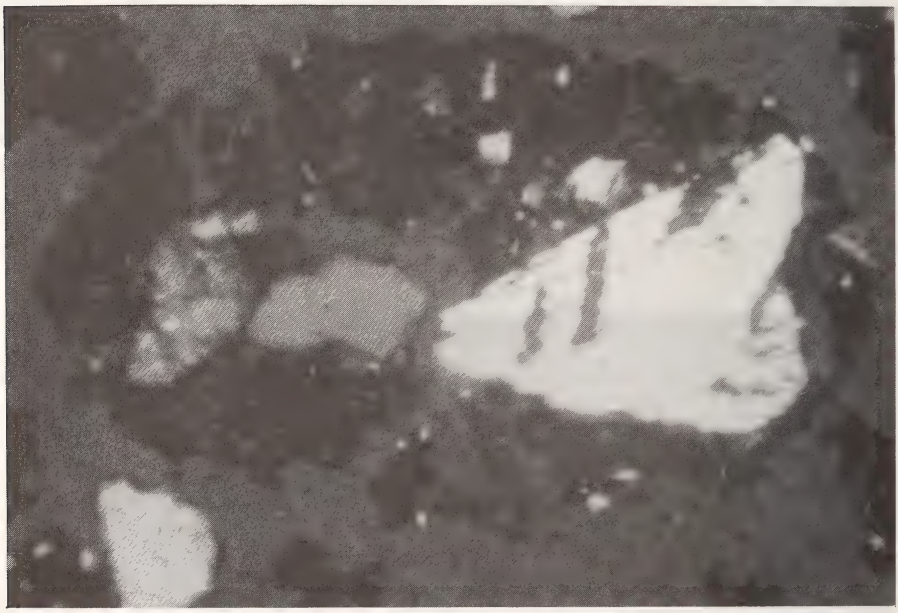

FIGURE 7. Resin-embedded soil thin section of mineral grain within an earthworm fecal pellet (Magnification: 120x).

Summary

Coleman and Hendrix (1988) point out that as human populations increase, greater demands will be placed on various ecosystems producing food and fibre, and in order for these systems to evolve into long-term or perpetually sustainable productive systems, human societies will require trans-disciplinary research in agriculture and basic sciences. McCabe *et al.* (1988) have proposed that a soil of best quality is a soil of maximum biological activity. To maintain maximum biological activity, cropping systems will have to be devised in which total production will be maximized, but utilization of organic matter produced will have to be shared amongst humans, plants and soil organisms.

Soil fauna, for many years ignored as a significant component of agroecosystems, is becoming recognized as an important influence on process-level dynamics of agroecosystems (Crossley *et al.* 1989). Recent research has focused on microbial-faunal interactions, and regulatory activity of the fauna. Other consequences of faunal activity include sub-surface herbivory, stimulation of plant growth, modulation of air and water infiltration rates, and direct effects of soil fauna on soil structure (*eg.* deposition of fecal pellets). Variables that integrate faunal influences on agroecosystem include decomposition and mineralization rates, primary production, and energy flow and nutrient cycling. The interactions of soil with other components of the biosphere on a planetary scale are among the major global questions of our time. The opportunities for extensive and fruitful inter-disciplinary research on soils amongst pedologists, chemists, biologists, agronomists and physicists to conserve and preserve this resource have never been better or the time more appropriate.

FIGURE 8. Resin-embedded soil thin section of fecal material of various soil animals within a subsurface soil horizon of coarse (sandy) texture (Magnification: 120x).

Acknowledgements

The authors acknowledge the assistance of G. Lambert and J.J. Miller.

References

Aitchison, C.W. 1979. Notes on low temperature activity of oligochaetes, gastropods and centipedes in Southern Canada. American Midland Naturalist, 102: 399-400.

Altemuller, H-J. 1986. Fluorescent light microscopy of soil/root interactions. Transactions XIII Congress International Society of Soil Scientists, Hamburg. pp. 1546-1547.

Aritajat, U., D.S. Madge, and P.T. Gooderham. 1977a. The effects of compaction of agricultural soils on soil fauna. II. Laboratory investigations. Pedobiologia, 17: 283-291.

Aritajat, U., D.S. Madge, and P.T. Gooderham. 1977b. The effects of compaction of agricultural soils on soil fauna I. Field investigations. Pedobiologia, 17: 262-282.

Bal, L. 1982. Zoological Ripening of Soils. Centre for Agricultural Publishing and Documentation, Wageningen. 365 pp.

Broadbent, A.B. and A.D. Tomlin. 1982. Comparison of two methods for assessing the effects of carbofuran on soil animal decomposers in cornfields. Environmental Entomology, 11: 1036-1042.

Brown, A.W.A. 1978. Ecology of Pesticides. John Wiley and Sons, New York. 525 pp.

Carpenter, A., J.M. Cherrett, J.B. Ford, M. Thomas, and E. Evans. 1985. An inexpensive rhizotron for research on soil and litter-living organisms. *In*: A.H. Fitter, D. Atkinson, D.J. Read, and M.B. Usher (Eds.). Ecological Interactions in Soil: Plants, Microbes and Animals. Blackwell Scientific Publications, Oxford. pp. 67-71.

Chapman, L.J. and D.F. Putnam. 1984. The Physiography of Southern Ontario. 3rd Ed. Ontario Geological Survey Special Vol. 2., Ontario Ministry of Natural Resources. 270 pp.

Christiansen, K. 1970. Experimental studies on the aggregation and dispersal of Collembola. Pedobiologia, 10: 180-198.

Coleman, D.C. and P.F. Hendrix. 1988. Agroecosystem processes. *In*: L.R. Pomeroy and J.J. Alberts (Eds). Concepts of Ecosystem Ecology (A comparative view), Springer-Verlag, New York.

Coleman, D.C., D.A. Crossley Jr., M.H. Beare, and P.F. Hendrix. 1988. Interactions of organisms at root/soil and litter/soil interfaces in terrestrial ecosystems. Agriculture, Ecosystems and Environment, 24: 117-134.

Crossley, D.A. Jr., D.C. Coleman, and P.F. Hendrix. 1989. The importance of the fauna in agricultural soils: research approaches and perspectives. Agriculture, Ecosystems and Environment, 27: 47-55.

Crosby, A.W. 1986. Ecological Imperialism: The Biological Expansion of Europe, 900-1900. Cambridge University Press, Cambridge, NY. 386 pp.

Curry, J.P. and C.A. Cunningham. 1978. A comparison of the epigeal arthropod fauna of old pasture and new leys of various floral types. Scientific Proceedings of the Royal Dublin Society, Series A, 6: 305-316.

Desender, K. and M. Vaneeschoutte. 1984. Phoretic associations of carabid beetles (Coleoptera, Carabidae) and mites (Acari). Revue d'Ecologie et de Biologie du Sol, 21: 363-371.

Doran, J.W. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Science Society of America Journal, 44: 765-771.

Edwards, C.A. 1969. Soil pollutants and soil animals. Scientific American, 220: 88-99.

Edwards, C.A. 1989. The importance of integration in sustainable agricultural systems. Agriculture, Ecosystems, and Environment, 27: 25-35.

Edwards, C.A. and K.E. Fletcher. 1971. A comparison of extraction methods for terrestrial arthropods. In: J. Phillipson (ed.). Methods of Study in Soil Ecology: Population, Production and Energy Flow. IBP Handbook 18. Blackwell Scientific Publications, Oxford. pp. 150-185.

Edwards, C.A. and K.E. Fletcher. 1988. Interactions between earthworms and microorganisms in organic matter breakdown. Agriculture, Ecosystems and Environment, 24: 235-247.

Edwards, C.A. and J.R. Lofty. 1969. The influence of agricultural practice on soil micro-arthropod populations. *In*: J.G. Sheals, (ed.). The Soil Ecosystem. Systematics Association London, Publication No. 8. pp. 237-247.

Edwards, C.A. and J.R. Lofty. 1977. Biology of Earthworms. 2nd ed. Chapman and Hall, London. 333 pp.

Edwards, C.A., D.E. Reichle, and D.A. Crossley Jr. 1970. The role of soil invertebrates in turnover of organic matter and nutrients. *In*: D.E. Reichle (ed.). Ecological Studies. Analysis and synthesis, Vol. 1. Springer-Verlag, Berlin. pp. 147-172.

Edwards, C.A. and A.R. Thompson. 1973. Pesticides and the soil fauna. Residue Reviews, 45: 1-79.

Ehlers, W. 1975. Observations on earthworm channels and infiltration on tilled and untilled loess soil. Soil Science, 119: 242-249.

Elton, C.S. 1958. The Ecology of Invasions by Animals and Plants. Methuen, London.

Foster, R.C. 1988. Microenvironments of soil microorganisms. Biology and Fertility of Soils, 6: 189-203.

Gates, G.E. 1958. On endemicity of earthworms in the British Isles with notes on nomenclature, taxonomy and biology (Oligochaeta: Lumbricidae). Annals and Magazine of Natural History, 13: 33-44.

Gates, G.E. 1966. Requiem - for megadrile utopias. A contribution toward the understanding of the earthworm fauna of North America. Proceeding of the Biological Society of Washington, 79: 239-254.

Haarlov, N. 1960. Microarthropods from Danish soils, ecology, phenology. Oikos, Supplementum 3: 1-176.

Hardin, G. 1960. The competitive exclusion principle. Science, 131: 1292-1297.

Hoffman, D.W., B.C. Matthews, and R.E. Wicklund. 1964. Soil Associations of Southern Ontario. Report No. 30 of the Ontario Soil Survey. Ontario Department of Agriculture, Toronto. 21 pp.

Holliday, N.J., A.D. Tomlin, and E.A.C. Hagley. 1982. Soil fauna of a pest-management apple orchard. Revue d'Ecologie et de Biologie du Sol, 19: 41-59.

House, G.J. and R.E. Stinner. 1987. Decomposition of plant residues in no-tillage agroecosystem: influence of litterbag mesh size and soil arthropods. Pedobiologia, 30: 351-360.

Jeffrey, D.W. 1987. Soil-Plant Relationships: An Ecological Approach. Croom Helm, London. 85 pp.

Joosse, E.N.G. 1971. Ecological aspects of aggregation in Collembola. Revue d'Ecologie et de Biologie du Sol, 8: 91-97.

Kay, B.D. and R.W. Sheard. 1988. Reversing trends: cropping systems to improve soil structure. Highlights, 11: 25-27.

Kevan, D.K.McE. (ed.). 1955. Soil Zoology. Butterworths Scientific Publications, London. 512 pp.

Krebs, C.J. 1978. Ecology: The Experimental Analysis of Distribution and Abundance. 2nd ed. Harper & Row, New York. pp. 504-505.

Kubiena, W.L. 1938. Micropedology. Collegiate Press, Inc., Ames, Iowa. 243 pp.

Kuhnelt, W. 1976. Soil Biology: With Special Reference to the Animal Kingdom. Faber and Faber, London. 483 pp. (English translation ofGerman edition published in 1950)

Lavelle, P. 1988. Earthworm activities and the soil system. Biology and Fertility of Soils, 6: 237-251.

Lloyd, M. 1963. Numerical observations on movements of animals between beech litter and fallen branches. Journal of Animal Ecology, 32: 157-163.

Lynch, J. 1988. Microbes are rooting for better crops. New Scientist, 28: 45-49.

Marshall, V.G., D.K.McE. Kevan, J.V. Matthews Jr., and A.D. Tomlin. 1982. Status and research needs of Canadian soil arthropods. Supplement to Bulletin of the Entomological Society of Canada, 14: 1-5.

Matthews, J.V. 1979. Tertiary and quarternary environments: historical background for an analysis of the Canadian insect fauna. *In*: H.V. Danks (eds.). Canada and Its Insect Fauna. Memoirs of the Entomological Society of Canada. No. 108. pp. 31-86.

May, R.M. 1973. Stability and Complexity in Model Ecosystems. Princeton University Press, Princeton, N.J. 235 pp.

McCabe, D.C., R. Protz, and A.D. Tomlin. 1988. Earthworm influence on soil quality in native sites of southern Ontario. Abstracts of Soil Science Society of America, Anaheim, California, Nov. 27 - Dec. 2, 1988. p. 281.

Mitchell, M.J. 1978. Vertical and horizontal distributions of oribatid mites (Acari: Cryptostigmata) in an aspen woodland soil. Ecology, 59: 516-525.

Moore, J.C. 1988. The influence of microarthropods on symbiotic and non-symbiotic mutualism in detrital-based below-ground food webs. Agriculture, Ecosystems and Environment, 24: 147-159.

Oades, J.M. 1989. An introduction to organic matter in mineral soils. *In*: J.B. Dixon and S.B. Weed (Eds.). Minerals in Soil Environments, 2nd Ed. Soil Science Society of America, Madison. pp. 89-159.

O'Connor, F.B. 1971. The Enchytraeidae. *In*: J. Phillipson (ed.). Methods of Study in Soil Ecology: Population, Production and Energy Flow. IBP Handbook 18. Blackwell Scientific Publications, Oxford. pp. 83-106.

Parmelee, R.W. and D.A. Crossley Jr. 1988. Earthworm production and role in the nitrogen cycle of a no-tillage ecosystem on the Georgia Piedmont. Pedobiologia, 32: 353-361.

Parr, T.W. 1978. An analysis of soil micro-arthropod succession. Scientific Proceedings of the Royal Dublin Society, Series A, 6: 185-196.

Pawluk, S. 1985. Soil micromorphology and soil fauna: problems and importance. Quaestiones Entomologicae, 21: 473-496.

Petersen, H. and M. Luxton. 1982. Quantitative ecology of microfungi and animals in soil and litter. Oikos, 39: 287-388.

Price, D.W. 1973. Abundance and vertical distribution of microarthropods in the surface layers of a California pine forest soil. Hilgardia, 42: 121-147.

Raw, F. 1959. Estimating earthworm populations by using formalin. Nature, 184: 1661-1662.

Reichle, D.E. 1977. The role of soil invertebrates in nutrient cycling. *In*: U. Lohm and T. Persson (eds.). Soil organisms as components of ecosystems. Ecological Bulletin, 25: 145-156.

Reynolds, J.W. 1977. The Earthworms (Lumbricidae and Sparganophilidae) of Ontario. Life Sciences Miscellaneous Publication of the Royal Ontario Museum. 141 pp.

Ruddiman, W.F. and H.E. Wright Jr. 1987. North America and Adjacent Oceans During the Last Deglaciation. The Geology of North America, Vol. 3. Geological Society of America, Inc., Boulder, Colorado. p. 501.

Rusek, J. 1985. Soil microstructures - contributions on specific soil organisms. Quaestiones Entomologicae, 21: 497-514.

Russell, E.J. 1950. Soil Conditions and Plant Growth. 8th ed. revised by E.W. Russell. Longmans, London. pp. 169-171.

Schaller, F. 1968. Soil Animals. The University of Michigan Press, Ann Arbor. 144 pp.

Shipitalo, M.J. and R. Protz. 1988. Factors influencing the dispersibility of clay in worm casts. Soil Science Society of America Journal, 52: 764-769.

Shipitalo, M.J., R. Protz, and A.D. Tomlin. 1988. Effect of diet on the feeding and casting activity of *Lumbricus terrestris* and *L. rubellus* in laboratory culture. Soil Biology and Biochemistry, 20: 233-237.

Smith, C.A.S., A.D. Tomlin, J.J. Miller, L.V. Moore, M.J. Tynen, and K.A. Coates. 1990. Large enchytraeid (Annelida: Oligochaeta) worms and associated fauna from unglaciated soils of the northern Yukon, Canada. Geoderma, 47: 17-32.

St. Remy, E.A. de and T.B. Daynard. 1982. Effects of tillage methods on earthworm populations in monoculture corn. Canadian Journal of Soil Science, 62: 699-703.

Thompson, A.R. 1971. Effects of nine insecticides on the numbers of earthworms and biomass of earthworms in pasture. Bulletin of Environmental Contamination and Toxicology, 5: 577-586.

Tomlin, A.D. 1977. Pipeline construction - impact on soil micro- and mesofauna (Arthropoda and Annelida) in Ontario. Proceedings of the Entomological Society of Ontario, 108: 13-18.

Tomlin, A.D. 1983. The earthworm bait market in North America. *In*: J.E. Satchell (ed.). Earthworm Ecology: From Darwin to Vermiculture. Chapman and Hall, London. pp. 331-338.

Tomlin, A.D. and F.L. Gore. 1974. Effects of six insecticides and a fungicide on the numbers and biomass of earthworms in pasture. Bulletin of Environmental Contamination and Toxicology, 12: 487-492.

Tomlin, A.D. and J.J. Miller. 1981. "Dauer" stage nematodes phoretic upon several arthropod species. Proceedings of the Entomological Society of Ontario, 112: 41-43.

Tomlin, A.D. and J.J. Miller. 1987. Composition of the soil fauna in forested and grassy plots at Delhi, Ontario. Canadian Journal of Zoology, 65: 3048-3055.

Upchurch, D.R. and J.T. Ritchie. 1984. Battery-operated color video camera for root observations in mini-rhizotrons. Agrononomy Journal, 76: 1015-1017.

Usher, M.B. 1976. Aggregation responses of soil arthropods in relation to the soil environment. *In*: R.M. Anderson and A. Macfadyen (eds.). The Role of Terrestrial and Aquatic Organisms in Decomposition Processes. Blackwell Scientific Publications, Oxford. pp. 61-94.

Voroney, R.P. 1988. Loss of organic matter in Ontario soils. Highlights, 11: 25-29.

Wallwork, J.A. 1970. Ecology of Soil Animals. McGraw-Hill, London. 283 pp.

Wallwork, J.A. 1976. The Distribution and Diversity of Soil Fauna. Academic Press, London. 355 pp.

Winter, J.P., R.P. Voroney, and D.A. Ainsworth. 1991. Soil microarthropods in no-till corn production. Canadian Journal of Soil Science (in press).

POLLINATION: A CRUCIAL ECOLOGICAL AND MUTUALISTIC LINK IN AGROFORESTRY AND SUSTAINABLE AGRICULTURE

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Proc. ent. Soc. Ont. 121:43-48

Pollination is the movement of pollen from floral anthers to floral stigmata. Although pollination is a relatively simple natural process, it is complicated by the many ways in which it may come about and crucial because of its consequences. Whether pollination between individual plants is required, as in species which are obligately out-crossing (allogamous), or takes place within individual plants (often within the same flower), as in self-pollinating species (geitonogamous and autogamous), it is the event which leads to the union of sperm cells from the pollen with cells in the plants' ovaries. After fertilization, the ovules and associated tissues develop, eventually to produce fruits with seeds; the initiators of the next generation of plants. There are higher plants which reproduce asexually by seeds or vegetative means and pollination is not required, but these reproductive strategies are specialized (see Richards 1986 for a recent review of plant breeding systems).

The process of pollination is believed to be basic to the evolutionary history of flowering plants, spanning at least 135 million years (Crepet 1983). The co-evolutionary processes involving first insects, then later birds, bats, and other mammals, in pollination, link inextricably the world's biomass of plants and animals. Proctor and Yeo (1973), Faegri and van der Pijl (1979), Kevan and Baker (1983, 1984), Meeuse and Morris (1984) and Barth (1985) provide the principles, theory, and examples of the intricate workings of pollination relationships. The length history of the mutualism of animal pollination and flowering plants has resulted in amazing diversity. There is a range of relationships from the extremely precise of one pollinating species for one species of plants, to generalist associations of pollinators which visit the flowers of many species of plants, and plants which may be pollinated by almost any flower visitor, including the wind. Clearly, the more precise pollination relationships are more vulnerable to disruption than the more general, even though the system of pollination in its totality seems well buffered. However, even the most well buffered systems can tolerate only so much disturbance, such as the effects of bioaccumulation of pesticides in food chains and of acid precipitation on forests attest.

It is generally accepted that the deterioration of the diversity and abundance of the world's biota is proceeding at an unprecedented rate and represents a moral, scientific, and economic tragedy (Wilson 1989). Pollination relationships contribute to the diversity and abundance of life on earth through the vital interchange of genetic and informational material (pollen and gene movement by pollinators, and sustenance in the form of nectar and pollen for the latter) and reproductive success of pollinators and their plants. The processes are not limited to the natural environment, they are an integral part of agricultural productivity as well (Free 1970; McGregor 1976). Human concerns in pollination run the gamut from conservation of natural ecosystem (Kevan 1975, 1990) through to productivity in the most highly intensive agriculture (Kevan 1990), such as hydroponically grown tomatoes (Banda

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and Paxton 1990; Welles and van Ravestijn 1990). For agriculture the value of insect pollinated crops was estimated at $20 billion for the U.S.A. (Levin 1983) and $1.2 billion for Canada (Winston and Scott 1984). The value of animal pollination to world agriculture has not been estimated, and to overall global productivity is inestimable.

That pollination systems are under global threat is not generally recognized, despite examples of their deterioration from various causes in widely separated parts of the world (Kevan and Baker 1983). Kevan *et al.* (1990) have introduced the concern from the viewpoint of sustainable agricultural productivity and the increasing recognition that many, current, high-input agricultural practices are, in the long run, destructive (see also Clark 1989; Crosson and Rosenberg 1989; Ruckelhaus 1989).

The diversity of pollinators in natural ecosystems ranges from lowly springtails (Collembola) to the most advanced of insects, the bees and specialized birds, bats, marsupials and other mammals. In agriculture in temperate regions, the European honeybee (*Apis mellifera*) is the most important pollinator (Free 1970; McGregor 1976; Jay 1986), but other bees are advocated and are better pollinators for some crops, e.g. alfalfa, blueberries, orchard fruits (Torchio 1987; Parker *et al.* 1987). Less well-known are the special pollination relationships of midges (Diptera: Ceratopogonidae) and cacao; weevils (Coleoptera: Curculionidae: *Elaeidobius*) and oil palm; bats and durian; and others (Kevan 1984). Even in northeastern North America there have been about 190 species of pollinators associated with low-bush blueberry flowers (Finnamore and Neary 1977). Free (1970) and McGregor (1976) list about 150 species of animal pollinated crop plants for the world. Their lists are becomingly increasingly incomplete as more information on new varieties of crop plants and newly recognized crop plants becomes available. The level of knowledge of the pollination requirements of tropical plants, from crops to natural vegetation, is sadly lacking (Kevan 1984).

The demise of pollinators has been caused by three major factors: 1) Pesticides, 2) Destruction of habitat, and 3) Diseases.

The dangers associated with pesticides and pollinators are well understood (Johansen 1977; NRCC 1981). Most problems arise from accidents, carelessness in application, ignorance or failure to recognize the consequences of application, and deliberate misuse in the face of label warnings or recommendations. In the perspective of agroforestry, the use of Fenitrothion to attempt control of spruce budworm in the forest of New Brunswick in the vicinity of commercial blueberry fields illustrates the problem. Fenitrothion, a substitute for DDT, has been known (since its registration for use in Canada) to be highly toxic to bees and it should not be used in the vicinity of blooming crop. Thus, its detrimental effect on blueberry pollination, which occurs at the time of the budworm spray programme, should have been predicted. The demise of the pollinator populations and diversity, together with the decline in blueberry crop (0.67 million kg/yr) has been documented by Kevan and Plowright (1989) and resulted in a landmark legal settlement for the blueberry growers (who sued) and environmental law. At the same time, Plowright and his co-workers showed the demise of native pollinators in the forest ecosystem as it was sprayed with Fenitrothion (see Kevan and Plowright 1989). Since the litigation, and a change in pesticide which could be used around blueberry fields, populations of native pollinators have recovered.

The extent to which pollinator populations are held at low levels by chronic applications of pesticides is unknown and has been of little concern until recently (Kevan *et al.* 1990).

Habitat destruction may take three forms: a) the destruction of nesting sites; b) the destruction of pollinators' food sources; and c) the destruction of sites for mating or special behaviour. The removal of hedgerows, and other features which contribute to environmental heterogeneity, in Europe has been suggested to have caused a large reduced in the populations of bumblebees (Peters 1972; Williams 1986). Similarly, the expansion of alfalfa fields in the Canadian prairies has been documented to be followed by a decline in the availability of native pollinators for the crop (Stephen 1955). In cacao plantations, the fastidious removal of rotting vegetation resulted in crop reductions because of the lack of

larval habitat for pollinating midges (Winder 1977). These, and other examples, are discussed in Kevan *et al.* (1990).

Less well known is the effect of the destruction of pollinator forage. That has been brought about by the reduction in the diversity of vegetation in agricultural settings through monoculture, herbicides, and removal of habitat. Sometimes plants which provide alternative sources of food to pollinators are seen as competitors for pollinators' attentions and are removed (Free 1968; Crane 1981). These effects have recently combined to cause considerable concern amongst lowbush blueberry growers in Main, U.S.A. The use of the herbicide, Velpar, on blueberry lands controls unwanted plants well. However, the blueberry pollinators require alternative sources of flora food when the blueberries are not in bloom. Velpar, and other management practices, seem to have reduced the amount of alternative forage for the pollinators to such an extent that their populations are in decline (Osgood, personal communication). The extent to which this sort of process may have affected other pollinator populations serving other crop plants is not known, but has been suggested to apply to orchard fruit, cranberries, and possibly others (Kevan *et al.* 1990).

The destruction of mating sites and other special sites for pollinators has been recognized as a potential threat to some species only recently, and firm examples are not available. The concern is especially great for pollinators which mate in the flowers of rare or endangered species of plants or which have special, highly localized resting sites (Torchio, personal communication).

The destruction of pollinators' habitats has come about because of errors in management practices and then overlooked because of the general lack of appreciation of the importance of pollinators other than honeybees.

Diseases of honeybees and their effect on pollination has evoked major concern since the recent introduction into North America of two mites, the tracheal mite (*Acarapis woodi*) and *Varroa jacobsoni*, which are parasitic on honeybees (see Needham *et al.* 1988). Kevan (1989) and Kevan *et al.* (1990) have placed the issues into the context of pollination in agricultural settings. They have noted that both diseases, which cause the bees and colonies to weaken and eventually die, are highly detrimental to European honeybees in North America, and are costly to control with the chemicals available. They suggest that many amateur beekeepers may abandon their hobby because of the greater intensity of management and watchfulness that will be required to maintain healthy colonies. For some beekeepers, the use of the chemicals may be unacceptable. In South and Central America, the effects of the invasion of Africanized bees have had a negative impact on beekeeping. Their effects on pollination are not understood and have been hardly studies (Roubik 1988). Although it is not expected that these highly defensive bees will enter Canada, their impact in the southern U.S.A. may be serious.

Because crop pollination in much of the temperate world (North American, Europe, and Asia) comes about by the widespread availability of domesticated honeybees, a change in the demography of beekeeping will affect crop production. It seems logical to propose that crop pollination will assume a different face in the future. Professional beekeepers may become, more and more, the providers of pollination services for fees (Kevan 1989). The potential for the use of alternative pollinators to service crops must be recognized so that research and development programmes can be initiated. And, native pollinators, together with their habitats and requirements, must be valued and studied towards encouraging their populations (Kevan *et al.* 1990; Kevan 1990).

In summary, it is clear that both agriculture and nature require pollination services. Problems exist in natural systems as a result of human interference with chemicals and habitat destruction. The European honeybee may not continue to provide the consistency and intensity of pollination required for agricultural crops. The mite diseases and the inexorable spread of the Africanized bees (Needham *et al.* 1988) will have profound effects on North American beekeeping. In addition, too little is known about the ecology of all but

a very few non-honeybee pollinators to provide for a manageable, alternative pollinator force at present.

Sustainable agriculture and agroforestry offer opportunity for attempting to solve some of the problems. Habitat destruction can be avoided easily, and habitats for some pollinators could be augmented as their requirements become better known. Hedgerows, windbreaks, and patches of fallow land and natural areas provide good habitat for nesting and foraging by beneficial insects, including pollinators (Kevan *et al.* 1990).

For agriculture as a whole, the diversification of pollinator assemblages for crops is clearly important. The value of the alfalfa leafcutting bee (*Megachile rotundata*) as a better pollinator than the honeybee for alfalfa has been clearly demonstrated (Richards 1984; Agriculture Canada 1989). Similarly, the alkali bee (*Nomia melanderi*) out-performs the honeybee in pollinating alfalfa in parts of the western U.S.A. (Torchio 1987). The value of orchard bees (*Osmia* spp.) is well known in Japan, but they have not received the attention they deserve in North America. Recently, blueberry bees (*Osmia ribifloris*) have been shown to have great potential (Torchio 1990a,b). Specialized pollinators of sunflowers (Parker and Frohlich 1985) and squash (Kevan *et al.* 1988) have also been studied. The value of bumblebees (*Bombus* spp.) for red clover seed production if well known (see Free 1970; Plowright and Laverty 1987), and interest in their culture and encouragement is expanding to other crops, including greenhouse tomatoes (van den Eijnde *et al.* 1990; Banda and Paxton 1990; Welles and van Ravestijn 1990). Other examples are discussed by Parker *et al.* (1987). Even in the tropics progress has been made in encouraging and diversifying pollinator populations and assemblages for particular crops (e.g. oil palm (PORIM 1985), cacao (Ismail and Ibrahim 1986), and passion fruit (Mardan *et al.* 1990)).

All the above strongly suggests that much can be done to avert a potential crisis in agricultural production brought about by pollinator problems. The issue has been recognized in Canada (Agriculture Canada 1989) but the fiscal will to address it with research and development at a level commensurate with the value of pollination seems lacking.

Pollination represents a biotic mutualism basic to the fauna and flora of earth. It ranks with seed dispersal by animals, the role of mycorrhizae in plant nutrition, the importance of nitrifying bacteria and legumes, and the role of soil organisms in soil fertility, aeration, and health. Sustainable agriculture also recognizes the mutualism of human-beings and the land use. It is the modern view of enlightened land stewardship and conservation based on a synthetic, holistic, and ecological approach. Pollination is one of several crucial ecological and evolutionary links in sustaining life as we know it. As such, it must be appreciated and nurtured.

References

Agriculture Canada. 1989. National workshop on bee and pollination research. Research Branch, Agriculture Canada, Ottawa.

Banda, H. and R. Paxton. 1990. Pollination of greenhouse tomatoes by bees. Programme and Summaries, The Sixth International Symposium on Pollination, August 27-31, 1990, Tilburg, Netherlands. p. 36 and Acta Horticulturae, (in press).

Barth, F.G. 1985. Insects and Flowers. The Biology of a Partnership. (Translated by M.A. Biederman-Thorson). Princeton University Press, Princeton, N.J. 297 pp.

Clark, W.C. 1989. Managing planet earth. Scientific American, 261(3): 46-54.

Crane, E. 1981. When important honey plants are invasive weeds. Bee World, 62: 28-30.

Crepet, W.L. 1983. The role of insect pollination in the evolution of angiosperms. *In*: L. Real (Eds.), Pollination Biology. Academic Press, Inc., New York. pp. 31-50.

Crosson, P.R. and N.J. Rosenberg. 1989. Strategies for agriculture. Scientific American, 261(3): 128-135.

Eijnde, J. van den, A. de Ruijter, and S. van der Steen. 1990. Method for rearing *Bombus terrestris* continuously and the production of bumblebee colonies for pollination purposes. Programme and Summaries, The Sixth International Symposium on Pollination, August 27-31, Tilburg, Netherlands. p. 25.

Faegri, K. and L. van der Pijl. 1979. The Principles of Pollination Ecology. 3rd Edition. Pergamon Press, London.

Finnamore, A.T. and M.E. Neary. 1977. Blueberry pollinators of Nova Scotia, with a checklist of the blueberry pollinators in Eastern Canada and Northeastern United States. Annales Societe Entomologique de Quebec, 23: 168-181.

Free, J.B. 1968. Dandelion as a competitor to fruit trees for bee visits. Journal of Applied Ecology, 5: 134-144.

Free, J.B. 1970. Insect Pollination of Crops. Academic Press, London. 544 pp.

Ismail, A. and A.G. Ibrahim. 1986. The potential of ceratopogonid midges as insect pollinators of cocoa in Malaysia. *In*: M.Y. Hussein and A.G. Ibrahim (Eds.). Biological Control in the Tropics. Universiti Pertanian Malaysia, Serdang, Selangor, Malaysia. pp. 471-484.

Jay, S.C. 1986. Spatial management of honeybees on crops. Annual Review of Entomology, 31: 49-66.

Johansen, C.A. 1977. Pesticides and pollinators. Annual Review of Entomology, 22: 177-192.

Kevan, P.G. 1975. Pollination and environmental conservation. Environmental Conservation, 2: 293-298.

Kevan, P.G. 1984. Insect pollination of economically important plants of tropical and sub-tropical Asia. Proceedings of the Expert Consultation on Beekeeping with *Apis mellifera* in Tropical and Sub-tropical Asia. Food and Agriculture Organization, Rome, Italy. pp. 77-85.

Kevan, P.G. 1989. Beekeeping and pollination at the cross-roads. Canadian Beekeeping, 14: 228-229.

Kevan, P.G. 1990. Pollination: A keystone process in global productivity. Programme and Summaries, The Sixth International Symposium on Pollination, August 27-31, 1990, Tilburg, Netherlands. p. 20 and Acta Horticulturae, (in press).

Kevan, P.G. and H.G. Baker. 1983. Insects as flower visitors and pollinators. Annual Review of Entomology, 28: 407-453.

Kevan, P.G. and H.G. Baker. 1984. Insects on flowers. *In*: C. Huffaker and R.L. Rabb (Eds.). Ecological Entomology. John Wiley, Inc., New York. Chapter 20.

Kevan, P.G., E.A. Clark, and V.G. Thomas. 1990. Insect pollinators and sustainable agriculture. American Journal of Alternative Agriculture, 5: 13-22.

Kevan, P.G., N.A. Mohr, M.D. Offer, and J.R. Kemp. 1988. The squash and gourd bee, *Peponapis pruinosa* (Hymenoptera: Anthophoridae) in Ontario, Canada. Proceedings of the Entomological Society of Ontario, 119: 8-15.

Kevan, P.G. and R.C. Plowright. 1989. Fenitrothion and insect pollinators. *In*: W.R. Ernst, P.A. Pearce, and T.C. Polluck (Eds.). Environmental Effects of Fenitrothion Use in Forestry. Environment Canada, Dartmouth, N.S. pp. 13-42.

Levin, M.D. 1983. Value of bee pollination to U.S. agriculture. Bulletin of the Entomological Society of America, 29: 50-51.

Mardan, M., I.M. Yatim, and M.R. Khalid. 1990. Nesting biology and foraging activity of carpenter bee (*Platynopoda latipes* Drury) on passion fruit (*Passiflora edulis flavicarpa*) in Malaysia. Supplemental Summaries. The Sixth International Symposium on Pollination, August 27-31, 1990, Tilburg, Netherlands. p. 1.

McGregor, S.E. 1976. Insect Pollination of Cultivated Crop Plants. United States Department of Agriculture, Agriculture Handbook No. 496. Washington. 411 pp.

Meeuse, B. and S. Morris. 1984. The Sex Life of Flowers. Facts on File Publications, New York. 152 pp.

Needham, G.R., R.E. Page, M. Delfinado-Baker, and C.E. Bowman (Editors). 1988. Africanized Honey bees and Bee Mites. Ellis Horwood Ltd., Chichester.

NRCC. 1981. Pesticide-Pollinator Interactions. National Research Council of Canada. Publication No. 18471. Ottawa. 190 pp.

Parker, F.D., S.W.T. Batra, and V.J. Tepedino. 1987. New pollinators for our crops. Agricultural Zoology Reviews, 2: 279-304.

Parker, F.D. and D.R. Frohlich. 1985. Studies on the management of the sunflower leafcutter bee *Eumegachile pugnata* (Say) (Hymenoptera: Megachilidae). Journal of Apicultural Research, 24: 125-131.

Peters, G. 1972. Causes of the decline of rare bumble bee species (Hum., *Bombus* and *Psithyrus*). Entomologische Berichte, 1972: 85-90.

Plowright, R.C. and T.M. Laverty. 1987. Bumble bees and crop pollination in Ontario. Proceedings of the Entomological Society of Ontario, 118: 155-160.

PORIM. 1985. Proceedings of the Symposium on Impact of the Pollinating Weevil on the Malaysian Oil Palm Industry, 21-22 February, 1984. Palm Oil Research Institute of Malaysia, Kuala Lumpur, Malaysia. 376 pp.

Proctor, M.C.F. and P.F. Yeo. 1973. The Pollination of Flowers. Collins, London.

Richards, A.J. 1986. Plant Breeding Systems. George Allen & Unwin, London. 529 pp.

Richards, K.W. 1984. Alfalfa leafcutter bee management in Western Canada. Agriculture Canada Publication No. 1495/E. 51 pp.

Roubik, D.W. 1988. An overview of Africanized honey-bee populations: reproduction, diet, and competition. *In*: G.R. Needham, R.E. Page, M. Delfinado-Baker, and C.E. Bowman (Eds.). Africanized Honey Bees and Bee Mites. Ellis Horwood Ltd., Chichester. pp. 45-54.

Ruckelhaus, W.D. 1989. Toward a sustainable world. Scientific American, 261(3): 166-174.

Stephen, W.P. 1955. Alfalfa pollination in Manitoba. Journal of Economic Entomology, 48: 543-548.

Torchio, P.F. 1987. Use of non-honey bee species as pollinators of crops. Proceedings of the Entomological Society of Ontario, 118: 111-124.

Torchio, P.F. 1990a. *Osmia ribifloris*, a native bee species developed as a commercially managed pollinator of highbush blueberry. Journal of the Kansas Entomological Society, (in press).

Torchio, P.F. 1990b. Diversification of pollination strategies for U.S. crops. Environmental Entomology, (in press).

Welles, G. and W. van Ravestijn. 1990. Use of bumble bees for the pollination of glasshouse tomatoes. Programme and Summaries, The Sixth International Symposium on Pollination, August 27-31, 1990, Tilburg, Netherlands. p. 37 and Acta Horticulturae, (in press).

Williams, P.H. 1986. Environmental change and the distribution of British bumble bees (*Bombus* Latr.). Bee World, 67: 50-61.

Wilson, E.O. 1989. Threats to biodiversity. Scientific American, 261(3): 108-116.

Winder, J.A. 1977. Some organic substrates which serve as insect breeding sites in Bahian cocoa plantations. Revista Brasileira de Biologia, 37: 125-131.

Winston, M.L. and C.D. Scott. 1984. The value of bee pollination to Canadian apiculture. Canadian Beekeeping, 11: 134.

THE GREENING OF THE FOREST: FOREST PEST MANAGEMENT INTO THE 21ST CENTURY

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Proc. ent. Soc. Ont. 121:49-59

Introduction

Canada's forest land represents almost 45% of the land base in this country and nearly 8% of the world's volume in forest resources. Approximately 1 in 10 jobs in this country are related, either directly (1 in 15) or indirectly, to the forest sector (Anonymous 1990). Timber products alone account for 18% of Canada's total exports (our single largest earner of foreign exchange). In addition, the complex ecosystems of Canadian forests are extremely important to tourism, an industry expanding at 17% per year, as well as through a variety of ecological processes including, watershed stability, water and air quality protection, and maintenance of a diverse pool for genetic resources and habitat (Anonymous 1990). The forests also represent an important source of public pride and beauty for Canadians.

The very nature of forest growth and production implies the need for sustainability. The Canadian Institute of Forestry has defined sustainable forest land management as **"Management which ensures that the use of any forest resource is biologically sustainable, and will not impair the biolcgical diversity or the use of the same land base for any other forest resource in the future"** (Anonymous 1990). Foresters have been trained for years in the concept of "sustained yield". This concept has meant maintaining a continuous supply of wood from the forest for an infinite number of harvests or rotations. Thus, it seems that foresters have always planted trees which will be harvested by their children and grandchildren. What has changed in recent years in Canada is the opportunity to put the concept of sustained yield into practice and the expansion of its definition to include multiple use objectives that go beyond the economic objectives of harvesting.

The following is an overview of management practices used to reduce the impact of feeding by forest insects. It is one component in the broader context of forest pest management which fits into a holistic approach to forest management. This review is an attempt to establish our current position or perspective on insect management in the forest, as well as identify our most likely directions in the future. In doing this, I have chosen to discuss, in sequence; the forests, the insect pests, the problems, and the solutions which are now part of forest pest management.

The Forests

Unlike the United States, Canadians own over 80% of their forested land. This land base is held by the provincial and federal governments in large tracts of Crown land. In most of these areas, we have two types of forests. First, the old, mature forests which we inherited from our parents and grandparents. In most cases, these stands were a result of natural succession from environmental conditions or events outside our control, eg. fire, wind storms, shifts in local water tables. In other cases, they resulted from human intervention, by manipulations of either aboriginal or immigrant peoples, eg. clearing or burning of the land for agricultural settlements, use for buildings and furniture. By the 1800's, a combination of these events produced relatively continuous areas of uniform forest types

(Great Lakes-St. Lawrence and Boreal forested areas) over large parts of Canada. Natural mortality and human utilization in these stands over the past 190 years has undoubtedly led to a more diverse mixture of tree species and ages than the original events might have produced. The national and provincial park systems in Ontario typify these mature forest types.

The second type of Canadian forest, and the one which will become increasingly more important, is the new forest. This type of forest has been established within the last 20-30 years and is currently being planted at a rate of ca. 100 million trees per year in each of our provinces. Although these forests will naturally age and become old forests, by definition, they will continue to be characterized by intensive forest management activities (seeding, fertilizing, thinning, and protection) which ensure a future supply of forest resources. These new forests are comprised of relatively large tracts of even-aged trees, usually planted as monocultures. Depending on the degree of past tending (removal of herbaceous or woody vegetation which competes with the crop tree), these plantations may or may not continue as strict monocultures.

The new forests have several specific uses, aside from direct timber or wood production. These may include areas for cone and seed production, nursery operations for seedling or ornamental and Christmas tree production, food or nut crops, energy biomass production, wildlife management, high use recreation, and watershed management. The new forests may also include urban treed areas which are being enhanced to improve the quality of life in cosmopolitan centres where the vast majority of Canadians now work and live.

Today, because a large part of the forest belongs to the public, both the old and new forest types are being put under increasing pressure to meet the demands of a variety of end uses for production and recreation. Although sometimes difficult to implement because of conflicting views, foresters have always considered this concept of "multiple use" in their planning objectives on forested land. Unfortunately, the employers of these foresters did not always share their broad concerns for sustained forest management, being side-tracked by short-term economic and political gains. Hopefully, the increased public pressure which has arisen with the environmental movement of the 1970's and 1980's will improve the opportunities of foresters to manage true multiple use forests for the benefit of all.

The Pests

In Canada, there are several key insects that feed on forest trees, causing levels of damage which are unacceptable in the sustained management of the forests. To some extent, old and new forests have similar pest species, however, for the purposes of the present discussion, I will separate insect pests which have been recently described or which are found only in high production stands from those occurring in mature natural growth forests.

In old forests, key pest insects include western species such as the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, the spruce beetle, *D. rufipennis* (Kirby), ambrosia beetles (Xylomycetophagus Scolytidae), the Douglas fir tussock moth, *Orgyia pseudotsugata* (McDunnough), the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst), and the western spruce budworm, *Choristoneura occidentalis* Freeman. In Eastern Canada, the vast majority of the insects that damage old forested areas are defoliators, including the eastern spruce budworm, *Choristoneura fumiferana* (Clemens), the jack pine budworm, *Choristoneura pinus pinus* Freeman, the hemlock looper, *Lambdina fiscellaria fiscellaria* (Guenee), the forest tent caterpillar, *Malacosoma disstria* (Hubner), and the gypsy moth, *Lymantria dispar* (Linnaeus). Most of these species experience dramatic changes in population density over varying periods of time, thus, reaching outbreak levels at regular intervals. Cerambycid species such as the whitespotted pine sawyer, *Monochamus scutellatus* (Say), are a problem in logging areas and some of the bark beetles such as the European elm bark beetle, *Scolytus multistriatus* (Marsham), also damage the wood directly. Both of

these species are major vectors of disease pathogens which ultimately kill mature trees; Dutch elm disease (*Ophistosoma ulmi* (Buisman) C. Moreau) by the bark beetle and the pinewood nematode (*Bursaphelenchus xylophilus* (Steiner and Buhrer) by the sawyer beetle.

At this point, rather than discussing all the potential species which can cause damage to mature forests across Canada, I will elaborate on only three key species which cause problems here in Ontario and at which pest management programs are being directed.

Gypsy Moth: The gypsy moth moved into the Eastern Canada in the 1970's from the United States and thus, has not had time to establish regular cycles in population densities. Control for this species has cost more than any other defoliating insect in North America (Doane and McManus 1981). Through repeated defoliations, it has caused extensive damage to mature stands in the northeastern hardwood forests of the USA. The gypsy moth was first reported at damaging levels in Ontario near Kaladar, Ontario in 1981. Since then, it has spread westward to where its range now extends to the north shore of Lake Erie and northward to Parry Sound (FIDS 1989).

The gypsy moth feeds primarily on oaks, but in late instars, will defoliate all deciduous and coniferous forests (Anonymous 1985). After several years of a gypsy moth outbreak, mortality becomes apparent. This leads to disruptions in expected stand density or age and can have an impact on public and private recreational use as well as expected timber production. Historically, attempts have been made to reduce gypsy moth populations through manual removal of egg masses and large scale chemical or biological insecticide programs against the larval stage.

Forest Tent Caterpillar: The forest tent caterpillar is another hardwood defoliator in Ontario, feeding primarily on poplar, birch, oak and maple species. This is a native insect which reaches outbreak levels approximately every 10 - 15 years (Witter 1979). Outbreaks last from 3 - 5 years and are considered to be controlled naturally by a virus and the pupal parasitoid, *Sarcophaga aldrichi* Parker. In southern Ontario, primary damage occurs on oak and maple while in northern Ontario the principal species attacked is poplar (Sippell 1962)

Repeated defoliation by the forest tent caterpillar leads to tree decline and dieback. Damage to oak is of consequence to some southern park areas where this species predominates, while sugar maple results in reduced sap production and dieback thus, lowering maple syrup production. Although damage to aspen is currently not a concern, future utilization of this species by the forest industry and emphasis on poplar plantations for biomass conversion may raise the importance of this insect in poplar production. When warranted, forest tent caterpillar is controlled through either pruning of the egg masses or the application of *Bacillus thuringiensis* Berliner.

Spruce Budworm: The spruce budworm is another native defoliating insect which causes extensive damage to conifers throughout Ontario. Spruce budworm populations cycle naturally reaching outbreak levels approximately every 25 years, with high numbers remaining over about a 6 - 10 year period (Royama 1984). To date, the cause of these regular cycles has not been determined, although federal researchers are attempting to answer this question through continuing studies in Ontario, Quebec and New Brunswick.

The spruce budworm is the most damaging insect pest on coniferous forests in eastern North America (Sanders *et al.* 1985). In Ontario during 1988, over 5.2 million hectares of boreal forested areas experienced defoliation and tree mortality (FIDS 1989). Trees die within 3 - 7 years of continuous feeding by the budworm on foliage of conifer species such as balsam fir, white and red spruce. This has major impact on forest management plans in that this wood, projected for use in the next 5 - 40 years is no longer available for timber or pulpwood production. Park areas in the northern part of the province, which contain a high proportion of susceptible species, also experience problems in that the areas become unsafe for campers or outdoors people, because of dieback, whole tree mortality, dramatic

changes in forest succession and increased fire hazard. Control of the spruce budworm usually entails the aerial application of chemical and biological insecticides or the cutting of dead or dying trees in areas which have already experienced extended periods of defoliation (salvage cuts).

Along with the development of our new forests, has arisen new insect pests. Intensive forest management has meant that we are now growing trees in a way similar to the production of agricultural crops. This has created the situation where trees, either young seedlings or older regeneration areas, are grown in monocultures with a continuing demand for a "high quality" product. Many insect pests which caused problems in agricultural crops in the past have now moved over into the intensive nursery and plantation areas and those which were once commonly associated with certain tree species at levels that went unnoticed, are now causing "unacceptable" damage under more stringent standards of production.

The new insect pests which are affecting these new Canadian forests are similar across the country. They include species attacking young nursery seedlings or burned areas that have been replanted, such as the black army cutworm, *Actebia fennica* (Tauscher), white grubs, *Cotinis nitida* (Linnaeus) and *Popillia japonica* Newman, the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), and leatherjackets, *Tipula paludosa* Meigen and *T. simplex* Doane. In regeneration sites, species such as the white pine weevil, *Pissodes strobi* (Peck), and the spruce budmoth, *Zeiraphera canadensis* Mutuura and Freeman, are causing extensive problems. Ornamental and Christmas tree plantations experience problems with the pine false webworm, *Acantholyda erythrocephala* (Linnaeus), the spider mites, *Oligonychus ununguis* (Jacobi) and *O. milleri* (McGregor), and the root weevils, *Otiorhynhcus sulcatus* (F.) and *O. ovatus* (Linnaeus). In seed and cone orchards, species such as the spruce coneworm, *Dioryctria reniculelloides* Mutuura and Munroe, and the seed cone maggots, *Strobilomyia laricis* sp. n., and *S. viaria* (Huckett), are reducing the amount of viable seeds for the establishment of new tree crops. Finally, in the urban setting, species mentioned previously, such as the introduced elm bark beetle, forest tent caterpillar and gypsy moth, as well as previously benign species such as the elm leaf beetle, *Pyrrhalta luteola* (Muller), and the oak leaf skeletonizer, *Bucculatrix ainsliella* Murtfeldt are causing increasing problems as more of our population move to urban areas and demand natural settings.

In Ontario, the key insect problems on new forests will undoubtedly be in those areas which are to supply our future wood supply needs, namely, regeneration sites and seed and cone orchards. The following section exemplifies two of these species which have the potential to significantly affect our future timber production.

White Pine Weevil: The white pine weevil is a native insect which has a long history of association with white pine throughout Ontario (Wallace and Sullivan 1985). In the last 10 years, white pine weevil has been reported on a number of other conifer species, including norway spruce, jack pine, white spruce, lodgepole pine, and sitka spruce. The adults appear in the spring, laying eggs in the leader of vigorously growing young pines. The leader of the current year's growth is killed as the larvae hatch and feed down the stem. It is not known how natural populations are regulated, although previous work has shown that overwintering survival and pupal mortality due to a predator, *Lonchaea corticis* Taylor, can affect populations significantly (Dixon and Houseweart 1982; Dixon *et al.* 1979).

Trees which have lost their leaders from feeding by white pine weevil lose growth in both height and diameter. Reductions in height growth mean that the tree will be out-competed for resources by taller, more dominant trees, and this, in turn, will change stocking (tree density and species composition). It may take 2 - 3 years for a tree to recover from a lost terminal and, in many cases, the internal damage remains, affecting sawlog timber when the tree is eventually harvested (Brace 1971). Reductions in tree diameter as a result of weevil feeding change the volume of timber expected to be harvested, ultimately changing the rotation age, usually delaying the expected harvest for several years. This damage is

even more significant in those tree species where the weevil damages the leader beyond the current year of growth or where it attacks the same tree repeatedly, year after year (eg. jack pine). Control of the weevil is restricted to labour-intensive clipping of infested leaders or ground applications of registered chemical insecticides. Even some of these insecticides may not be available in the future as their registration status is currently under review.

Seed Cone Maggots: The seed cone maggots which attack larch and black spruce are native species Very little is known about their life history or behaviour because they have only recently become a concern. Sampling techniques to determine population size or development are currently being worked out to establish monitoring programs for predicting damaging levels of these species.

Seed cone maggots oviposit directly into the cone scales of developing seed cones, and thus, the cone appears normal when viewed from the outside except for a slight reduction in cone growth (Hedlin *et al.* 1981). It is not until the larvae have emerged from the scales or germination is attempted with the cones that the extent of damage is apparent. Reduced seed crops lower the availability of healthy seedlings for planting in regeneration sites. They also can disrupt provenance trials where superior trees are being grown to produce seedlings from the best genetic stock. No control measures are currently available for seed cone maggots.

The Problem

The major problem facing the forest sector in Ontario, today, as well as other parts of Canada, is that of a predicted "wood gap". In previous years, despite a policy of sustained yield, the optimism and avarice of the past 100 years has left us with a dwindling supply of old forests. By the year 2000, a significant amount of merchantable timber from these old forests will have been utilized by the forest industry in timber and pulp production. The remaining "old growth forests" will either have been bought up privately (and perhaps, fallen under the developers hands in urban regions) or have been set aside as wildlife and nature preserves for the use and enjoyment of the public. At the same time, our new forests, which we have been establishing, will not be fully functional for timber production until somewhere around the year 2030. This means that there will be a period between the years 2000 and 2030 when the timber industry, and thus, the people of Canada, will experience a wood shortage. As suggested in the introduction, this can have serious consequences for the economy of this country.

One way of addressing the predicted shortage of wood is maintaining or preserving those parts of the old forest which are likely to be lost between now and 2020. Similarly, if we can protect and accelerate the establishment and growth of the new forest from now into the year 2030, we may be able to close the gap which currently exists. By protecting trees from damaging insects and reducing losses, both on the old and new forests, we may get one step closer to this goal. Thus, forest pest management practices are aimed at reducing losses in the forests in order to maximize forest productivity. Sustainability simply means that we must continue this protection or pest management practices *ad infinitum*. The major problem facing us then is protecting our forests from damaging insects over the long-term.

At a more specific level, in the old forests, defoliating insects cause major changes in forest succession. By removing the photosynthate annually from large areas of forest, these insects accelerate nutrient cycling, erosion, dieback, and on a larger scale, succession. This generally is incompatible with forest planning, disrupting the size, number, and species of trees expected on a given area. It can also interfere with people's ability to enjoy the natural setting by changing wildlife distribution and abundance and reducing the visual and aesthetic qualities of the forest.

Insect pests attacking the new forests are a problem, not only because they disrupt forest management like the defoliators, but also because they destroy trees which have already cost money to establish. Unlike the defoliators, which are feeding on older trees planted by nature, insects in nurseries or on regeneration sites are consuming whole trees, or parts there of, which represent money that we, as a nation, have invested in for our future. Protection from such losses must be enhanced in order to ensure that we have forests for tomorrow.

The Solution - Forest Pest Management

Protection of the forest against damaging insects on a sustained basis requires the implementation of forest pest management (FPM). Stern *et al.* (1959) first used the term "pest management" to describe those activities which can be integrated to suppress damaging insects. Waters and Cowling (1976) and Waters and Stark (1980) later elaborated the definition, using the term to describe a broader decision support system in forestry. Today only a few of the aspects discussed by these authors are actually implemented in the field. The majority of components in their theoretical forest pest management system are still at the research level.

From the entomological perspective, Waters and Cowling's (1976) definition of FPM described two major components: impact assessment and control tactics. These components are an essential part of the solution to the "wood gap" problem. The following section describes our current status in forest pest management practices based on impact assessment and control tactics. Where possible, I have also tried to identify areas which have the greatest potential for implementation and for future research.

Impact Assessment: Central to the concept of FPM is the identification of insects which cause economic damage. In forestry, the economic threshold is considerably more difficult to ascertain than in agriculture because often the damage does not become economic until 10 - 60 years after insect attack, when the crop is harvested (eg. leader loss from weevil on 10-year-old jack pine stands that will not be harvested for a further 60 years). Many events can occur in the forest, both compensatory and more devastating (eg. fire, natural succession), in that time and thus, the results of preventative measures can be obscured or negated. The changes that result are often strongly associated with the interest rate expected on money invested over this long period of time and this is difficult to predict (Rawat *et al.* 1987). Also, because forests have many uses, over different stages of their development, the economic impact of insect damage is hard to put a dollar value on; eg. losses due to defoliation and changes in species composition for wildlife habitat or soil erosion.

To overcome the difficulty in estimating future worth of protected or damaged forested areas, computer simulations have become increasingly helpful. The literature is replete with references to models which have been developed to predict insect populations over long periods of time or the consequences of insect damage and protection on forest stands (MacLean and Erdle 1984; Régnière 1982; Rose 1973). These models have been built up from long-term experimental studies to measure the changes and probability of insect damage (MacLean and Ostaff 1989; Alfaro *et al.* 1985; Piene 1980). At the moment, these models tend to be too theoretical and specific to be of practical value, but they represent the basis on which truly integrated systems can be structured to study the impact on forest stands. Unquestionably, future research will continue in this area, as we become more knowledgable about the impact of insects on forest stands and advances are made in computer technology.

The development of efficient sampling systems will also have high priority in future pest management programs. Although Forestry Canada, through the Forest Insect and Disease Survey (FIDS), provides extensive surveys of pest populations from year to year, few sampling plans which accurately predict specific pest populations and damage are

available to the forest manager. Some species have been studied intensively, like the spruce budworm, but these are rare in the annals of sampling research. In many cases, it is our inability to predict damaging populations that results in our considering an insect as a serious problem (eg. gypsy moth, white pine weevil, root weevils, etc.). In order to truly implement FPM programs in the future, rapid progress in the area of sampling design will have to be made.

Control Tactics: The second area of relevance to FPM is the identification and development of control measures which will be both effective and environmentally acceptable. One of the most influential and benign ways to reduce specific insect populations is through the manipulations of vegetation. Some of the insect problems which we are now experiencing on the old forests resulted from past activities which have changed the forest. A good example of this is the harvesting of preferred tree species in parts of eastern Canada which has left extensive areas regenerated to balsam fir. These stands are highly susceptible to outbreaks of the spruce budworm, and because the forest industry now utilizes balsam fir, long-term control operations are required.

Foresters have had considerable training in the area of stand manipulation, controlling forest conditions, such as the amount and distribution of understory vegetation and the density, age, and species of trees present. The production of white pine in Ontario today characterizes the potential of this type of pest management. Fast-growing poplar are often planted with young white pine to provide an overstory or shading effect. This reduces the attack by white pine weevil by obscuring the growing tips of the white pine and forcing them to grow tall and narrow (less suitable to weevil survival). In the future, we will continue to rely on this kind of expertise to manipulate forest stands to reduce insect attack, because it represents true sustainable pest management. This approach is preventative, however, and can only deal with long-term problems; it fails to address insect damage in the short-term.

Historically, our reaction to pest problems on forest stands has been short-term, being somewhat characterized as "crisis management". Much of our effort has been spent "putting out the fires" of insect damage. Since the 1940's, a key component in our arsenal has been chemical insecticides. Starting with the widespread use of DDT in the 1940's and 1950's and ending with the organophosphates and carbamates of the 1970's and 1980's, we have attempted to combat species on our old forests, such as the spruce budworm, Douglas fir tussock moth and hemlock looper, with aerial applications of these compounds (Prebble 1975). Because of public concerns about toxicity and the broader environmental impact of these insecticides, most provincial jurisdictions today do not condone the use of chemical insecticides in aerial applications on forested land. Unfortunately, this has left the forest manager with very few, if any, options for the short-term control of insect pests.

To meet this need for short-term solutions to pest problems in the context of FPM, research is continuing in a number of key areas. Much of this work is directed at finding effective and environmentally acceptable alternatives for reducing pest populations, including compounds that are increasingly host specific. Studies are being conducted by Forestry Canada, at their 6 regional and 2 national laboratories, as well as at some universities and provincial institutes.

One of these areas of research is the development of newer, more effective insecticides that have low impact on non-target species. These compounds can be considered "biorationals" in that they are based on natural biological products, but are now synthesized and produced in the laboratory. The products currently being researched include plant derivatives, insect growth regulators (IGR's), and disruption pheromones. With the plant derivatives, the emphasis is on compounds like the synthetic pyrethroids, which have low residual properties. Although these insecticides may be toxic to some non-targets, they could prove particularly useful in ground applications against foliar feeding species. Research to identify sex pheromones which will disrupt the natural mating cycles of some species such

as the spruce budmoth is on-going in New Brunswick while researchers in Sault Ste. Marie have achieved experimental success using IGRs against such difficult species as the white pine weevil (Retnakaran and Jobin, in press).

The other area of intensive research in forest pest management is the use of true biological agents for suppression. This includes such naturally-occurring agents as bacteria, viruses, protozoa, fungi, nematodes, predators and parasitoids. Although in 1981, a significant component of Forestry Canada was devoted to research in this area (97 person years across Canada) (Hulme 1982), the complex nature of this work means that the results which are directly applicable to the field are slow in coming.

Undoubtedly the most successful biological control agent to have been developed to date is *Bacillus thurigiensis* Berliner. The use of this bacterial agent, which is found naturally in the soil and stored product insects, has been increasing exponentially since its commercial introduction in the 1970's (Morris *et al.* 1986). This has been due to two main factors: 1) more consistent results and 2) reduced operational costs. Research is now aimed at isolating and synthesizing the toxic crystal (the active ingredient) and improving the formulation and application of the product. *B.t.* is effective against most major lepidopterous insect pests in the forest and is currently the only insecticide applied aerially in Ontario against the spruce budworm, gypsy moth, and forest tent caterpillar. In other parts of Canada, it has been used against the western spruce budworm and the hemlock looper. Its limitations appear to be somewhat variable results when applied in unfavourable weather or under high population levels and its relatively broad effect on all lepidopterans feeding on foliage at the time of application.

Viruses represent another group of biological control agents which are being produced for application against forest insects. Perhaps the greatest success story with this agent is the use against the European pine sawfly during 1950's and 1960's which reduced this pest well below economically damaging levels. This insect is no longer considered a problem in pine plantations, principally due this virus. Although in the United States, two virus compounds are currently registered for application on forested lands, Virtuss® and Gypcheck®, viruses are not readily available in Canada. This is partially due to the stringent registration process required by our federal government and partially because these is as yet no commercial production. The Forest Pest Management Institute (FPMI) in Sault Ste. Marie has two products, TM Biocontrol® and Virtus®, registered for control of the Douglas fir tussock moth and another, LeContevirus®, available for control of the red headed pine sawfly. In Canada, viruses are being tested experimentally against the gypsy moth with some degree of success (one product, Gypcheck® has been submitted for registration), but have failed to provide satisfactory control of the spruce budworm in extensive tests conducted over the past 10 years (J. Cunningham, Forest Pest Management Centre, Sault Ste. Marie). The future development and use of viruses will depend, to a large extent, on the ability to register these products in this country and our assurance that they will be target specific.

A number of other studies have been conducted to determine the effectiveness of various biological agents or entomopathogens such as protozoa, fungi, and nematodes (Hulme and Green 1984). Most of this work has been conducted at federal government laboratories and universities over the past 10 - 20 years. The microsporidian, *Nosema fumiferanae* (Thompson), which is a factor in the decline of natural spruce budworm populations, has been studied since the 1970's. *Nosema* spp. have been used successfully against damaging herbivores such as grasshoppers in the prairies, and work by Wilson (1977) suggests that it has potential for suppressing budworm populations. Further studies may be warranted, particularly to develop an understanding of its impact in the population dynamics of this pest (Wilson *et al.* 1984).

Similarly, pathogenic fungi have been examined by several researchers for their potential use against forest defoliating insects, such as the hemlock looper, spruce budworm, and gypsy moth. Most of this work has been aimed at improving our basic understanding of the

pathogen/host system. To date, however, no fungi have been developed for commercial application against forest insects (Wilson *et al.* 1984). Current studies are directed at genetic manipulation of fungi to improve virulence (Hulme and Green 1984).

Little work has been done on the use of nematodes for controlling forest insect pests (Hulme and Green 1984). Recently, however, these entomopathogens are being investigated for their potential against the spruce budworm, structural pests like termites, and ornamental pests such as white grubs and root weevil (D. Eidt, Forestry Canada-Maritimes Region). Continued research in this area should identify nematodes as strong candidates for biological control of forest insects, particularly those which are cryptic and found in dark moist habitats such as soil.

The remaining natural enemies of forest insects, including predators and parasitoids, have been investigated over the past 80 years in Canada. A number of success stories in biological control have been reported in forestry through the introduction of these agents for control of pest problems (McGugan and Coppel 1962; Reeks and Cameron 1971; Kelleher and Hulme 1984). Approximately one-third of the forest insect pests against which predators and parasitoids have been released in Canada have been almost permanently controlled and the remaining one-third can be controlled for one to several pest generations (Hulme 1988). In recent years, predaceous ants, in the genus *Formica* sp. released in jack pine plantations in Quebec have shown indirect evidence that they can reduce populations of the Swaine jack pine sawfly (Hulme and Green 1984). Other mammalian and avian predators also have potential for suppressing forest insect populations and further studies are needed to identify their impact on both target and non-target species.

Hulme and Green (1984) reported 31 species of parasitoids and predators released in Canada between 1969 and 1980; all but 3 where hymenopterans. Approximately half of these natural enemies have been shown to be established and are now linked to reductions in pest populations. In general, the emphasis has been on introductions of exotic species of parasitoids, but current thought suggests that native species may be just as appropriate for biocontrol programs. In the future, studies will concentrate not only on these inoculative releases but also on inundative releases with native or introduced parasitoids. The recent work on the egg parasitoid, *Trichogramma minutum* Riley, against the spruce budworm is a good example of the potential for inundative releases in modern forest pest management (Smith *et al.* 1990). Continued work in this area requires basic research on the rearing of natural enemies and knowledge about the population dynamics of the pest insects against which they will be used (Hulme and Green 1984).

Conclusions

Insect species which attack trees in old forest areas are often difficult to control because the areas in which they are found are relatively rugged and inaccessible from the ground. On the other hand, species which damage the new forest present difficulties because there are often no known sampling programs, the levels of protection required are high, and control measures are either non-existent or extremely labour intensive. These factors will determine the future direction of research for pest management.

It is quite possible that the insects which we now consider pests in our old forests, such as the spruce budworm and gypsy moth, may be of less concern in the future. Evidence for this can be seen in European forests, where these stands are generally more intensively managed than in Canada and widespread outbreaks of defoliators are rarely encountered. How we adapt to the projected changes in our forests and the systems we design to deal with the arising pest problems will be determined by our creativity and ability to support the necessary research. As pointed out by Wallace (1990) in a recent review, research in the areas of survey and impact assessment, population dynamics, and improved control

techniques, including biological agents, must be supported in order to meet the challenge of sustained pest management.

The crisis of the "wood gap", although the major challenge facing the forest sector, is not the only one. Increasingly, an educated public is becoming involved in the programs for forest management conducted in this province. Their pressure to develop multiple use areas and ensure environmentally acceptable management programs makes any proposed activities subject to intense scrutiny, including pest management. This, combined with world recognition of the desire and necessity for forest health and conservation, places an even greater burden of responsibility on the shoulders of our foresters.

Sustainability means that our forests will remain green indefinitely. In order to achieve this, our foresters will have to make sound pest management decisions based on the availability of impact assessments and acceptable tactics for control. Without continued support for research and development, these tools for a green forest will become a scarce resource.

References

Anonymous. 1990. CIF/IFC policy statement on sustainable development. Forestry Chronicle, 66(2): 173-179.

Anonymous. 1985. Insects of Eastern Forests. United States Department of Agriculture, Forest Service Miscellaneous Publication Number 1426. 608 pp.

Alfaro, R.I., A.J. Thomson, and G.A. Van Sickle. 1985. Quantification of Douglas-fir growth losses caused by western spruce budworm defoliation using stem analysis. Canadian Journal of Forest Research, 15: 5-9.

Brace, L.G. 1971. Effects of white pine weevil damage on tree height, volume, lumber recovery and lumber value in eastern white pine. Canadian Forestry Service, Petawawa Forest Experimental Station, Publication Number 1303. 33 pp.

Dixon, W.N. and M.W. Houseweart. 1982. Life tables of the white pine weevil, *Pissodes strobi,* in central Maine. Environmental Entomology, 11: 555-564.

Dixon, W.N., M.W. Houseweart and S.M. Sheffer. 1979. Fall temporal activity and overwintering sites of the white pine weevil, *Pissodes strobi,* in central Maine. Annals of the Entomological Society of America, 72: 840-844.

Doane, C.C. and M.L. McManus (Eds). 1981. The Gypsy Moth: Research Toward Integrated Pest Management. United States Department of Agriculture, Forest Service Technical Bulletin 1584. 757 pp.

FIDS (Forest Insect and Disease Survey). 1989. Forest Insect and Disease Conditions in Canada 1988. B.H. Moody (Ed). Forestry Canada, Publications and Distribution Centre, Petawawa National Forestry Centre. 105 pp.

Hedlin, A.F., H.O. Yates III, D.C. Tovar, B.H. Ebel, T.W. Koerber, and E.P. Merkel. 1981. Cone and Seed Insects of North American Conifers. Canadian Forestry Service, United States Forest Service, Secretaria de Agricultura y Recursos Hidraulicos, Mexico. 122 pp.

Hulme, M.A. 1982. Biological Control in the Canadian Forestry Service. DPC-X-11, Canadian Forestry Service. 45 pp.

Hulme, M.A. 1988. The recent Canadian record in applied biological control of forest insect pests. Forestry Chronicle, 64(1): 27-31.

Hulme, M.A. and G.W. Green. 1984. Biological control of forest insect pests in Canada 1969-1980: retrospect and prospect. p. 215-227. *In*: Biological Control Programmes Against Insects and Weeds in Canada 1969-1980. J.S. Kelleher and M.A. Hulme (Eds). Commonwealth Institute of Biological Control Technical Communication. 410 pp.

Kelleher, J.S. and M.A. Hulme (Eds). 1984. Biological Control Programmes Against Insects and Weeds in Canada 1969-1980. Commonwealth Institute of Biological Control Technical Communication. 410 pp.

MacLean, D.A. and T.A. Erdle. 1984. A method to determine effects of spruce budworm on stand yield and wood supply projections for New Brunswick. Forestry Chronicle, 60: 167-173.

MacLean, D.A. and D.P. Ostaff. 1989. Patterns of tree mortality caused by an uncontrolled spruce budworm outbreak. Canadian Journal of Forest Research, 19: 1087-1095.

McGugan, B.M. and H.C. Coppel. 1962. Biological control of forest insects 1910-1958. pp. 35-127. *In*: A Review of the Biological Control Attempts Against Insects and Weeds in Canada. Commonwealth Institute of Biological Control Technical Communication. 410 pp.

Morris, O.N., J.C. Cunningham, J.R. Finney-Crawley, R.P. Jaques, and G. Kinoshita. 1986. Microbial insecticides in Canada: Their registration and use in agriculture, forestry and public and animal health. Supplement of the Bulletin of the Entomological Society of Canada, 18(2): 1-43.

Piene, H. 1980. Effects of insect defoliation on growth and foliar nutrients of young balsam fir. Forestry Science, 26: 665-673.

Prebble, M.L. (Ed). 1975. Aerial Control of Forest Insects in Canada. Environment Canada. 330 pp.

Rawat, J.K., K.L. Belli, S.M. Smith and J.C. Nautiyal. 1987. A pest and timber management model: jack pine budworm and jack pine. Canadian Journal of Agricultural Economics, 35: 441-461.

Reeks, W.A. and J.M. Cameron. 1971. Current approaches to biological control of forest insects 1959-1968. pp. 105-112. *In*: Biological Control Programmes Against Insects and Weeds in Canada. Commonwealth Institute of Biological Control Technical Communication. 410 pp.

Régnière, J. 1982. A process-oriented model of spruce budworm phenology (Lepidoptera: Tortricidae). Canadian Entomologist, 114: 811-825.

Retnakaran, A. and L. Jobin. Control of the shite pine weevil (Coleoptera: Curculionidae) with diflubenzuron. Journal of Economic Entomology. (in press)

Rose, D.W. 1973. Simulation of jack pine budworm attacks. Journal of Environmental Management, 1: 259-276.

Royama, T. 1984. Population dynamics of the spruce budworm, *Choristoneura fumiferana.* Ecological Monographs, 51: 473-491.

Sanders, C.J., R.W. Stark, E.J. Mullins, and J. Murphy (Eds). 1985. Recent Advances in Spruce Budworms Research. Proceedings of CANUSA Spruce Budworms Research Symposium. 527 pp.

Sippell, W.L. 1962. Outbreaks of the forest tent caterpillar, *Malacosoma disstria* Hbn., a periodic defoliator of broad-leaved trees in Ontario. Canadian Entomologist, 94: 408-416.

Smith, S.M., J.R. Carrow, and J.E. Laing (Eds). 1990. Inundative release of the egg parasitoid, *Trichogramma minutum* (Hymenoptera: Trichogrammatidae), against forest insect pests such as the spruce budworm, *Choristoneura fumiferana* (Lepidoptera: Tortricidae), the Ontario Project 1982-1986. Memoirs of the Entomological Society of Canada. (in press, November)

Stern, V.M., R.F. Smith, R. Van den Bosch, and K.S. Hagen. 1959. The integrated control concept. Hilgardia, 29(2): 1-81.

Wallace, D.R. 1990. Forest entomology or entomology in the forest? Canadian research and development. Forestry Chronicle, 66(2): 120-125.

Wallace, D.R. and C.R. Sullivan. 1985. The white pine weevil, *Pissodes strobi* (Coleoptera: Curculionidae): A review emphasizing behaviour and development in relation to physical factors. Proceedings of the Entomological Society of Ontario, Supplement 116: 39-62.

Waters, W.E. and E.B. Cowling. 1976. Integrated forest pest management: a silvicultural necessity. pp. 149-177. *In*: Integrated Pest Management. J.L. Apple and R.F. Smith (Eds). Plenum Press, New York. 200 pp.

Waters, W.E. and R.W. Stark. 1980. Forest pest management: concept and reality. Annual Review of Entomology, 25: 479-509.

Wilson, G.G. 1977. The effects of feeding microsporidian (*Nosema fumiferanae*) spores to naturally infected spruce budworm (*Choristoneura fumiferana*). Canadian Journal of Zoology, 55: 249-250.

Wilson, G.G, D. Tyrrell, and T.J. Ennis. 1984. C. Application of microsporidia and fungi, and of genetic manipulation. pp. 260-266. *In*: Biological Control Programmes Against Insects and Weeds in Canada 1969-1980. J.S. Kelleher and M.A. Hulme (Eds). Commonwealth Institute of Biological Control Technical Communication. 410 pp.

Witter, J.A. 1979. The forest tent caterpillar (Lepidoptera: Lasiocampidae) in Minnesota: a case history review. Great Lakes Entomologist, 12(4): 191-197.

SEASONAL HISTORY AND BEHAVIOR OF THE ALFALFA SNOUT BEETLE, *OTIORHYNCHUS LIGUSTICI* (COLEOPTERA: CURCULIONIDAE), IN EASTERN ONTARIO[1]

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Abstract. *Proc. ent. Soc. Ont.* 121:61-69

Studies in eastern Ontario showed that the alfalfa snout beetle, *Otiorhynchus ligustici* (L.) has a 2-year life cycle and overwinters in the soil as a final instar larva and adult in the first and second year, respectively. Emergence of the adults from hibernation followed the inversion of soil temperatures in April and appeared to be triggered by an increase in ambient temperatures from zero to 3.8°C. Migration began in mid to late April when daily air temperatures reached 15°C. Oviposition began in early May, and peaked about 2 weeks later. Calendar dates for these events varied by as much as 3 weeks between years, but in terms of degree-days (DD) (base 5°C) after 1 March, emergence, peak migration and peak oviposition occurred annually at 52, 152 and 318 DD, respectively.

The eggs were deposited in the soil within 2 to 3 cm of the tap root. Hatching occurred in mid June and the younger larvae (instars 1 to 5) fed on the alfalfa root system, burrowing as deep as 35 cm in the soil. Instars 6 and 7 fed on the tap root, generally in the upper 10 cm of soil. The larvae were fully grown by the approach of winter and retreated to an average depth of ca. 24 cm in response to the fall overturn of soil temperatures. Pupation occurred in mid to late June within the hibernation sites and adult eclosion occurred 3 to 4 weeks later. The new adults remained in or near the pupation sites for 8 to 9 months. Their distribution in the soil corresponded to that of the larvae. However, they appeared to adjust their vertical distribution in response to frost penetration. There are two broods of the beetle that appear in alternate years.

Introduction

In 1986, the alfalfa snout beetle, *Otiorhynchus ligustici* (L.) was discovered near Prescott, Ontario (Loan *et al.* 1986). Although the pest had been recorded two decades earlier on Wolfe Island, 85 km to the southwest at the entrance to the St. Lawrence River, Loan *et al.* documented the first mainland record in Canada. Both infestations are believed to be extensions of an historic introduction from Europe to the United States and contained during the past 50 years within a six-county area of upstate New York (G. Cooke, personal communication) bordering the eastern end of Lake Ontario (Fig. 1).

[1]This is contribution number 1274 from the Plant Research Centre.

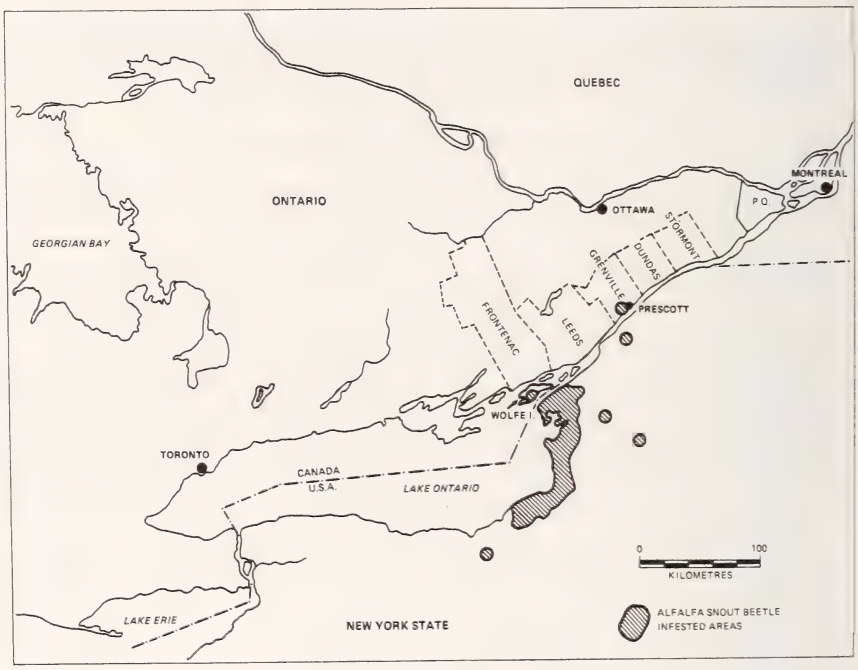

FIGURE 1. Distribution of *Otiorhynchus ligustici* in Ontario and New York.

The new infestation in eastern Ontario encompasses 12 km² in south Grenville County (Harcourt and Guppy 1987), an area large enough for us to conclude that the beetle had arrived several years earlier. It may have special concern to Ontario's Agriculture because in New York the direction of spread has been essentially northeasterly along the lake. In Ontario, there is no major barrier to check its dispersal and in Europe the weevil is most abundant in cooler regions north of latitude 45° N.

Otiorhynchus ligustici is primarily a pest of alfalfa, but both the adults and larvae are polyphagous. In North America its food plants include the true clovers (*Trifolium*), the sweet clovers (*Melilotus*), and a wide variety of weeds (Palm 1935). In Europe, additional plant species have been recorded as hosts (Jorgensen 1953) and in recent years hops (*Humulus lupulus*) have been considered to be one of the most important crops attacked (Z. Ruzicka, personal communication). The weevil reproduces parthenogenetically (Palm 1935; Jorgensen 1953; Hanuss 1958; York 1974), and the report of males and mating by some authors is doubtful (Hanuss 1958). The flightless adults are dark grey and about 12 mm long. The eggs are spherical to shortly ovate and are on average 0.9 mm by 0.75 mm in size. The larvae are grub-like, creamy-white and legless; when fully grown they attain a length of about 13 mm. The pupae are about 11 mm long. The life cycle of the beetle requires two years (Guppy and Harcourt 1989) and there are even- and odd-year broods, Brood A and Brood B, respectively, based on the year of adult activity (Harcourt and Binns 1989). Hibernation occurs in both the larval and adult stages.

Although there are many articles on *O. ligustici*, relatively few reports are based on critical investigations of its basic biology. Jorgensen (1953) and Hanuss (1958) have studied the biology of the beetle in Europe and compared their findings with those of earlier authors from Europe and from North America, notably Vassiliev (1914) in Russia and Palm (1935)

and Lincoln and Palm (1941) in New York State. This paper describes the seasonal history and behaviour of the beetle in eastern Ontario.

Methods

The study was made from 1986 to 1989, in 2 adjacent fields of alfalfa located on a dairy farm within the new population epicentre (Loan *et al.* 1986). The seasonal history and habits of the beetle were determined by means of soil excavations to unearth the immature stages and hibernating adults, visual observations of adult activity, and dissections of captured adults. To observe the larval, pupal and the adult stages during hibernation, quadrats of soil, 30 x 30 cm, were removed in consecutive 5 cm layers to a depth of 40 cm. The excavations were made every 2 weeks from November to March and more frequently during the rest of the year. Soil temperatures at these depths were recorded by means of thermometer probes buried in the field at the study site.

From early spring, adult activity was followed visually, and by recording the number of adults taken in 16 pitfall traps. The traps were glass bowls, 20 cm in diameter, placed in the soil surface at 10m intervals at the study site. The inner surface of the bowls was treated with dry film lubricant to prevent the beetles from escaping. Live beetles were collected at 2-3 day intervals and dissected to determine ovarian development. Activity was timed phenologically to degree-day (DD) accumulation and plant development. Air temperatures were obtained from a local weather station in Grenville County (Kemptville College of Agriculture), and DD were calculated from maximum and minimum temperatures (°C) beginning on 1 March. The sine curve approximation of Baskerville and Emin (1969) was used to compute heat units above a base threshold of 5°C for beetle activity (York 1974).

Oviposition activity was followed in the field. From mid April to June, quadrats of soil, 16 cm x 16 cm and 5 cm deep and containing at least one crown of alfalfa, were dug twice weekly and taken to the laboratory for processing. Preliminary studies showed that 95% of the eggs occurred in this profile. Coarse soil particles and debris were removed by screening and the eggs were recovered from the remaining soil by flotation in a saturated salt solution. Newly-hatched larvae, also recovered by this process, served as additional indicators of the date of hatch. In all three years, eggs were stripped from beetles collected twice weekly during late April and/or early May and incubated in the laboratory at 24°C to determine the date when they became viable.

During the study, both broods were observed. Hibernating adults of one brood were commonly collected in samples with larvae of the other.

Results and discussion

Seasonal History and Habits

In spring of the first year of the 2-year life cycle, the adults emerged from hibernation and dispersed to feed and lay eggs; these hatched in early summer and the larvae fed until late fall when they were fully-grown and entered hibernation. During the second year, metamorphosis was resumed in early summer when pupation occurred; the resulting adults were inactive until the following spring (see Fig. 2).

Adult Activity

Emergence From Hibernation. The adults emerged from hibernation during April in each of the three years (Table I). Ascent of the beetles to the ground surface was related to the inversion of soil temperatures in spring, and movement appeared to be triggered by a rise in ambient temperatures from zero to 3.8°C. However, because of differences in the

warming process in the soil between years, the dates that ascent began varied from 4 to 18 April. The beetles reached the surface 3 to 5 days later. Degree-day summations from 1 March were more reliable than average calendar dates for timing the process of emergence. Thus, upward movement began, on average, at 43 DD and was completed 9 DD later (Table II).

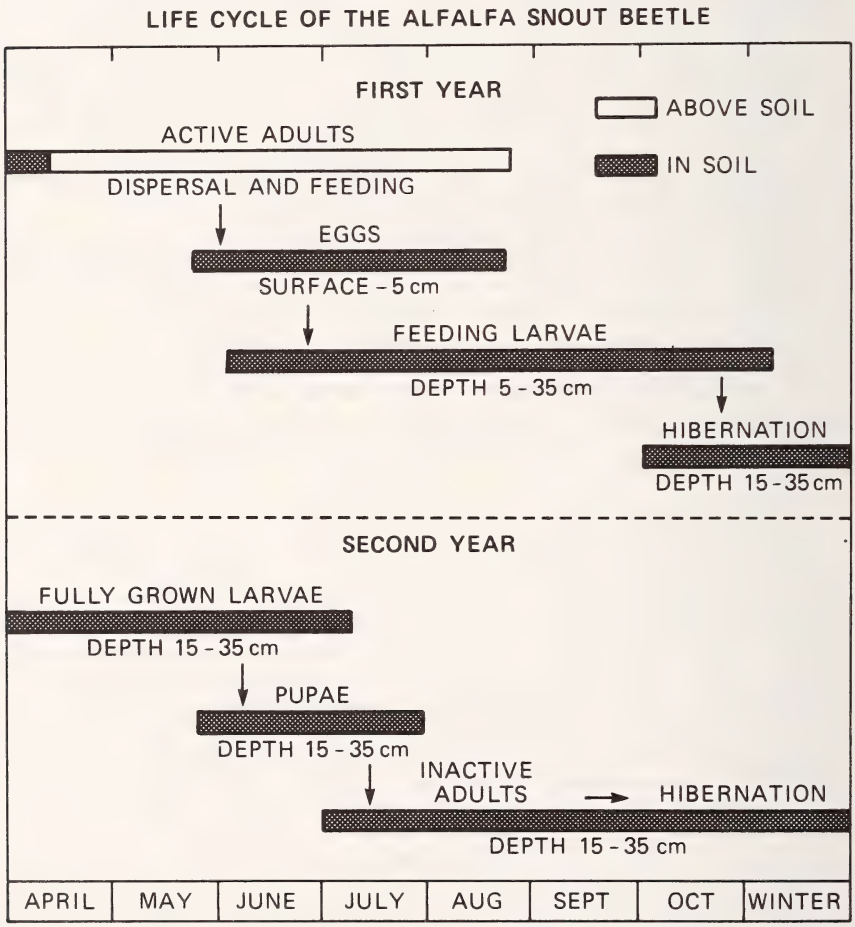

FIGURE 2. Seasonal development of *Otiorhynchus ligustici* in eastern Ontario, 1986-1989.

Migration. The adults migrate by walking, but movement is limited to a few hundred meters during the season (Annand 1937; Nielsen and Edmonds 1969). This allows the beetles to exploit local food supplies. However, the spread of the beetle over longer distances during migration is attributed to its transport on farm equipment or other vehicles and by clinging on debris in waterways (Nielsen and Edmonds 1969). We speculate that water was the route to Canada, in that Prescott is downstream of the main area of infestation

in northern New York (Fig. 1). On reaching the soil surface, the adults hide in the ground litter until weather conditions are suitable for migration. Based on pitfall trap captures, migration began in mid or late April when daily maximum air temperatures rose to 15°C. Counts of adults moving along roadways indicated that migration peaked 8 to 16 days later, the dates varying from 20 April to 16 May. In terms of DD summations, migration began, on average, at 77 DD and peaked at 152 DD (Table II).

TABLE I. Observed dates for biological events in seasonal history of adults of *Otiorhynchus ligustici*.

	1987	1988	1989
Reached surface	Apr 7	Apr 12	Apr 22
Migration began	Apr 12	Apr 28	Apr 30
Migration peaked	Apr 20	May 9	May 16
Onset of oviposition	May 1	May 15	May 17
Peak oviposition	May 19	May 29	May 30
Peak hatch	June 9	June 18	June 20

TABLE II. Phenological time in DD for biological events in the seasonal history of adults of *Otiorhynchus ligustici*[1].

	1987	1988	1989	mean
Ascent began	41	47	41	43
Reached surface	54	54	47	52
Migration began	79	80	73	77
Migration peaked	147	156	154	152
Onset of oviposition	192	195	178	188
Peak oviposition	303	328	322	318
Peak hatch	555	583	574	571

[1]Degree-days above 5°C were accumulated from 1 March.

Workers from New York (G. Cooke, personal communication) have associated the time of blooming of wild serviceberries, *Amelanchier* spp., with migration of the beetle and used this as a cue to its spring activity. This relationship holds for eastern Ontario as well. Peak migration additionally corresponds to the time of full bloom of wild Canada plum, *Prunus*

nigra Ait., which occurs in eastern Ontario, following the accumulation of 155 DD after 1 March (Matthewman and Harcourt 1972).

Oviposition. The eggs were deposited singly, as a rule within 2 to 3 cm of the alfalfa tap root. Oviposition began during the first half of May and peaked about 2 weeks later (Table I). In 1987, the first eggs were recovered on May 1. Reproductive development was first detected on 19 April when 10% of the beetles showed signs of ovarian development. On 21 April, 70% of the adults had ovarian development and the ovaries in 10% of them contained partially developed ova. The first mature eggs were observed on 24 April and by 29 April about 80% of the beetles contained mature eggs which showed signs of development after 48 h of incubation.

In 1988, the general pattern of ovarian development was similar to 1987. The first signs of ovariole growth were on 6 May, one week following the onset of migration, and mature eggs stripped from beetles on May 15 were viable, indicating that oviposition had started (Table I). In 1989, migration peaked a week later than in 1988, but our observations set the beginning of oviposition only two days later. The peak period of oviposition occurred at mid May in 1987 and near the end of May in the other two years. Peak hatch, estimated from the thermal requirement for eggs (unpublished data), probably followed peak oviposition by about three weeks each year (Table I).

The phenological time for the onset and peak of oviposition showed little variation between years (Table II); therefore, the mean values for accumulated DD, 188 and 318, respectively, appear to provide a reliable guide for marking annual oviposition activity.

Larval development

On hatching in early summer, the larvae burrowed downwards in the soil and fed on the alfalfa roots for the remainder of the growing season (Fig. 2). Larval development was followed by measuring the head capsule widths of specimens collected at 2-week intervals throughout the summer and early fall of 1987. A total of 280 larvae was measured (Table III) and at the extremes of each range, the decision to assign a specimen to one category or another was based on body size. The range of head capsule widths indicate that there are seven larval instars. These measurements correspond to those reported by Palm (1935) for New York.

The early instar larvae fed lightly on the surface of the alfalfa root and in doing so marked the cortex with small grooves as they gradually worked deeper into the flesh. Older larvae chewed spiral channels over the tap root and frequently ate into the core. Eventually the final instar larvae completely girdled the root and often severed it several cm below the crown.

During July and August, larval instars 1-5 fed at soil depths of 5 to 35 cm. However, in late summer, the sixth and seventh instars moved into the upper 10 cm. The vertical distribution of feeding larvae for the three years 1987-89 (Fig. 3) corroborate the findings of Palm (1935) and Lincoln and Palm (1941).

As a rule, the larvae were fully grown by the onset of winter. The descent to hibernation sites corresponded to the fall overturn of soil temperatures; it began in late November and was virtually completed by mid December. The vertical distributions (Fig. 3) suggest that the larvae tended to winter more deeply in 1987-88 than in 1986-87, with mean depths of 25.5 cm and 21.9 cm in the two winters, respectively. These differences, although small, are attributed to variations in frost penetration; in 1986-87 the soil did not freeze below 10 cm but in 1987-88 it froze to a depth of 20 cm.

Pupae

The overwintered larvae began to pupate in mid to late May, and 50% had pupated by 21 and 30 of June in 1987 and 1988, respectively. Eclosion occurred 3 to 4 weeks later, in mid to late July. Vertical distribution of the pupae was identical to that indicated for the overwintered larvae in Figure 3.

TABLE III. Width of head capsules of the larval instars of *Otiorhynchus ligustici*.

Instar	Number of specimens	Range	Mean[1]
1	82	0.35 - 0.45	0.42
2	33	0.48 - 0.61	0.53
3	28	0.67 - 0.96	0.76
4	24	0.99 - 1.28	1.13
5	35	1.34 - 1.70	1.52
6	52	1.76 - 2.02	1.87
7	26	2.05 - 2.43	2.20

[1]SE of the mean for each stage was <0.035

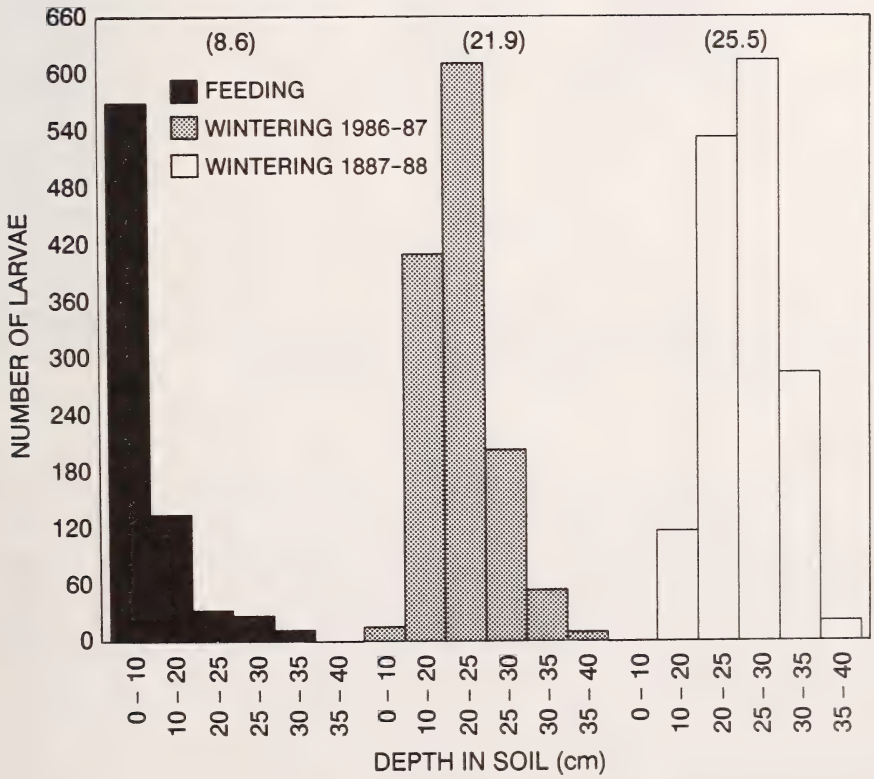

FIGURE 3. Vertical distribution of *Otiorhynchus ligustici* in soil in eastern Ontario: feeding larvae 1987, 1988, and 1989, inclusive; wintering larvae 1986-1987 (Brood A) and 1987-1988 (Brood B). Mean depths are given in parentheses.

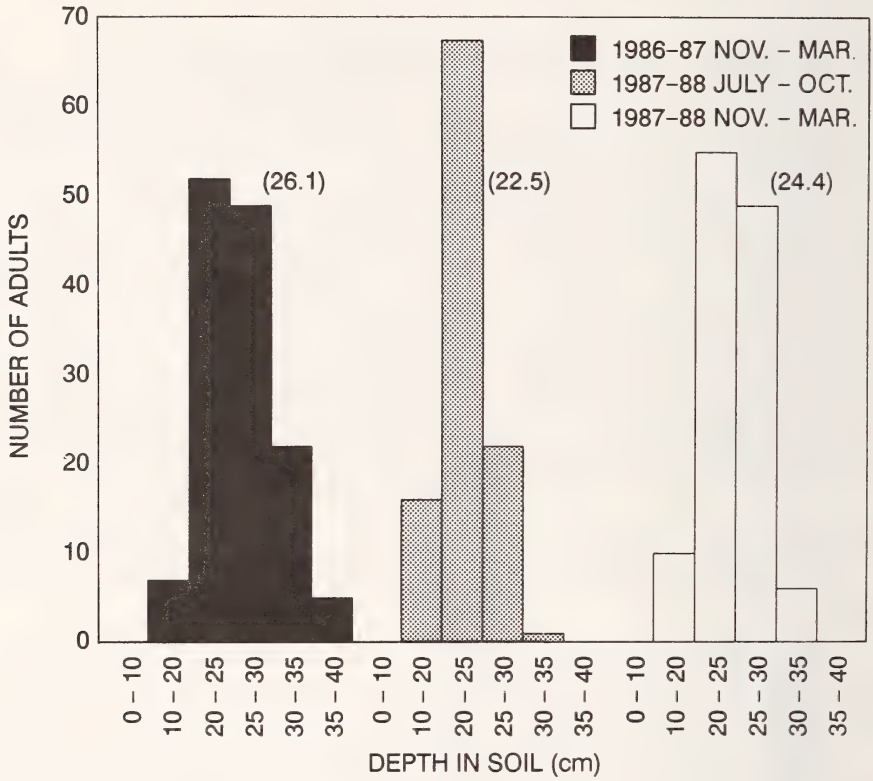

FIGURE 4. Vertical distribution of quiescent adults of *Otiorhynchus ligustici* in soil in eastern Ontario: 1986-1987 November to March (Brood B); 1987-1988 July to October and November to March (Brood A). Mean depths are given in parentheses.

Quiescent adults

The new adults are essentially inactive for 8 to 9 months, remaining in or near pupation sites until the following April. The vertical distribution of the two broods (Fig. 4) was similar for the November to March period except for a higher percentage at the 30-40 cm levels for Brood B. For the two periods in 1987-88 (Brood A) the adults were found at shallower depths from July to October, with 78% of them above 25 cm, than from November to March, when only 54% were found above 25 cm. This suggests that the "quiescent" adults may respond to soil ambient conditions and adjust their vertical distribution accordingly. Hanuss (1958) reported similar movements of adults in Germany, observing that in fall the hibernating adults moved 10 cm deeper into the soil, apparently in response to an increase in soil moisture. The suggested movement of the beetles in Ontario in 1987-88 may have been in response to temperatures; larvae in 1987-88 (Brood B) wintered more deeply in the soil as well, apparently because soil temperatures were lower than in the previous winter. It is interesting to note that the vertical distribution of Brood A adults from July to October in 1987-88 (Fig. 4) was similar to that of the corresponding wintering larvae in 1986-87, in that 78 and 79%, respectively, were found above 25 cm.

Our studies on the seasonal history and habits of the alfalfa snout beetle in eastern Ontario corroborate those of Palm (1935) and Lincoln and Palm (1941) in New York and generally agree with the findings of Hanuss (1958) and Jorgensen (1953) in Europe. However, the use of DD summations adds precision to the timing of seasonal events related to activities of the adults. Calendar dates for the occurrence of an event varied by as much as 3 weeks between years whereas DD differences were small. Therefore, DD indices should enable the timing of activity more accurately. This approach is direct, it is not time consuming and the accumulating data allow for the prediction of activity. Furthermore, it eliminates the need for pre-activity scouting.

References

Annand, P.N. 1937. The alfalfa snout beetle. Journal of Economic Entomology, 30: 715-721.

Baskerville, G.L. and P. Emin. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology, 50: 514-517.

Guppy, J.C. and D.G. Harcourt. 1989. The alfalfa snout beetle, a new pest of alfalfa in Ontario. Canadex Leaflet 121.620.

Hanuss, K. 1958. Untersuchungen uber den KleeLuzernerussler *Brachyrhinus* (*Otiorrhynchus*) *ligustici* L. [Investigations on the clover-alfalfa snout beetle, *B. ligustici* L.]. Zeitschrift fur angewandte Entomologie, 43: 233-281.

Harcourt, D.G. and M.R. Binns. 1989. Sampling technique for larvae of the alfalfa snout beetle, *Otiorhynchus ligustici* (Coleoptera: Curculionidae). Great Lakes Entomologist, 22: 121-126.

Harcourt, D.G. and J.C. Guppy. 1987. Alfalfa snout beetle. Canadian Agricultural Insect Pest Review, 65: 23.

Jorgensen, J. 1953. Biology of the alfalfa snout beetle *Otiorrhynchus ligustici* (L.) in Denmark. Kongelige VetHojsk Aarsskrift 1953: 105-146.

Lincoln, C. and C.E. Palm. 1941. Biology and ecology of the alfalfa snout beetle. Cornell University Agricultural Experiment Station Memoir, 236, 45 pp.

Loan, C.C., F. Meloche, and C.M. Maund. 1986. A new discovery of the alfalfa snout beetle, *Otiorhynchus ligustici* (Coleoptera: Curculionidae), in eastern Ontario. Proceedings of the Entomological Society of Ontario, 117: 87-90.

Matthewman, W.G. and D.G. Harcourt. 1972. Phenology of egg-laying of the cabbage maggot, *Hylemya brassicae* (Bouche) on early cabbage in eastern Ontario. Proceedings of the Entomological Society of Ontario, 102: 28-35.

Nielsen, D.G. and C.M. Edmonds. 1969. New York's own alfalfa snout beetle. New York's Food and Life Sciences 2: 13-15.

Palm, C.E. 1935. The alfalfa snout beetle, *Brachyrhinus ligustici* L. Cornell University Agricultural Experiment Station Bulletin 629, 47 pp.

York, A.C. 1974. Contributions to the biology of the alfalfa snout beetle, *Otiorhynchus ligustici* (L.). Ph.D. Thesis, Cornell University, Ithaca, N.Y. XII + 177 pp.

Vassiliev, I.V. 1914. The principal insects injurious to Lucerne. Part II. *Otiorrhynchus* (*Cryphiphorus*) *ligustici*, L., its description, life-habits, and methods of fighting it. [In Russian]. Memoirs of the Bureau of Entomology of the Scientific Committee of the Central Board of Land Administration and Agriculture, Petrograd, 82, 39 pp.

Received 17 August 1990; accepted 27 September 1990

ENTOMOPATHOGENIC FUNGI IN INSECTS IN ALFALFA FIELDS IN SOUTHWESTERN ONTARIO

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Abstract *Proc. ent. Soc. Ont.* 121:71-78

Eleven species of Entomophthorales (Zygomycotina) belonging to the genera *Conidiobolus* (Ancylistaceae), *Entomophthora*, *Erynia* (Entomophthoraceae), and *Neozygites* (Neozygitaceae) were recorded on different species of insects in alfalfa fields in southwestern Ontario, Canada. The alfalfa weevil, *Hypera postica* was found to be infected by *Erynia phytonomi*, an undescribed *Erynia* sp. and *Beauveria bassiana* (Deuteromycotina: Hyphomycetes, Moniliaceae). Attempts to introduce these fungal pathogens into populations of alfalfa weevil in alfalfa fields which had been free of pathogens for several years were successful only with *B. bassiana*.

Introduction

The alfalfa weevil, *Hypera postica* (Gyllenhal) and the weevils, *Hypera meles* (Fabricius) and *Hypera punctata* (Fabricius), are considered to be important pests of alfalfa and clover throughout the northern part of the North American continent. The population dynamics, including the effects of parasites and pathogens, especially of the alfalfa weevil, have been studied extensively (Arthur 1886; Harcourt *et al.* 1977; Johnson *et al.* 1984; Puttler *et al.* 1978, 1979).

A fungus found on the clover leaf weevil in New York State, U.S.A., was described by Arthur (1886) as *Entomophthora phytonomi* Arthur (Entomophthorales). Recently this fungus was transferred (Humber and Ben-Ze'ev 1981) to the genus *Erynia* Nowakowski as *Erynia phytonomi* (Arthur) Humber *et al.* in a major taxonomic reorganization of the order Entomophthorales (Ben Ze'ev and Kenneth 1982a, 1982b; Ben-Ze'ev *et al.* 1987; Humber 1981; Humber and Ben-Ze'ev 1981). Another synonym is *Zoophthora phytonomi* (Arthur) Batko.

Several decades after the description of *E. phytonomi* by Arthur (1886), the fungi *Entomophthora (Tarichium) punctata* Garbowski and *Tarichium phytonomi* Jaczewski were described as the causal agents of death of the alfalfa weevil in Poland and the U.S.S.R., respectively (MacLeod and Müller-Kögler 1970). They were considered by MacLeod and Müller-Kögler to belong to one species, *Tarichium punctatum*. Another fungal pathogen, *Beauveria bassiana* (Balsamo) Vuillemin, a fungus that kills several species of insects, was found in alfalfa weevils in the U.S.A. (Essig 1926). More recently, *E. phytonomi* was reported to attack the alfalfa weevil, *H. postica*, in Ontario (Harcourt *et al.* 1974) and in Israel (Ben-Ze'ev and Kenneth 1980). The latter authors found that the form and dimensions of the Israeli isolate were similar to those of the species described by Arthur but

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the Canadian isolate, despite several morphological similarities, appeared to belong to another species.

Preliminary observations in 1978 to 1980 (Jaques unpublished) indicated that mortality of the alfalfa weevil by *Erynia* and *Beauveria* species rarely occurred in fields of alfalfa on or near the Harrow Research Station in southwestern Ontario. The study reported here was to identify the fungi that cause disease in populations of insects in alfalfa fields in this area, especially fungi infecting the alfalfa weevil. A second aim of the study was to introduce fungal pathogens into field populations of the alfalfa weevil.

Methods, results and discussion

Twelve species of entomopathogenic fungi were found in insects on alfalfa during the study (Table I). Eleven of these are Zygomycetes in the order Entomophthorales and one is in the Hyphomyctes. Descriptions of the life stages of the species and experiments to propagate isolates and to assess infectivity are discussed.

TABLE I. Fungi infecting insects in alfalfa fields in southwestern Ontario.

Order and Family	Genus and Species	Host Insect
Zygomycotina: Entomophthorales		
Ancylistaceae	*Conidiobolus obscurus*	Aphids
	Conidiobolus thromboides	Aphids
Entomophthoraceae	*Entomophthora muscae*	Seedcorn maggot, *Dehlia platura*
	Entomophthora planchoniana	Aphids, *Myzus persicae* and *Rhopalosiphum padi*
	Erynia echinospora (or *Erynia dipterigena*)	Flies (Diptera: Lauxaniidae)
	Erynia neoaphidis	Aphids, *Acyrthosiphon pisum* and *Myzus persicae*
	Erynia petchii	Meadow spittlebug, *Philaenus spumarius*
	Erynia phytonomi	Alfalfa weevil, *Hypera postica*
	Erynia sp.	Alfalfa weevil, *Hypera postica*
	Erynia radicans	Potato leafhopper, *Empoasca fabae*, Aphids
Neozygitaceae	*Neozygites fresenii*	Aphids
Deuteromycotina: Hyphomycetes		
Moniliaceae	*Beauveria bassiana*	*Hypera postica* (Adults)

Entomophthorales

Conidiobolus obscurus and *Conidiobolus thromboides*

A mixed population of aphids, including *Acyrthosiphon pisum* (Harris), *Aphis fabae* Scopoli and *Myzus persicae* (Sulzer), developed on alfalfa plants that were transplanted in October from the field to pots and kept in a glasshouse (21-25°C, 30-50% RH). About 10 days after transplanting, a few aphids infected by *Entomophthora planchoniana* Cornu and *Erynia neoaphidis* Remaudiere and Hennebert were found on the plants.

Artificial inoculation of the aphids with *Erynia radicans* (Brefeld) Humber, Ben-Ze'ev and Kenneth was attempted by inverting Petri dishes of conidiating colonies of the fungus overnight over aphid-infested alfalfa plants enclosed in plastic bags to increase relative humidity. Examination of aphids found dead after 3 days indicated infection by a species of *Conidiobolus* which produced both conidia and resting spores. After 10 days, substantial numbers of aphids were killed by fungi. Many of the dead aphids examined were found to be infected with *Conidiobolus obscurus* (Hall and Dunn) Remaudiere and Keller, *Conidiobolus thromboides* Drechsler, and *E. neoaphidis*. The two *Conidiobolus* species were distinguished according to the criteria of Remaudiere *et al.* (1979) and Latge (1983). Aphids infected by *E. radicans* were not found. Because the alfalfa was transplanted from the field, it is considered that *C. thromboides* and *C. obscurus*, like *E. neoaphidis*, occurred naturally in the populations of the aphids in the field and developed when conditions were favourable.

Conidiobolus obscurus and *C. thromboides* were isolated on Entomophthora Complete Medium (ECM) (Ben-Ze'ev 1980) and were grown also on Potato Dextrose Agar (PDA) and on Saboraud Maltose Agar + 1% yeast extract (SMYA). *C. obscurus* grew slowly and sparsely on PDA without folding the medium or changing its colour but it grew vigorously on the other two media changing the colour of the medium around the colony to yellow-brown and folding the surface. The mycelium was cream coloured. The mycelium of *C. thromboides* was white, producing conidia much more copiously than did *C. obscurus* without folding the medium or changing its colour. Resting spores of both species were obtained in culture.

Entomophthora muscae

A 12-nucleate strain (Ben-Ze'ev and Ewen 1982; Ben-Ze'ev and Zelig 1984) of the *Entomophthora muscae* complex (Keller 1984, 1987) was found in a dead adult of a seedcorn maggot, *Dehlia* (=*Hylemya*) *platura* (Meigen) which was hanging by the rostrum from a leaf of an alfalfa plant in a field in October 1980. Adults of *D. platura* infected with this strain of *E. muscae* were found in the same field in the following year; the first infected specimen was found on 2 June, 1981 and within a week an epizootic of the fungus was in progress. Large numbers of fungus-killed adults were found hanging singly or in clusters of 3 to 6 flies on alfalfa leaves and on weeds. The epizootic recurred in 1982; adults of *D. platura* infected with the fungus were found in samples taken (May 14-17) from several alfalfa fields, from a field of rye adjacent to one of the alfalfa fields near Harrow and from graminaceous weeds in the city of Windsor. Most of the fungus-killed seedcorn maggots on rye were hanging from tips of the rye plants infected by the phytopathogen, *Claviceps purpurea*, demonstrating a coincident occurrence of an entomopathogen and a phytopathogen similar to that described by Ingold and Plunkett (1979).

Primary conidia of this strain of *E. muscae* were 10- to 13-nucleate and measured (n=50) 27.1 x 22.6 µm (range 22.1-31.6 x 18.2-26.9 µm); the length/width ratio was 1.21 (1.1-1.36); and average diameter of nuclei (n=50 conidia) was 3.2 µm. A different 12-nucleate strain of *E. muscae* with average conidial dimensions of 22.7 x 17.8 µm was found in adults of *D. platura* and *Dehlia antiqua* (Meigen) in Michigan (Carruthers *et al.* 1985).

Entomophthora planchoniana

Entomophthora planchoniana Cornu was found in a dead aphid, probably *M. persicae*, on alfalfa plants brought from the field into the glasshouse in October (see *Conidiobolus*

spp.), in unidentified aphids on alfalfa in a field near Harrow in June 1981, and in the aphid, *Rhopalosiphum padi* (L.) on barley in a field of alfalfa and barley at the Research Station, Harrow, in May 1982.

Erynia echinospora or *Erynia dipterigena*

Erynia echinospora (Thaxter) Remaudiere and Keller and *Erynia dipterigena* (Thaxter) Remaudiere and Keller are very similar in the conidial stage and are best distinguished by differences in resting spores. Because resting spores were not found, the isolates may have been either species. The fungus, or fungi, were found in several individuals of red flies (unidentified genus and species of Diptera: Lauxaniidae) which were abundant in alfalfa fields near Harrow in September 1981.

Erynia neoaphidis

Erynia neoaphidis Remaudiere and Hennebert caused mortality of approximately 10 percent of a population of aphids, *A. pisum* and unidentified aphids, in a field of alfalfa in October 1980. This fungus was found later in these species of aphids on alfalfa plants brought from the field to a glasshouse (see *Conidiobolus* spp.). In addition, a population of unidentified aphids in an alfalfa field in June 1981 was infected by *E. neoaphidis* and *E. planchoniana*. Resting spores were not found in infected aphids; this species is considered to be lacking this kind of spore (Remaudiere and Hennebert 1980; Courtois and Latteur 1984). One isolate of *E. neoaphidis* from *A. pisum* was cultivated on ECM and SMYA and was found several years later to be capable of producing resting spores *in vitro* (Uziel and Kenneth 1986).

Erynia petchii

A mummified meadow spittlebug, *Philaenus spumarius* (L.), was collected by sweeping in an alfalfa field at the Arkell Experimental Station, University of Guelph, Guelph, Ontario, in July 1982. Conidiophores and rhizoids emerged and primary conidia were produced and discharged during a 24-hour rehydration period. The size and shape of these structures and the characteristics of the host at death were typical of *Erynia petchii* (Ben-Ze'ev and Kenneth) (Ben-Ze'ev and Kenneth 1981, 1982b). This is the first reported occurrence of *E. petchii* outside of England (Petch 1934).

An interesting characteristic of *E. petchii* is that the nucleus in a substantial number of primary conidia divided into two daughter nuclei immediately after a short germ-tube started to form. Some conidia with two nuclei but without a germ-tube were seen among germinating conidia, but not among freshly discharged ones, indicating that nuclear division occurred in some conidia before germination became visible. This characteristic was not noticed in earlier studies on this fungus (Ben-Ze'ev and Kenneth 1981; Petch 1934) or in studies on other species of *Erynia*.

A small colony of *E. petchii* was established on ECM but the fungus ceased to grow after one week. Transfers to fresh ECM or SMYA were not successful

Erynia phytonomi and *Erynia* sp.

Populations of alfalfa weevil, *H. postica*, in alfalfa fields at several locations in southern Ontario were sampled in 1978 to 1982 to determine populations of the alfalfa weevil and the occurrence of parasitic, predacious and pathogenic biological control agents (Harcourt *et al.* 1979, 1981a). Larvae killed by a fungus, tentatively identified as *Erynia* (=*Entomophthora*) *phytonomi* (Arthur) Humber, Ben-Ze'ev and Kenneth, were found in fields on the Arkell Experimental Station and at the University of Guelph in each sample year (D.G. Harcourt and C.R. Ellis personal communication). Adult weevils killed by *Beauveria bassiana* (Balsamo) Vuillemin were also found in these samples.

Larvae collected at Guelph in June 1981 and 1982 by the authors, near Ottawa in June 1981 by Dr. J.C. Guppy, Research Station, Agriculture Canada, Ottawa, Ontario and near

Columbia, Missouri, U.S.A., in September 1980 by Dr. B. Puttler, United States Department of Agriculture, Columbia, Missouri, were found to contain conidia of *E. phytonomi* as defined by Ben-Ze'ev and Kenneth (1980). Isolates grown in culture on ECM produced smooth-walled, subhyaline resting spores characteristic of this species (Ben-Ze'ev and Kenneth 1980; Harcourt *et al.* 1981b). In addition, some larvae from these sources were dark grey to black and contained rough-walled, brown resting spores as described by Harcourt *et al.* (1974). These spores were externally very similar to the resting spores of *Conidiobolus osmodes* Drechsler found in dead larvae of *H. postica* in Israel (Ben-Ze'ev and Kenneth 1980) and in southern France (Papierok *et al.* 1986). Several entomophthoroid nuclei were found in resting spores in our specimens from Ontario and Missouri indicating that the fungus was a species of *Erynia* different from *E. phytonomi*. The staining of nuclei of these spores with acetocarmine demonstrated that they were not resting spores of the genus *Conidiobolus*; nuclei of *Conidiobolus* do not stain with acetocarmine. Similarly, the fungi in specimens of *H. postica* examined by Tyrrell *et al.* (1981) and by Dr. D. Perry (personal communication) in which nuclei of resting spores were stained by acetocarmine were not spores of the genus *Conidiobolus*.

Primary conidia of *Erynia* species found in some of the *H. postica* larvae in our collections differed in size from conidia of *E. phytonomi* and resembled the conidia of the fungus reported as *Entomophthora phytonomi* by Harcourt *et al.* (1974) and later tentatively named *Zoophthora punctata* by Harcourt *et al.* (1981b) and Tyrrell *et al.* (1981). A description of the conidial and resting spore stages of this species of *Erynia* is being prepared (D.M. MacLeod and D. Tyrrell personal communication).

Introduction of *E. phytonomi* and *Erynia* species into a field population of *H. postica* was attempted by treating 1-m^2 areas in the centre of 10m by 10m plots in a field of alfalfa at the Harrow Research Station, a locality in which infection of *H. postica* by these fungi was not recorded previously. Twenty dead *H. postica* larvae collected near Ottawa with symptoms of infections by *E. phytonomi* were attached to alfalfa plants in each of five of the plots. Twenty dead larvae from the same source containing resting spores of *Erynia* sp. were attached to plants in each plot in a second group of five plots. Plant debris and soil (to 10 mm depth) from an alfalfa field at the Arkell Experimental Station in which *E. phytonomi* and *erynia* species were found in the previous 3 years was spread (2kg/m^2) in the remaining five plots. None of the treatments resulted in detectable infection or mortality of *H. postica* larvae by either of the two pathogens during the next two seasons (June-July 1982 and 1983) in or adjacent to the marked plots indicating a failure to introduce the pathogens.

Erynia radicans

Empoasca fabae (Harris) (Homoptera: Cicadellidae) and an unidentified aphid infected with the conidial stage of *Erynia radicans* (Brefeld) Humber, Ben-Ze'ev and Kenneth were found on alfalfa at the Harrow Research Station in July and August 1982.

Neozygites fresenii

Unidentified aphids infected with the conidial stage of *Neozygites fresenii* (Thaxter) Remaudiere and Keller were found on weeds in an alfalfa field at the Harrow Research Station in August and September 1981.

Hyphomycetes

Beauveria bassiana

Adults of *H. postica* that died after collection in September and October 1980 from the Arkell Experimental Station were found to be infected by *Beauveria bassiana* (Balsamo) Vuillemin (identified by Prof. R.G. Kenneth, Hebrew University of Jerusalem, Israel). Likewise, some adults and larvae collected in October 1980 at the Harrow Research Station were killed by this fungus.

Laboratory tests showed that *B. bassiana* isolated and grown in pure culture on SMYA caused high mortality of larvae and adults of *H. postica*. Test insects were reared in groups of 10 in 75-ml plastic cups at 25°C. All fourth-instar larvae and adults brush-painted with suspensions of conidia were killed with typical symptoms of death by the fungus. Likewise, 95% of the 100 larvae and adults that fed on alfalfa leaves previously dipped in a suspension of the fungus (10^5 conidia/ml) were killed in 10 to 12 days.

Conidia of *B. bassiana* were applied in April to two plots (each 10 x 10m) in an alfalfa field at Harrow that had been infested with *H. postica* in the previous year. Conidia were propagated in Petri dishes on SMYA and suspended in distilled water containing Tween 20 (0.01% v/v). Each plot was sprayed with a 20-L volume of suspension containing 1 x 10^5 conidia/ml using a compressed-air sprayer (275 Kpa pressure). Ten laboratory-reared larvae were fed alfalfa leaves collected from the plants 1, 3 and 5 days after spraying to assess efficacy of the application. Ten, 10, and 9 of the test larvae that fed on the leaves in the respective samples were killed by the fungus in 7 to 12 days.

Fungus-killed larvae or adults were not found in the sprayed plots or in the nontreated plots in a six-month period following application of *B. bassiana*. However, mortality of larvae, pupae and adults of *H. postica* collected from the plots and reared in the laboratory at a high relative humidity indicated that the fungus remained active in the treated plots and affected the survival of the insect. Mortality by *B. bassiana* among insects collected from treated plots in June, July, September and October was 10 to 20% in 12 days after collection. No mortality by *B. bassiana* occurred among weevils collected from the nontreated plots.

The diversity of species of entomofungi found in the alfalfa weevil, aphids and other insects associated with alfalfa fields in southern Ontario in this study indicates the potential that entomofungi may have in the natural regulation of pests of this crop. Introduction of the entomofungi to supplement other biological control agents in control of the alfalfa weevil warrants evaluation.

Acknowledgements

One of the authors, I.S.B., was supported during this study by a Post-Doctoral Fellowship granted by the Natural Sciences and Engineering Research Council of Canada. We are grateful to the colleagues who contributed infected insects, identifications and personal communications and to Daniel R. Laing for his excellent technical assistance.

References

Arthur, J.C. 1886. Disease of clover-leaf weevil, *Entomophthora phytonomi* Arthur. Annual Report of the New York Experiment Station, 4: 252-262,291.

Ben-Ze'ev, I. 1980. Systematics of entomopathogenic fungi of the '*sphaerosperma* group' and their prospects for use in biological pest control. Ph.D. thesis. The Hebrew University of Jerusalem (in Hebrew with English summary, Appendices and Tables). 119 pp.

Ben-Ze'ev, I. and A.B. Ewen. 1982. On the taxonomic value of certain pathobiological interactions between entomogenous Entomophthorales and their hosts (Entomophthorales Discussions: Pathobiology, 4 pp.). Proceedings of the III International Colloquium on Invertebrate Pathology, September 1982, Brighton, U.K.

Ben-Ze'ev, I. and R.G. Kenneth. 1980. *Zoophthora phytonomi* and *Conidiobolus osmodes* (Zygomycetes: Entomophthoraceae), two pathogens of *Hypera* species (Col: Curculionidae) coincidental in time and place. Entomophaga, 25: 171-186.

Ben-Ze'ev, I. and R.G. Kenneth. 1981. *Zoophthora radicans* and *Zoophthora petchii* sp. nov. (Zygomycetes: Entomophthorales), two species of the '*Sphaerosperma* group' attacking leaf-hoppers and frog-hoppers (Hom.). Entomophaga, 26: 131-142.

Ben-Ze'ev, I. and R.G. Kenneth. 1982a. Features-criteria of taxonomic value in the Entomophthorales. I. A revision of the Batkoan classification. Mycotaxon, 14: 393-455.

Ben-Ze'ev, I. and R.G. Kenneth. 1982b. Features-criteria of taxonomic value in the Entomophthorales. II. A revision of the genus *Erynia* Nowakowski 1881 (=*Zoophthora* Batko 1964). Mycotaxon, 14: 456-475.

Ben-Ze'ev, I., R.G. Kenneth, and A. Uziel. 1987. A reclassification of *Entomophthora turbinata* in *Thaxterosporium* gen. nov., Neozygitaceae fam. nov. (Zygomycetes: Entomophthorales). Mycotaxon, 28: 313-326.

Ben-Ze'ev, I. and Y. Zelig. 1984. *Entomophthora israelensis* sp. nov. (Zygomycetes: Entomophthorales), a fungal pathogen of gall midges (Diptera: Cecidomyiidae). Mycotaxon, 21: 463-474.

Carruthers, R.I., D.L. Haynes, and D.M. MacLeod. 1985. *Entomophthora muscae* (Entomophthorales: Entomophthoraceae) mycosis in the onion fly, *Dehlia antiqua* (Diptera: Anthomyiidae). Journal of Invertebrate Pathology, 45: 81-93.

Courtois, P. and G. Latteur. 1984. Etude quantitative de la survie des corps hyphaux d'*Erynia neoaphidis* Remaud. et Henn. (Zygomycetes: Entomophthoraceae) en fonction de la temperature et de l'humidite relative. Parasitica, 40: 211-220.

Essig, E.O. 1926. Coleoptera. *In*: E.O. Essig (Ed.), Insects of Western North America. The MacMillan Company, New York. pp. 369-521.

Harcourt, D.G., C.R. Ellis, and J.C. Guppy. 1979. Distribution of *Microtonus aethiopoides*, a parasite of the alfalfa weevil (Coleoptera: Curculionidae) in Ontario. Proceedings of the Entomological Society of Ontario, 110: 35-39.

Harcourt, D.G., J.C. Guppy, and M.R. Binns. 1977. The analysis of intrageneration change in Eastern Ontario populations of the alfalfa weevil, *Hypera postica* (Coleoptera: Curculionidae). The Canadian Entomologist, 109: 1521-1534.

Harcourt, D.G., J.C. Guppy, D.M. MacLeod, and D. Tyrrell. 1974. The fungus *Entomophthora phytonomi* pathogenic to the alfalfa weevil, *Hypera postica*. The Canadian Entomologist, 106: 1295-1300.

Harcourt, D.G., J.C. Guppy, and C.R. Ellis. 1981a. Distribution of *Microtonus colesi* (Hymenoptera: Braconidae), a new parasite of the alfalfa weevil in Ontario. Proceedings of the Entomological Society of Ontario, 112: 33-37.

Harcourt, D.G., J.C. Guppy, D.M. MacLeod, and D. Tyrrell. 1981b. Two *Entomophthora* species associated with disease epizootics of the alfalfa weevil, *Hypera postica* (Coleoptera: Curculionidae), in Ontario. Great Lakes Entomologist, 14: 55.

Humber, R.A. 1981. An alternative view of certain taxonomic criteria used in the Entomophthorales (Zygomycetes). Mycotaxon, 13: 191-240.

Humber, R.A. and I. Ben-Ze'ev. 1981. *Erynia* (Zygomycetes: Entomophthorales): emendation, synonymy and transfers. Mycotaxon, 13: 506-516.

Ingold, C.T. and B.E. Plunkett. 1979. An epidemic of *Entomophthora* on flies and its relationship with the *Spacelia* stage of *Claviceps*. Bulletin of the British Mycological Society, 13: 35-37.

Johnson, J.A., I.M. Hall, and K.Y. Arakawa. 1984. Epizootiology of *Erynia phytonomi* (Zygomycetes: Entomophthorales) and *Beauveria bassiana* (Deuteromycetes: Moniliales) parasitizing the Egyptian alfalfa weevil (Coleoptera: Curculionidae) in southern California. Environmental Entomology, 13: 95-99.

Keller, S. 1984. *Entomophthora muscae* als Artenkomplex. Mitteilungen der Schweizerischen Entomologischen Gesellschaft, 57: 131-132.

Keller, S. 1987. Arthropod-pathogenic Entomophthorales of Switzerland. 1. *Conidiobolus*, *Entomophaga* and *Entomophthora*. Sydowia, 40: 122-167.

Latge, J.P. 1983. *Conidiobolus obscurus* et les Entomophthorales Pathogenes de Pucerons. D.Sc. thesis, Universite de Paris-Sud. Vol. 1. 119 pp.

MacLeod, D.M. and E. Müller-Kögler. 1970. Insect pathogens: Species originally described from their resting spores mostly as *Tarichium* species (Entomophthorales: Entomophthoraceae). Mycologia, 62: 33-66.

Papierok, B., J.P. Aeschliman, and C. Loan. 1986. Two entomophthoralean fungi occurring on *Hypera postica* in southern France. Journal of Invertebrate Pathology, 48: 377-380.

Petch, T. 1934. Notes on entomogenous fungi. 86. *Entomophthora aphrophorae* Rostrup. Transactions of the British Mycological Society, 19: 179-180.

Puttler, B., D. Hostetter, S.H. Long, and R.E. Pinnell. 1978. *Entomophthora phytonomi*, a fungal disease of the alfalfa weevil in the Mid-Great Plains. Environmental Entomology, 7: 670-671.

Puttler, B., D. Hostetter, S.H. Long, R.E. Munson, and J.L. Huggans. 1979. Distribution of the fungus *Entomophthora phytonomi* in larvae of the alfalfa weevil in Missouri. Journal of Economic Entomology, 72: 220-221.

Remaudiere, G. and G.L. Hennebert. 1980. Revision systematique de *Entomophthora aphidis* Hoffm. in Fres. Description de deux nouveaux pathogenes d'aphides. Mycotaxon, 11: 269-321.

Remaudiere, G., J.P. Latge, and B. Papierok. 1979. Reconsideration taxonomique de *Entomophthora obscura* Hall et Dunn. Annales de Microbiologie (Paris), 130A: 151-162.

Tyrrell, D., D.M. MacLeod, J.C. Guppy, and D.G. Harcourt. 1981. Entomophthoraceous fungi on the alfalfa and clover leaf weevils in Ontario. Proceedings of the XIV Annual Meeting of the Society for Invertebrate Pathology, August, 1981. Bozeman, Montana.

Uziel, A. and R.G. Kenneth. 1986. *In vivo* resting-spore formation in *Erynia neoaphidis*. *In*: R.A. Samson, J.M. Vlak, and D. Peters (Eds.). Fundamental and Applied Aspects of Invertebrate Pathology. Proceedings of the IVth International Colloquium on Invertebrate Pathology, Wageningen, The Netherlands. p. 230.

Received 27 June 1989; accepted 17 July 1990

ACQUISITION AND TRANSMISSION OF *PSEUDOMONAS CICHORII* BY *LIRIOMYZA TRIFOLII* (DIPTERA: AGROMYZIDAE)

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Abstract. *Proc. ent. Soc. Ont.* 121:79-84

Adults of the serpentine leafminer, *Liriomyza trifolii* (Burgess) were able to acquire and transmit *Pseudomonas cichorii* (Swingle) Stapp. both *in vitro* from cultures of the bacteria, and *in situ* from infected to non-infected chrysanthemums. Forty-three percent of adult leafminers exposed to *P. cichorii* in culture jars acquired the bacterium. More infected leafminers were detected by homogenizing (43.0%) as compared to rinsing (15.0%), suggesting ingestion of bacteria by leafminers. The use of the wetting agents Tween 20® and bacitracin enhanced the recovery of *P. cichorii* from homogenized adults of *L. trifolii*.

A mean of 7.9 bacterial leafspots per plant was observed after a 48 h exposure of healthy chrysanthemums to 10 adult leafminers which had been confined on infected chrysanthemums for 24 h. Less than 5% of leafminers observed under a scanning electron microscope had detectable bacterial particles on the cuticle that were in the size range expected for *P. cichorii*. Larval leafminers acquired *P. cichorii* and transmitted bacteria as did adults when confined to culture jars. When *P. cichorii* was introduced to chrysanthemums after oviposition by leafminers, there was a 41.7% reduction in subsequent emergence of prepupae.

Introduction

The bacterium *Pseudomonas cichorii* (Swingle) Stapp. was identified as the causal agent of a leafspot disease of florists' chrysanthemum (*Chrysanthemum morifolium* Ramat.) in Florida (McFadden 1961). In 1983, this disease caused economic losses to chrysanthemums in Canada (Matteoni 1984). Price and Harbaugh (1982) and Poe (1983) had noticed an interaction between serpentine leafminers, *Liriomyza* spp., and bacterial leafspot in chrysanthemums. A serpentine leafminer, *Liriomyza trifolii* (Burgess), has been a major pest of chrysanthemums in Canada since the late 1970s (Broadbent 1983). Matteoni and Broadbent (1988, 1989) noted the interaction between *L. trifolii* and bacterial leafspot in an Ontario greenhouse in 1984 and demonstrated that wounds on chrysanthemum foliage, caused by feeding and oviposition, provided sites for ingress of the bacteria.

In this study, the role of *L. trifolii*, as a vector of *P. cichorii* on chrysanthemums was examined. The epidemiological significance of this interaction is discussed.

Materials and Methods

Plant Material. Commercially-produced rooted chrysanthemum (cv. Manatee Iceberg) cuttings were grown as stock plants for at least 8 weeks without the use of pesticides. Cuttings from these stock plants were rooted under mist, potted in a 4:2:1 Vineland loam:peat:sand mixture in 10 cm diameter clay pots, and grown for 3 to 8 weeks. The growing tips and all but 4 or 5 mature leaves were removed from plants of the same age before testing.

Leafminer culture. A culture of *Liriomyza trifolii* was established from an infestation on chrysanthemum in a greenhouse on the Niagara Peninsula. Approximately 100-150 adult leafminers were maintained in 0.2 m^3 cages on chrysanthemum cv. Manatee Iceberg at 27°C, 65% RH and 16 h light. Test chrysanthemums were exposed to leafminers for feeding or oviposition or both, four plants at a time. Adult leafminers were shaken from plants after a 1 h exposure.

Bacterial strains and inoculation. Bacteria were isolated from infected chrysanthemum and identified as *P. cichorii* (Matteoni and Broadbent 1988). Bacterial cultures were maintained at 4°C either in culture tubes containing sterilized water or on nutrient agar (Difco Laboratories, Detroit, MI) in 9 cm diameter Petri dishes. Bacteria were inoculated and reisolated regularly from test chrysanthemums to ensure pathogenicity.

For inoculation, *P. cichorii* was smeared onto dishes of nutrient agar supplemented with glucose (1.0% w:v) and incubated 18-24 h at 27°C. Bacteria were rinsed from the agar surface and diluted in sterilized tap water (pH 7.0). Except where noted, bacterial suspensions were adjusted to a concentration of 1-5 x 10^8 colony forming units (cfu)/mL with a spectrophotometer based on a standard curve established previously (absorbance = 0.26 at λ = 690 nm).

Chrysanthemums were inoculated with bacteria in one of two manners. Bacterial suspensions were sprayed on leaves "to runoff" with a hand-held mist bottle at 14 kPa from a distance of 15-30 cm. A second method involved "pierce-inoculation" of individual leaves with an insect pin (no. 00) dipped in a suspension of *P. cichorii* (Matteoni 1984). After inoculation, plants were misted with sterilized tap water and placed in polyethylene bags (81.5 x 47.0 cm) for 48 h to develop leafspots (Jones *et al.* 1985).

Acquisition of *P. cichorii*. Wide-mouth glass jars (8 cm diameter x 6.5 cm) of *P. cichorii* for acquisition experiments were prepared by pouring to a depth of 1.5 cm, nutrient agar supplemented with glucose (1.0% w:v) and seeded with a suspension of *P. cichorii*, to an approximate concentration of 10^3 cfu/mL agar. These jars were covered and incubated for 24 h at 27°C and then uncovered and inverted to allow the agar surface to partially dry for 24 h at 27°C. To test whether *L. trifolii* acquired *P. cichorii* from agar culture, ten newly-emerged adult leafminers (<24 h) were placed into each of five jars with bacterial culture and five jars with nutrient agar only (control). Jars were covered with screening, inverted, and incubated for two days at 27°C. This experiment was repeated four times.

Adults were removed from the jars and separated according to sex. Dead leafminers stuck in agar (<10%) were discarded. To recover the bacterium, individual leafminers were either rinsed in sterilized tap water with moderate agitation for 20 s supplied by a Vortex-Genie® (Scientific Industries, Inc., Bohemia, NY) or homogenized in sterilized tap water for 10 s with an Ultra-Turrax® SDT tissue homogenizer (Tekmar Co., Cincinnati, OH) using 1.0 mL/adult. Immediately after rinsing or homogenization, 0.5 mL was spread evenly over a nutrient agar plate, and incubated for 48 h at 27°C in an inverted position. Bacterial colonies with morphology similar to that of *P. cichorii* were isolated, purified and identified using standard biochemical tests (Sands *et al.* 1980, Fahy and Lloyd 1983). Presence of *P. cichorii* and its population levels were calculated.

To determine whether or not wetting agents enhanced recovery of the bacterium from insects, ten pairs (one male and one female) of leafminers were homogenized in each of five treatments: sterilized tap water alone (control), or amended with Tween-20® (polyoxyethylenesorbitan, at 300 µg/mL, or bacitracin (Sigma Chemical Co., St. Louis, MO) at 1, 10 and 100 µg/mL of sterilized tap water. Bacitracin acts as a wetting agent at these non-bactericidal concentrations (M. Parthasarathy, pers. comm.). The homogenates were tested for the presence of bacteria as described above.

Acquisition of *P. cichorii* from infected chrysanthemums by *L. trifolii* was also tested. In each of ten replicated tests, five chrysanthemum plants were pierce-inoculated with *P. cichorii*, as described above, and placed in polyethylene bags (81.5 x 47.0 cm) to maintain high humidity (>95% RH) for 4 days in a growth chamber at 27°C, 70% RH, 16 h light (18

μmol^{-1} m^{-2} PAR at plant height). These plants, stripped to 4 or 5 symptomatic leaves, were then covered with glass lamp chimneys (base 8.5 cm diameter x 16.5 cm height) with mesh-screened tops. Five noninoculated (control) plants also were placed in lamp chimneys. Fifteen newly emerged (< 24 h) leafminer adults were aspirated into each lamp chimney. The covered plants were kept for 24 h at 27°C, after which 10 leafminers per cage were aspirated from lamp chimneys directly into separate jars containing nutrient agar. After 24 h at 27°C, leafminers were removed, and the jars were kept for 48 h to see if any colonies of *P. cichorii* developed on the agar.

The acquisition of *P. cichorii* by larvae of *L. trifolii* was tested. In each of twelve replicated trials, ten chrysanthemums were exposed to leafminer for 1 h. Five of these plants were mist-inoculated with *P. cichorii*, within 1 h of egg deposition, and five were sprayed with sterilized tap water (control). These plants were placed in separate plastic bags for 24 h in a growth chamber at 27°C and 16 h light. After 6 days, the plants were removed and all the leaves were placed on sterile trays to collect and count emergent pupae which were placed in petri dishes at 30°C. Ten newly emerged adult leafminers (days 13-15 after oviposition) were placed in each jar of agar. After 24 h, the leafminers were removed and *P. cichorii* colonies were allowed to develop at 27°C for 4 days. The proportion (P) of adult leafminers carrying *P. cichorii* was estimated with the 'maximum likelihood equation' $P = 1-Q^{1/n}$ where Q is the proportion of jars from which *P. cichorii* was not isolated and n is the number of leafminers per jar (Gibbs and Gower 1960).

Transmission of *P. cichorii*. Preliminary studies had demonstrated that adult leafminers could successfully transmit *P. cichorii* from an agar culture to chrysanthemums under conditions of high humidity, so we tested whether transmission of *P. cichorii* from infected chrysanthemums to non-infected chrysanthemums could occur. In each of 10 replicated tests, five chrysanthemums were pierce-inoculated with *P. cichorii* suspension and five were sprayed with sterilized tap water (control). These plants were placed in polyethylene bags (81.5 x 47.0 cm) for 4 days to maintain high humidity and kept in a growth chamber at 27°C and 16 h light. Plants were stripped to the bottom 4-5 leaves and covered with lamp chimneys and each exposed to 15 newly emerged adult leafminers for 24 h at 27°C. Ten of these leafminers per lamp chimney were transferred to clean chrysanthemum plants under clean lamp chimneys for 48 h at 27°C. The leafminers were then removed and plants were misted with sterilized tap water and placed in polyethylene bags for 3 days to observe leafspot development.

Scanning electron microscopy (SEM). Leafminers exposed to either infected or healthy chrysanthemums for 48 h were refrigerated to immobilize them and then fixed by exposing them to fumes of glutaraldehyde at 25°C for 30 minutes. More than 100 leafminers were then attached to SEM stubs with double sticky tape, gold-coated, and observed with a Hitachi S-570 SEM at 20 kV for presence of bacteria.

Healthy and infected chrysanthemum leaves also were prepared for observation by SEM to examine the distribution and availability of populations of bacteria on the leaf surface. Plants were pierce-inoculated, and individual leaf lesions which resulted from infected plants and leaf sections from noninoculated plants were fixed in paraformaldehyde-glutaraldehyde (Karnovski 1965) for 48 h at 4°C, gradually returned to room temperature for dehydration in a graded series of acetone and subjected to critical point drying. Leaves were mounted, coated, and observed as described above.

Results and Discussion

Acquisition of *P. cichorii*. Adults of *Liriomyza trifolii* were able to acquire *P. cichorii* both *in vitro* from cultures of the bacteria, and *in situ* from infected chrysanthemum plants. Of the 335 adult leafminers exposed to bacterial cultures in jars, 144 (43.0%) acquired this bacterium, with a mean of 30.0 cfu/leafminer. There were no significant differences

(χ^2=0.098; P<0.50; n=335; df=1) between the number of males (44.0%) and females (42.3%) which acquired *P. cichorii* from jar cultures. However, significantly more (χ^2=45.600; P<0.005; n=335; df=1) infested leafminers were detected by the homogenizing technique (43.0%) as compared to the rinsing technique (15%). The increased recovery of bacteria by homogenizing may reflect ingestion of the bacteria by leafminer, dispersal of bacterial aggregates into smaller cfu, or increased ability to wet the cuticle.

The addition of wetting agents (Table I) significantly enhanced recovery of *P. cichorii* from *L. trifolii* (P<0.001 by orthogonal contrasts, Snedecor and Cochran 1967). Tween 20® and the two higher rates of bacitracin significantly (P<0.05) increased the numbers of cfu/leafminer detected by homogenizing.

TABLE I. Effect of wetting agents on the recovery of bacteria from ten pairs of *Liriomyza trifolii* (1 male plus 1 female), previously exposed to agar cultures of *Pseudomonas cichorii*.

Treatment	Concentration (μg/mL)	Mean cfu/leafminer[1]
Tap water	-	3.5 a
Tween-20®	300	99.7 b
Bacitracin	1	20.4 a
Bacitracin	10	90.1 b
Bacitracin	100	206.1 c

[1] Means (cfu = colony forming units) followed by the same letter are not significantly different at the P < 0.05 level as determined by LSD.
Orthogonal contrasts: Water vs. any wetting agent : P<0.001.
Tween 20® vs. Bacitracin: P<0.20. N.S.

In the tests of acquisition from infected chrysanthemum, bacteria were isolated in 39 jars (78%) with a mean of 2.1 (± 1.0 S.D.) *P. cichorii* colonies/jar. No *P. cichorii* colonies were observed in any of the 50 control jars. When individual leafminers were evaluated by the homogenizing technique, over half (58.9%) of the 141 adult leafminers which were exposed to infected plants had acquired *P. cichorii*. There was no significant difference (χ^2=0.743; P<0.50; n=141; df=1) between the percentage of males (54.8%) and females (62.0%) which acquired bacteria from infected plants. There was a mean bacterial count of 72.0 cfu/male and 50.0 cfu/female.

Larval leafminers can acquire *P. cichorii*; 13.6% (14/103 jars) of jars containing adult leafminers, which had been exposed as larvae to *P. cichorii*, had one or more colonies of the bacteria. The proportion of leafminers carrying *P. cichorii* was estimated from the 'maximum likelihood equation' as 1.4%. There were no colonies present in the controls (0/119 jars). Also, the number of leafminers surviving to the pupal stage was diminished by the presence of *P. cichorii*. The mean number of pupae recovered from the control and

treated jars was 210.7 (± 98.8) and 122.8 (± 84.8), respectively, representing a significant 41.7% reduction from control levels of leafminer larvae surviving to the pupal stage ($t=2.68$, df-18, $P<0.01$, paired comparison t-test, Snedecor and Cochran 1967).

Transmission of *P. cichorii*. *Liriomyza trifolii* transmitted bacteria from infected to healthy chrysanthemums, and caused a mean of 7.9 (± 4.6) leafspots/plant (1.6 leafspots/leaf). No leafspots were observed on control plants. The relatively low number of bacterial lesions may be attributed to the short exposure time of 48 h. There would be an exposure time in a commercial chrysanthemum crop of 12-13 weeks per crop cycle.

Bacterial leafspot requires wet conditions for development (Jones *et al.* 1985). Most greenhouse operators are able to reduce humidity and avoid water splash; however, propagation benches, which must be misted regularly, are conducive to *P. cichorii* development.

Scanning electron microscopy. Of the more than 100 leafminers of both sexes observed by SEM, only 5 individuals reared on infected chrysanthemums had detectable bacterial particles in the size range (2-4 x 1-2 µm) expected for *P. cichorii*. Most particles were observed on the ventral, abdominal region or on tarsi. The 5% of contaminated leafminers detected by observation with SEM was relatively low compared to the number of contaminated leafminers detected through homogenizing of leafminers and culture on agar (59%). This discrepancy may be attributed to ingestion of bacteria, loss of bacteria during specimen preparation for SEM, or our inability to locate the bacteria by SEM searching.

SEM micrographs of infected chrysanthemum leaves showed extensive bacterial populations on the adaxial surface corresponding to sunken lesions. Therefore, bacteria were available for external acquisition by leafminers, either to their tarsi, while walking on the adaxial leaf surface, or to their ventral abdomen, particularly when female ovipositors pierced the leaf epidermis; internally, when both sexes fed on the exudate from leaf wounds, or in the larval stage while feeding on infected leaf tissues.

Conclusions

Our study has demonstrated that *L. trifolii* can serve as a vector of *P. cichorii* in chrysanthemums under conditions of leaf wetness or high humidity. Harrison *et al.* (1980) listed other *Pseudomonas* spp. known to be transmitted to cultivated crops by Diptera, including species of Sciaridae, Phoridae, Anthomyiidae, Tephritidae, and Chloropidae. Our study is the first evidence implicating Agromyzidae.

Interactions between insects and bacteria, with few exceptions, are not obligate but accidental (Harrison *et al.* 1980). Such is the case with the interaction between *L. trifolii* and *P. cichorii*. Bacterial leafspot occurs in the absence of leafminer. However, the additional means of ingress by the bacterium into the leaf are associated with both oviposition wounds (Matteoni and Broadbent 1988) and accidental transmission by leafminers. There were deleterious effects of bacterial leafspot on leafminers' survival to the pupal stage. Whether this reduced survival resulted from decreased quality of the infected chrysanthemum leaves, or a direct effect on leafminers' eggs or larvae was not determined.

Acknowledgements

Appreciation is gratefully expressed to Carla Carlson and Barbara Tehrani for technical assistance, and to Yoder Canada Ltd. for supplying rooted chrysanthemum cuttings.

References

Broadbent, A.B. 1983. *Liriomyza trifolii* on chrysanthemums in Ontario greenhouses. *In*: S.L. Poe (Ed.), The III Annual Industry Conference on Leafminer, San Diego (Nov. 1982). Society of American Florists. pp. 90-100.

Fahy, P.C. and A.B. Lloyd. 1983. *Pseudomonas*: The fluorescent pseudomonads. *In*: P.C. Fahy and G.J. Persley (Eds.), Plant Bacterial Diseases. A Diagnostic Guide. Academic Press. Toronto. pp. 141-188.

Gibbs, A.J. and J.C. Gower. 1960. The use of a multiple transfer method in plant virus transmission studies - some statistical points arising in the analysis of results. Annals of Applied Biology, 48: 75-83.

Harrison, M.D., J.W. Brewer and L.D. Merrill. 1980. Insect involvement in the transmission of bacterial pathogens. *In*: K. Harris and K. Maramorosch (Eds.), Vectors of Plant Pathogens. Academic Press, N.Y. pp. 201-276.

Jones, J.B., A.R. Chase, B.K. Harbaugh and B.C. Raju. 1985. Effect of leaf wetness, fertilizer, leaf age, and light intensity before inoculation on bacterial leafspot of chrysanthemum. Plant Disease, 69: 782-784.

Karnovski, M.J. 1965. A formaldehyde-glutaraldehyde fixative of high osmolarity for use in electron microscopy. Journal of Cell Biology, 27: 137A.

Matteoni, J.A. 1984. Bacterial leaf spot and black stem necrosis of chrysanthemum. Canada Agriculture, 30: 24-27.

Matteoni, J.A. and A.B. Broadbent. 1988. Wounds caused by *Liriomyza trifolii* (Diptera: Agromyzidae) as sites for infection of chrysanthemum by *Pseudomonas cichorii*. Canadian Journal of Plant Pathology, 10: 47-52.

Matteoni, J.A. and A.B. Broadbent. 1989. Interactions between *Liriomyza trifolii* and the bacterium *Pseudomonas cichorii* on florists' chrysanthemum. Canadian Journal of Plant Sciences, 69(1): 266.

McFadden, L.A. 1961. A bacterial leafspot of florists' chrysanthemum, *Chrysanthemum morifolium*. Plant Disease Reporter, 45: 16-19.

Poe, S.L. 1983. Leaf spot bacterium *Pseudomonas* transmitted by *Liriomyza trifolii*. Virginian Journal of Science, 34: 105 (Abstract).

Price, J.F. and B.K. Harbaugh. 1982. Effect of cultural practices on *Liriomyza*. *In*: D.J. Schuster (Ed.), Proceedings of the Institute of Food and Agricultural Sciences-Industry Conference on Biology and Control of *Liriomyza* Leafminers, Orlando (Nov. 1981). pp. 156-167.

Sands, D.C., M.N. Schroth and D.C. Hildebrand. 1980. *Pseudomonas*. *In*: N.W. Schaad (Ed.), Laboratory Guide for Identification of Plant Pathogenic Bacteria. American Phytopathological Society, St. Paul, MN. pp. 36-44.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical Methods. Iowa State University Press, Ames. 593 pp.

Received 19 September 1989; accepted 26 March 1990

ANTENNAL MORPHOLOGY OF THE MALE *HYDRAECIA MICACEA* AS COMPARED TO CONSPECIFIC FEMALES AND MALE *HELIOTHIS VIRESCENS* (LEPIDOPTERA: NOCTUIDAE)

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Abstract *Proc. ent. Soc. Ont.* 121:85-94

Scanning electron microscopy was used to compare antennae of males of *Hydraecia micacea* Esper (potato stem borer, PSB) with antennae of conspecific females and males of *Heliothis virescens* (F.) (tobacco budworm, TBW). Antennae of all insects had a mean number of 75 segments. The gross dimensions for all insects were similar with the exception of a ventral bulge in the midsection of the antennae of males of PSB. Three types of sensilla trichodea were found in our study. The largest type of trichoid sensillum was found only on the antennae of males of PSB. Sensilla trichodea were most numerous on the midsection of the antennae of male PSB, but TBW had relatively higher numbers of sensilla trichodea at the base of the antenna. Females of PSB had the least number of sensilla trichodea, except on the penultimate segment where all moths had similar numbers. Type 3 sensilla trichodea were most numerous and occurred in similar numbers on both male and female PSB moths. Other sensilla found on all moths included sensilla basiconica, sensilla chaetica, sensilla coeloconica, sensilla styloconica and sensilla auricillicum. The number of and structures of these sensilla were similar in all insect types.

Introduction

The antennae are the most common structure by which insects detect semiochemicals (Mayer and Mankin 1985). Consequently, detailed knowledge of antennal morphology is critical for gaining insight into pheromone perception (Mayer *et al.* 1981). Given that sex pheromones for several hundred species of Lepidoptera have been identified, it is surprising that few studies have attempted to correlate the external structure of the antennae of the perceiving sex with the quantity of sex pheromone produced. Studies that have addressed this point (Mayer *et al.* 1981 and references therein; Grant and O'Connell 1986) as well as general studies on antennal structure (Jefferson *et al.* 1970; Sanes and Hildebrand 1976; Liu and Liu 1984) have demonstrated that considerable diversity exists at both the inter- and intraspecific levels and have been useful in elucidation of neural mechanisms involved in various semiochemical communications systems. This interspecific diversity has suggested

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that morphological adaptations of antennae could be correlated with the amount of pheromone that is released by the sending sex.

Our studies on the amount of sex pheromone present in the glands of females of the potato stem borer moth, *Hydraecia micacea* (Esper) (PSB), a noctuid of the subfamily Amphipyrinae, indicated that a total of only 3.6 ng of the four pheromone components were present during the peak period of production (Teal *et al.* 1983). Further, studies in which the volatile compounds released by females during the period of pheromone production were collected and analyzed as described by Teal *et al.* (1985, 1986), indicated that the compound which comprises the major proportion of the pheromone blend (69%), tetradecanyl acetate, was released at a rate of only 7.2 ng per h. This release rate was approximately one/tenth of that released by females of another noctuid, *Heliothis virescens* (F.), the tobacco budworm, TBW, of the subfamily Noctuinae (Teal *et al.* 1986). We, therefore, hypothesized that males of the PSB would require an antenna more efficient at collecting airborne molecules than that of males of the tobacco budworm. The following reports the results of comparative studies on the antennal structure of males of the TBW and of adults of both sexes of the PSB.

Materials and Methods

Potato stem borers were obtained from a laboratory culture maintained at the University of Guelph. These insects were reared at 25°C using the method described by West *et al.* (1985) on an artificial diet prepared as described by Hinks and Byers (1976). Male TBW were obtained as pupae from the Bioenvironmental Insect Control Laboratory, USDA, Stoneville, Mississippi.

Heads of adults were removed, placed in pentane for ca. 1 min., then rinsed in acetone and put in freshly prepared 2% OsO_4 in 0.02M phosphate buffer (pH 7.3-7.4) for 24 hours. Fixed specimens were then dehydrated in a 30, 50, 70, 80, 90, 95, 100% ethanol series for 15 min. at each concentration with absolute alcohol being changed twice. Specimens were coated with gold-palladium to a thickness of 20-30 nm using a Technics Hummer V® sputter coater. An ETEC Autoscan Corporation scanning electron microscope was used at 10 and 20 kV. Since each antenna was found to be structurally similar along its entire length, the third, thirtieth and penultimate annuli were chosen to represent the base, middle and distal areas of the antennae. All sensilla counts were made from SEM micrographs.

Results and Discussion

The number of annuli and annuli widths of male PSB antennae were not markedly larger than found for female PSB or male TBW antennae except at the midsection where individual annuli of the antennae of male PSB bulged ventrally about 75 µm more than the antennae of female PSB (Table I; Fig. 1 a-d). This ventral bulging has not been previously reported in the Noctuidae. This protrusion is similar to, but not as pronounced as, the ventral elongation on the antennae of male *Manduca sexta* (L.) (Lepidoptera: Sphingidae) (Sanes and Hildebrand 1976). Sensilla of all types were found almost exclusively on the ventral protrusion of both PSB and *M. sexta* antennae. The dorsal surface of all antennae in the present study were covered with scales.

There were three main morphological types of sensilla trichodea on the antennae of PSB males that were designated types 1, 2 and 3. Type 1, long trichodea, were arranged in a single row on the periphery of the ventral bulge of the antennae and formed a circular fan configuration (Fig. 1a,b). This arrangement effectively presented a fan of long sensilla gainst air flow when males were oriented upwind with antenna extended forward, the usual position when male PSB are presented with sex pheromone (Burns and Teal 1989). These

sensilla were 3-4 μm wide at the base with a maximum length of ca. 225 μm on the most lateral sides of the antennae and became progressively shorter toward the ventral side. The organization of long sensilla was similar to that of *M. sexta* (Sanes and Hildebrand 1976). They are larger than the type 1 trichoid sensilla of *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae) described by Jefferson *et al.* (1970). Long trichodea were absent on the 3rd and penultimate segments of male PSB and were not found on either female PSB or male TBW (Table II). Shorter type 2 and 3 sensilla trichodea were found inside the circle of the long trichodea on the antennae of males of PSB.

TABLE I. Mean counts and measures of gross dimensions of antennae of male and female potato stem borer and male tobacco budworm (n=10)

Moth	No. of segments Mean (min-max)	Segment width (μm) Third Mean (min-max)	Thirtieth Mean (min-max)	Penultimate Mean (min-max)
		Hydraecia micacea (PSB)		
Male	75 (67-82)	204 (186-256)	197 (185-210)	73 (70-93)
Female	75 (67-79)	190 (169-230)	151 (142-161)	70 (67-72)
		Heliothis virescens (TBW)		
Male	75 (70-85)	183 (160-209)	148 (137-158)	72 (70-81)

Type 3 trichodea were similar to the type 2 sensilla reported by Jefferson *et al.* (1970). They were less than 3 μm in diameter at the base and included relatively long and straight sensilla with a terminal hook as well as shorter, more curved sensilla (Fig. 2a, 3a,b) These sensilla were located randomly on the ventral protrusion of male PSB (Fig. 1b, 2a) and were located randomly on the entire ventral segment of female PSB (Fig. 3a). Type 2 sensilla on the antennae of male TBW were arranged in rows that were most pronounced on the ventral lateral sides of the antennal segments (Fig. 1d, 3b). Arrangements and numbers of type 2 sensilla on the antennae of male TBW were more similar to those of male *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae) (Jefferson *et al.* 1970) than to those of male PSB.

Type 3 trichodea corresponded to type 3 described by Jefferson *et al.* (1970) and were distinguished by a ridged or convoluted surface, a uniform thickness along their length and a blunt end (Fig. 2b). Similar numbers were found on both sexes of adult PSB. They occurred only on the lateral edges of the antennae of females of the PSB and laterally within the circle of type 1 trichodea in males. The few present on the antennae of male TBW also occurred primarily on the lateral sides.

TABLE II. Range in number of sensilla on three segments of male and female *Hydraecia micacea* and male *Heliothis virescens* (n=3).

	Male PSB			Female PSB			Male TBW		
Sensilla type	Third	30th	Penultimate	Third	30th	Penultimate	Third	30th	Penultimate
Trichodea									
1	0	68-76	0	0	0	0	0	0	0
2	41-56	71-95	40-45	27-33	69-108	42-50	97-117	102-123	47-53
3	2-6	10-15	2-5	0-3	13-16	0	0	0	0-5
S. chaetica	0	7	6-8	0-3	7	6-8	0	6	5
S. coeloconica	0-2	5-8	4-5	1	3-10	4-7	0	5-11	5-7
S. styloconica	1	1	1	0	1	1	0	1	1
S. auricillicum	0-2	5-6	1-2	0-1	4-6	2	0	2-3	1-2

The number of sensilla trichodea varied among insects (Table II). The midsection of the antennae of PSB males had the highest total number of trichodea (a minimum of 149 on the 30th segment), but had the fewest type 2 trichodea. TBW (minimum number of trichodea = 102, 30th segment) had the highest number of type 2 sensilla on segment 30 and twice as many type 2 sensilla on the third segment as male PSB. Female PSB had the lowest number of trichodea (minimum number = 82, 30th segment) on all but the penultimate segment where there were approximately equal numbers of trichodea on all moths (Table II).

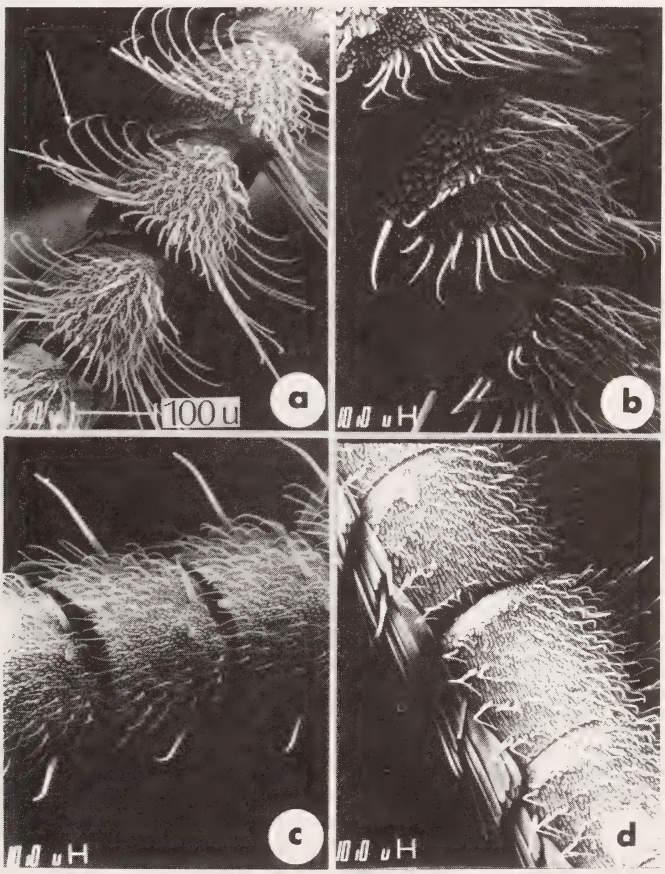

FIGURE 1. Comparison of gross morphology of antennal segment 30 in male PSB (a,b), female PSB (c), and male TBW (d). Arrows indicate type 1 sensilla trichodea.

Sensilla trichodea were of particular interest because of their function in the perception of sex pheromones in other species (Mayer *et al.* 1981; Mayer and Mankin 1985; Grant and O'Connell 1986). The absence of type 1 trichodea from the antennae of female PSB

contributes to the sexual dimorphism of PSB. This dimorphism is paralleled in *M. sexta* (Sanes and Hildebrand 1976). The type 1 sensilla of *M. sexta* detect pheromone (Sanes and Hildebrand 1976; Hildebrand and Montague 1986). If the type 1 sensilla present on the antenna of males of the PSB can detect pheromone then the fan shaped circular arrangement would enable PSB males to sample a larger cross section of air than TBW males. This is due in part to their length and in part to the increased surface area of the sensilla. The structural similarity of type 2 sensilla trichodea to those sensitive to sex pheromones in *T. ni* (Grant and O'Connell 1986) suggested that type 2 trichoid sensilla perceive sex pheromone in male PSB. No function has been reported for type 3 sensilla.

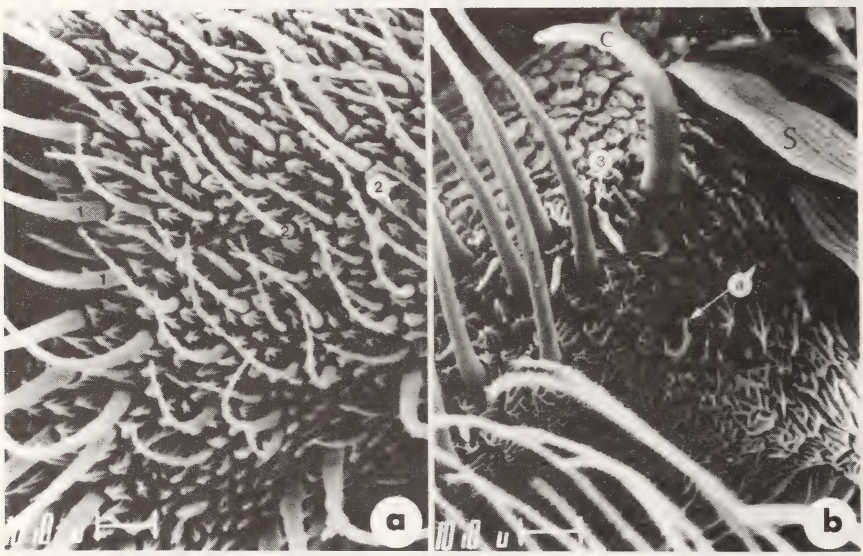

FIGURE 2. Detail of the 30th segment of male PSB antennae: a) ventral, b) lateral, S = scale; c - sensilla chaetica; a = sensillum auricillicum; 1, 2, 3 = sensilla trichodea types 1, 2, and 3, respectively.

Five other types of sensilla were found: sensilla basiconica, sensilla chaetica, sensilla coeloconica, sensilla styloconica, and sensilla auricillicum. Most were similar in structure to the sensilla types reported by Jefferson *et al.* (1970).

Sensilla basiconica were generally few in number and were randomly located on the ventral surface of the antennae of all moths. They were characterized by their short length, slight curvature and blunt end (Fig. 3b, 4a). They are similar to those described on *Yponomeutidide vigintipunctatus* (Retzius) (Lepidoptera: Yponomeuditidae) by Cuperus (1985) and *Mamestra configurata* Walker (Lepidoptera: Noctuidae) by Liu and Liu (1984). Counts of sensilla basiconica were included with type 2 sensilla trichodea since varying angles in the micrographs made differentiation from shorter trichoid sensilla difficult. The function of sensilla basiconica has not been clearly demonstrated by other workers.

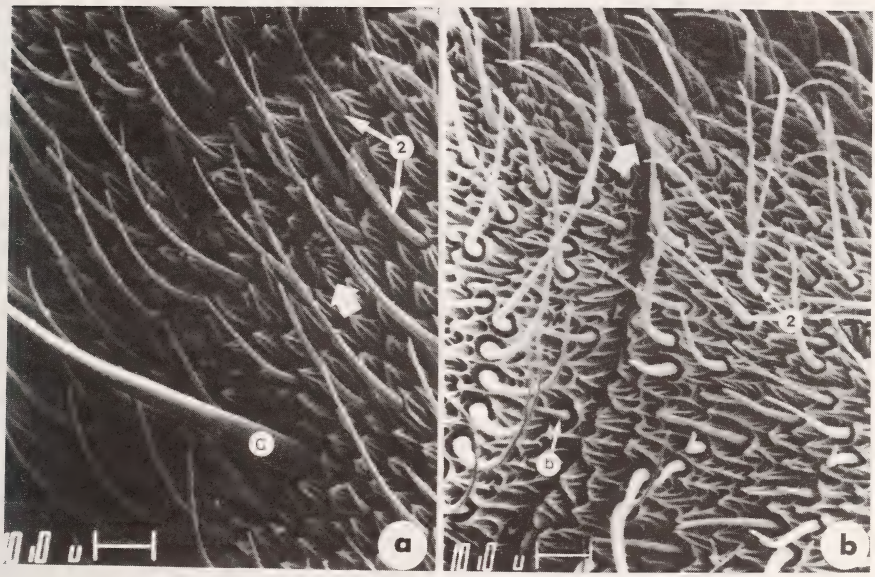

FIGURE 3. Detail of the 30th segment of a) female PSB antenna. Arrow indicates sensilla coeloconica; a = sensilla auricillicum, b) male TBW antenna. Arrow indicates sensilla styloconica; b = sensilla basiconica. Both figures a and b: s = scale; c = sensilla chaetica; 2, 3 = sensilla trichodea 2 and 3, respectively.

Both male and female PSB had chaetica on all segments, with a consistent number on every segment except the most basal (Fig. 1, 2b, 3a; Table II). Male TBW had one fewer chaetica per segment than PSB antennae. All chaetica were similar to those reported for other noctuids (Jefferson *et al.* 1970), and had a pore at the tip like *M. configurata* (Liu and Liu 1984). Sensilla chaetica are reported to have both a contact-chemoreceptive and mechanoreceptive function (Altner and Prillinger 1980), and we expect that they are not involved in pheromone perception by either PSB or TBW.

Sensilla coeloconica were present on all moths and on all annuli surveyed (Table II). Typically, there was a circle of spines surrounding a central peg (Fig. 3a), as described for other noctuids (Jefferson *et al.* 1970). Rarely, the spines were not present, leaving the central peg exposed (Fig. 4b). Sensilla coeloconica appeared to be located in a random pattern on the ventral surface of all antennae.

Sensilla auricillicum were covered with fine, grooved ridges (Fig. 4c). They were most plentiful on the 30th segment of all insects but were absent from the 3rd antennal segment of male TBW (Table II). They were located laterally and closely grouped in all moths (Fig. 2b) but were usually under the scales of the TBW. Similar sensilla have been found in several species of moths (Jefferson *et al.* 1970; Cuperus 1985), but no function has been reported.

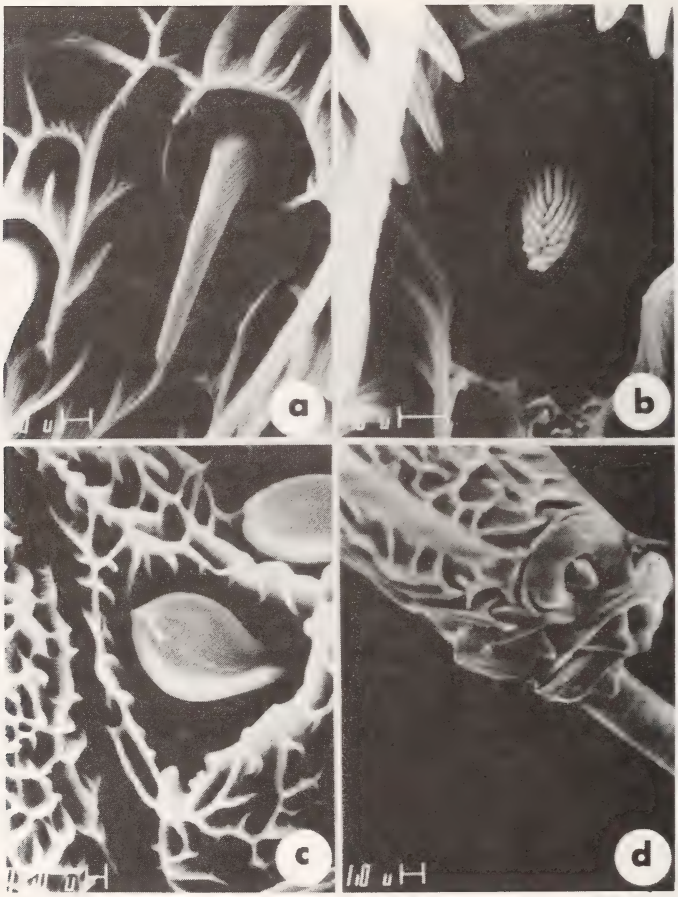

FIGURE 4. Four types of sensilla: a) Sensillum basiconica (from PSB females), b) sensillum coeloconica without spines (from PSB females), c) sensillum auricillicum (from PSB male), d) terminal end organ with papillae (from PSB female).

One sensillum styloconica was located on the most ventral and distal position on the 30th and penultimate segment of male PSB and TBW and on all segments surveyed of the female PSB antennae (Fig. 3a). The structures had either 1 or 2 terminal papillae. The terminal end organ resembled the styloconica in structure, but was more complex, especially on female PSB (Fig. 4d). Analogous terminal end organs on the antennae of male PSB and TBW generally had 2-3 papillae. On some adult PSB, a papillae-like structure was visible within a pit near the groups of sensilla auricillicum at the lateral edges of the antennae (Fig. 4c). The ventral styloconica and terminal end organs have been reported in several other species (Jefferson *et al.* 1970). In *Mamestra brassica* styloconica were found to contain both temperature and humidity receptors (Becker cited in Altner and Prillinger 1980).

The ability of a male to locate the pheromone source is primarily mediated by behavioural and neurophysiological parameters (Dethier 1986). Behaviourally, males of both species have similar search patterns for mate location (Burns and Teal 1989; Teal *et al.*

1981). Neurophysiological parameters include the function of sensilla trichodea, the pore density on pheromone-sensitive sensilla (Grant and O'Connell 1986), as well as the number and specificity of receptor sites and the threshold potential of sensilla neurons (Chapman 1982). Neurophysiological and ultrastructural studies of individual sensilla will help to establish the function of the sensilla trichodea of PSB and help to elucidate the contributions of both morphology and physiology to the sensitivity of both male moths. However, it seems that at least some of the sensitivity of PSB males to sex pheromone may be manifest at the morphological level since we have found that in male moths of similar size and behaviour, antennae of a larger outline correlate with the female emitting a lower rate of sex pheromone.

References

Altner, H. and L. Prillinger. 1980. Ultrastructure of invertebrate chemo-, thermo-, and hygroreceptors and its functional significance. International Review of Cytology, 67: 69-139.

Burns, E.L. and P.E.A. Teal. 1989. Response of male potato stem borer moths, *Hydraecia micacea* (Esper), to conspecific females and synthetic pheromone blends in the laboratory. Journal of Chemical Ecology, 15: 1365-1378.

Chapman, R.F. 1982. Chemoreception: The significance of receptor numbers. Advances in Insect Physiology, 16: 247-356.

Cuperus, P.L. 1985. Inventory of pores in antennal sensilla of *Yponomeutide* spp. (Lepidoptera: Yponomeutidae) and *Adoxophyes orana* F.V.R. (Lepidoptera: Tortricidae). International Journal of Insect Morphology and Embryology, 14: 347-359.

Dethier, V.G. 1986. Chemoreception and behavior from an evolutionary and comparative perspective. *In*: T.L. Payne, M.C. Birch and C.E.J. Kennedy (eds.), Mechanisms in Insect Olfaction. pp. 1-10, Clarendon Press, Oxford.

Grant, A.J. and R.J. O'Connell. 1986. Neurophysiological and morphological investigations of pheromone-sensitive sensilla on the antenna of male *Trichoplusia ni*. Journal of Insect Physiology, 332: 503-515.

Hildebrand, J.G. and R.A. Montague. 1986. Functional organization of olfactory pathways in the central nervous system of *Manduca sexta*. *In*: T.L. Payne, M.C. Birch and C.E.J. Kennedy (eds.), Mechanisms in Insect Olfaction. pp. 279-285. Clarendon Press, Oxford.

Hinks, C.F. and J.R. Byers. 1976. Biosystematics of the Genus *Euxoa* (Lepidoptera: Noctuidae). V. Rearing procedures and life cycles of 36 species. Canadian Entomologist, 108: 1345-1357.

Jefferson, R.M., R.E. Rubin, S.U. McFarland, and H.H. Shorey. 1970. Sex pheromones of noctuid moths. XXII. The external morphology of the antennae of *Trichoplusia ni*, *Heliothis zea*, *Prodenia ornithogalli*, and *Spodoptera exigua*. Annals of the Entomological Society of American, 63: 1227-1238.

Liu, H.J. and T.P. Liu. 1984. Sensilla on the antennal flagellum of the bertha armyworm moth, *Mamestra configurata* Walker (Lepidoptera: Noctuidae): A scanning electron microscope study. Annals of the Entomological Society of America, 77: 236-245.

Mayer, M.S. and R.W. Mankin. 1985. Neurobiology of pheromone perception. *In*: G.A. Kerkut and L.I. Gilbert (eds.), Comprehensive Insect Physiology, Biochemistry and Pharmacology. Vol. 9. pp. 95-144. Pergamon Press, Ltd., Toronto.

Mayer, M.S., R.W. Mankin, and T.C. Carlysle. 1981. External antennal morphometry of *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae). International Journal of Insect Morphology and Embryology, 10: 185-201.

Sanes, J.S. and J.G. Hildebrand. 1976. Structure and development of antennae in a moth, *Manduca sexta*. Developmental Biology, 51: 282-299.

Teal, P.E.A., J.R. McLaughlin, and J.H. Tumlinson. 1981. Analysis of the reproductive behavior of *Heliothis virescens* (F.) under laboratory conditions. Annals of the Entomological Society of America, 74: 324-330.

Teal, P.E.A., E.R. Mitchell, J.H. Tumlinson, R.R. Heath, and H. Sugie. 1985. Identification of volatile sex pheromone components released by the southern armyworm, *Spodoptera eridania* (Cramer). Journal of Chemical Ecology, 11: 717-725.

Teal, P.E.A., J.H. Tumlinson, and R.R. Heath. 1986. Chemical and behavioral analysis of volatile sex pheromone components released by calling *Heliothis virescens* (F.) females (Lepidoptera: Noctuidae). Journal of Chemical Ecology, 12: 107-125.

Teal, P.E.A., R.J. West, and J.E. Laing. 1983. Identification of a blend of sex pheromone components of the potato stem borer (Lepidoptera: Noctuidae) for monitoring adults. Proceedings of the Entomological Society of Ontario, 114: 15-19.

West, R.J., J.E. Laing, and P.E.A. Teal. 1985. Method for rearing the potato stem borer, *Hydraecia micacea* (Esper) (Lepidoptera: Noctuidae), in the laboratory. Journal of Economic Entomology, 78: 219-221.

Received 8 August 1989; accepted 3 August 1990

PUPAL ORIENTATION AND EMERGENCE SUCCESS OF THE EGG PARASITOID *EDOVUM PUTTLERI* (HYMENOPTERA: EULOPHIDAE)

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Abstract. *Proc. ent. Soc. Ont.* 121:95-100

The orientation of pupae and the emergence success of adults of *Edovum puttleri* were examined for individuals developing in egg masses of *Leptinotarsa decemlineata* laid on potato leaves, which faced up or down, in light or in darkness. When egg masses faced down, 98% of the parasitoids pupated with their heads pointing down, away from the surface of the leaf. When egg masses faced up, 63% of the individuals pupated facing down; these individuals faced the leaf surface. More adults (20%) emerged from egg masses that faced down, because of the superior emergence of individuals with their heads pointed away from the leaf surface (89% emergence compared with 66% for those that faced the leaf surface). Presence or absence of light did not significantly affect pupal orientation or adult emergence from egg masses that faced down, but for egg masses facing up, significantly fewer adults emerged from those kept in the dark (62%) than from those exposed to light (77%).

Introduction

Edovum puttleri Grissell [Hymenoptera: Eulophidae], a solitary egg parasitoid of *Leptinotarsa* spp. [Coleoptera: Chrysomelidae], was imported to North America from Central America as a potential control agent for the Colorado potato beetle, *L. decemlineata* (Say) (Puttler and Long 1983; Logan *et al.* 1987). The parasitoids have been released against *L. decemlineata* in cultivations of potato and eggplant (Schroder and Athanas 1985; Lashomb *et al.* 1987a; Sears and Boiteau 1989), and suppression of *L. decemlineata* has been observed in eggplant cultivations (Lashomb unpublished).

The wasps did not overwinter successfully in New York State, and are thought to be unable to establish in temperate North America (Obrycki *et al.* 1985). Thus, to be used in control programs, *Edovum puttleri* must be reared in large numbers for annual releases, so it is necessary to maximize parasitoid production from the mass-rearing system.

Mortality (14-31%) of *E. puttleri* reared in the laboratory occurred principally when adult parasitoids failed to escape from the host egg (Lashomb *et al.* 1987b; Ruberson *et al.* 1987). The larvae of most adults that failed to emerge had pupated with their heads pointed toward the leaf surface (Lashomb *et al.* 1987b; Maini and Nicoli 1990). From the results of our experiments, we demonstrate that orientation of the host egg mass during immature development of *E. puttleri* affects orientation of the parasitoid pupae, and we show a subsequent effect of pupal orientation on adult emergence.

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Materials and Methods

Adults and immatures of *E. puttleri* were reared at 26° ± 0.1°C, 16L:8D and 60-70% R.H.; adults had constant access to water and undiluted honey. Females were caged with males, and were exposed daily to egg masses of *L. decemlineata* from the third day after emergence to gain parasitization experience. Egg masses, produced by *L. decemlineata* reared on greenhouse grown potato plants (*Solanum tuberosum* L. var. 'Superior'), were harvested by cutting out a leaf disc approximately 1.5 cm. in diameter under the egg mass. For the experiment, leaf discs and masses (<48h old), were attached to 9 cm. Petri dishes with a small drop of non-toxic glue (15 masses per dish) and exposed for 16h to 10-12 day old female wasps at a density of approximately 10 females per egg mass.

Immediately following parasitism, dishes were randomly assigned to one of four treatments as follows: 1. egg masses facing down, dish covered with aluminum foil; 2. egg masses facing down, dish uncovered; 3. egg masses facing up, dish covered with aluminum foil; 4. egg masses facing up, dish uncovered. The dishes were placed on the middle shelf of an environmental chamber containing fluorescent lights running from top to bottom on one side of the chamber. The experiment was replicated 3 times (12 dishes in total).

We recorded the orientation of each pupa relative to the surface of the leaf, and whether or not the adult parasitoid had emerged successfully. Pupal orientation was recognized easily, even if the adult had emerged. If a brownish-gold dome of meconium was visible at the top of the host egg, the wasp had pupated with its head towards the leaf surface. If the parasitoid had pupated pointing away from the leaf surface, the top of the host egg appeared black.

Data are expressed as a percentage orientation or emergence per egg mass. All statistical comparisons were made using Wilcoxon 2-sample tests (SAS Institute 1985). The variability of the data are expressed as 25% and 75% quartiles.

Results

The average number of eggs of *L. decemlineata* per mass was 35 ± 17 (SD), with an average of 15 ± 12 eggs per mass parasitized by *E. puttleri* (n = 156 egg masses).

Egg mass position significantly affected pupal orientation for each light condition ($P < 0.0001$, Wilcoxon 2-sample tests, Table I). Light condition had no significant effect on pupal orientation in egg masses facing up ($P = 0.63$, Wilcoxon 2-sample test) or facing down ($P = 0.21$, Wilcoxon 2-sample test, Table I). When the egg masses faced down, 98% of the individuals pupated with their heads pointing down, whereas, when egg masses faced up, 63% pupated with their heads pointing down (Table I).

Significantly more adults emerged from egg masses that faced down for each light condition ($P < 0.0001$; Wilcoxon 2-sample tests, Table II). Presence or absence of light did not significantly affect adult emergence if the masses faced down ($P = 0.54$, Wilcoxon 2-sample test), but for egg masses facing up, significantly fewer adults emerged from those egg masses kept in the dark ($P = 0.003$, Wilcoxon 2-sample test, Table II).

Significantly fewer parasitoids that had pupated with their heads towards the leaf emerged successfully (66% emergence, Q25 = 50%, Q75 = 100%, n = 89 egg masses), than those that had pupated facing away from the leaf (89% emergence, Q25 = 90%, Q75 = 100%, n = 147 egg masses) ($P < 0.0001$; Wilcoxon 2-sample test).

TABLE I. Mean percentage (25% and 75% quartiles) of *Edovum puttleri* per egg mass that pupated facing down for each combination of egg mass orientation and light condition (n = number of parasitized egg masses).

	Light condition		
	Light	Dark	All masses
	Facing down		
Percentage	97a	99a	98
Q25% - Q75%	99-100	100-100	100-100
n	44	34	78
	Facing up		
Percentage	61b	65b	63
Q25% - Q75%	45-83	52-84	46-84
n	45	33	78

Means within each column are significantly different from each other (Wilcoxon 2-sample tests; $P < 0.001$).
For each row, means followed by the same letter are not significantly different from each other (Wilcoxon 2-sample tests: Facing down $P = 0.21$; facing up $P = 0.63$).

Discussion

For several species of eusocial Hymenoptera, pupal orientation is determined by both gravitational cues, and tactical cues provided by the brood cell (Ishay 1975; Ebert 1980; Kevan 1987). Our results show the presence of a strong geotactic response in the pupating larvae of *E. puttleri*. Furthermore, our data suggest that presence or absence of light is not a factor in pupal orientation. Kingsley (unpublished) glued individual eggs of *L. decemlineata* horizontally to cards, and exposed them to *E. puttleri* for parasitization. He found 73.4% (n = 274) of the parasitoids pupated with their heads opposite the original attachment point of the egg to the leaf. Thus, for egg masses facing down, the effects of egg shape and gravity would seem to act in concert, as virtually all pupae were oriented facing the ground. When masses faced up, these cues apparently conflicted; some larvae appeared to react to the gravitational cue, and others to the tactile cue provided by the shape of the host egg.

The cues involved in pupal orientation of *E. puttleri* are likely an adaptation to the oviposition habits of their hosts. *L. decemlineata* eggs normally are deposited on the undersurface of the leaves (Gibson *et al.* 1925). In this situation, if the parasitoid pupae face down, they also face away from the leaf surface. The adaptive significance of this is apparent from our results, as adult emergence was 23% greater for those pupae that faced away from the leaf surface. Ishay (1975) found that 80% of the adults of *Vespa orientalis* Fab. that fail to emerge from their pupal cells were oriented with their heads pointing into

the roof of the comb. The imago eclosed, but failed to chew out of the cell. Similarly, most adults of *E. puttleri* that failed to emerge came from pupae facing towards the leaf in the middle of tightly packed egg masses. The adult would push out of the bottom of its own host egg but become trapped by the bottoms of the surrounding eggs. We believe that reduced emergence from egg masses held facing up in the dark can be explained by the inability of some parasitoids to find their way out from among the host eggs without light.

TABLE II. Mean percentage (25% and 75% quartiles) of *Edovum puttleri* per egg mass that emerged for each combination of egg mass orientation and light condition (n = number of parasitized egg masses).

	Light condition		
	Light	Dark	All masses
	Facing down		
Percentage	92a	90a	91
Q25% - Q75%	90-100	89-100	90-100
n	44	34	78
	Facing up		
Percentage	77b	62c	71
Q25% - Q75%	68-93	46-78	59-89
n	45	33	78

Means within each column are significantly different from each other (Wilcoxon 2-sample tests; $P < 0.001$).
For facing down, means followed by the same letter are not significantly different from each other (Wilcoxon 2-sample test: $P = 0.54$).
For facing up, means followed by different letters are significantly different (Wilcoxon 2-sample tests: $P = 0.003$).

Application of these results could lead to an increase in yields of parasitoids in mass rearing, with little or no extra input of manpower or resources. Following this study in February 1987, the Beneficial Insect Lab in Trenton, New Jersey, U.S.A., began storing all parasitized egg masses facing down and recorded a 21% increase in yields of adults in the five weeks following the change (D. Palmer pers. comm.).

Acknowledgements

We thank J. Hwang and A. Zitzman for technical assistance and R.J. Bennett, J. Brodeur, J.E. Laing, and several anonymous reviewers for criticism of the manuscript. We are indebted to the Beneficial Insects Rearing Laboratory of the New Jersey Department of Agriculture and to the USDA-APHIS Laboratory at Mission Texas for the use of data and shipments of parasitoids. This study was supported with federal funds from the U.S.D.A. under agreement 58-32U4-6-13, IPM Pilot Tests, U.S.D.A. 86-CRSR-2-2773. New Jersey Agricultural Experiment Station Publication Number D-08149-08-88, supported by State funds and by the U.S. Hatch Act.

References

Ebert, R. 1980. Influence of juvenile hormone on gravity orientation in the female honeybee larva (*Apis mellifera* L.). Journal of Comparative Physiology, 137: 7-16.

Gibson, A., R.P. Corham, H.F. Hudson, and J.A. Flock. 1925. The Colorado potato beetle in Canada. Canada Department of Agriculture New Series Bulletin, No. 52: 1-30.

Ishay, J. 1975. Orientation by pupating larvae of *Vespa orientalis* (Hymenoptera: Vespidae). Insectes Sociaux, 22: 67-74.

Kevan, P.G. 1987. Texture sensitivity in the life of honeybees. *In* R. Menzel and A. Mercer (eds.), Neurobiology and Behavior of Honeybees, Springer-Verlag, New York, pp. 96-101.

Lashomb, J.H., Y.S. Ng, R.K. Jansson, and R. Bullock. 1987a. *Edovum puttleri* (Hymenoptera: Eulophidae), an egg parasitoid of Colorado potato beetle (Coleoptera: Chrysomelidae): development and parasitism on eggplant. Journal of Economic Entomology, 80: 65-68.

Lashomb, J.H., J.D. Krainacker, R.K. Jansson, Y.S. Ng, and R. Chianese. 1987b. Parasitism of *Leptinotarsa decemlineata* (Say) eggs by *Edovum puttleri* Grissell (Hymenoptera: Eulophidae): effects of host age, parasitoid age, and temperature. Canadian Entomologist, 119: 75-82.

Logan, P.A., R.A. Casagrande, T.H. Hsiao, and F.A. Drummond. 1987. Collections of natural enemies of *Leptinotarsa decemlineata* [Coleoptera: Chrysomelidae] in Mexico. 1980-1985. Entomophaga, 32: 249-254.

Maini, S. and G. Nicoli. 1990. *Edovum puttleri* [Hym.: Eulophidae]: biological activity and responses to normal and frozen eggs of *Leptinotarsa decemlineata* [Col.: Chrysomelidae]. Entomophaga, 35: 185-195.

Obrycki, J.J., M.J. Tauber, C.A. Tauber, and B. Gollands. 1985. *Edovum puttleri* (Hymenoptera: Eulophidae), an exotic egg parasitoid of the Colorado potato beetle (Coleoptera: Chrysomelidae): response to temperate zone conditions and resistant potato plants. Environmental Entomology, 14: 48-54.

Puttler, B. and S.H. Long. 1983. Host specificity tests of an egg parasite, *Edovum puttleri* (Hymenoptera: Eulophidae), of the Colorado potato beetle, *Leptinotarsa decemlineata* (Coleoptera: Chrysomelidae). Proceedings of the Entomological Society of Washington, 85: 384-387.

Ruberson, J.R., M.J. Tauber, and C.A. Tauber. 1987. Biotypes of *Edovum puttleri* Grissell (Hymenoptera: Eulophidae): responses to developing eggs of the Colorado potato beetle. Annals of the Entomological Society of America, 80: 451-455.

SAS Institute. 1985. SAS/STAT Guide for Personal Computers: Version 6 Edition. SAS Institute, Cary, N.C.

Schroder, R.F. and M.M. Athanas. 1985. Review of research on *Edovum puttleri* Grissell, egg parasite of the Colorado potato beetle. *In*: D.N. Ferro and R.H. Voss (eds.), Proceedings of the Symposium on the Colorado Potato Beetle, XVII International Congress of Entomology, Massachusetts Experiment Station, Amherst, pp. 29-32.

Sears, M.K. and G. Boiteau. 1989. Parasitism of Colorado potato beetle (Coleoptera: Chrysomelidae) eggs by *Edovum puttleri* (Hymenoptera: Eulophidae) on potato in Eastern Canada. Journal of Economic Entomology, 82: 803-810.

Received 1 August 1990; accepted 1 October 1990

RESISTANCE TO MALATHION IN POPULATIONS OF INDIAN MEAL MOTH, *PLODIA INTERPUNCTELLA* (LEPIDOPTERA: PYRALIDAE)

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Abstract. *Proc. ent. Soc. Ont.* 121:101-104

Samples of Indian meal moth populations collected from Blenheim, Leamington, Merlin, Midland, Wallaceburg, and Walton during 1988 and 1989 were compared to a laboratory susceptible strain for resistance to malathion. A discriminating dose of technical grade malathion dissolved in analytical grade acetone was applied topically to fifth instar larvae. All wild populations tested from southwestern Ontario were at least 10-fold resistant to malathion by comparison with the average of reported LD_{50} values for susceptible strains.

Introduction

The Indian meal moth, *Plodia interpunctella* (Hübner) causes serious losses to stored grains throughout the world (Sinha and Watters 1985). Stored grains attacked include maize, cereals and, less frequently, soybeans. Larvae initially attack the endosperm and then move to the bran (Madrid and Sinha 1982). The larvae spin silk particularly when they approach pupation. That activity often results in a mat of spoiled grain up to 40 cm thick in the top portion of the grain pile.

Malathion is recommended for the control of stored product pests. It is applied as a grain protectant in a dust or spray formulation (Madrid *et al.* 1983), or as a surface treatment after storage bins have been emptied and cleaned (Bereza 1986).

Resistance of the Indian meal moth to malathion is recognized throughout the world (Cogan 1982). In North America, resistance has been reported in Georgia, Kansas, Alabama, Florida, and Illinois (Zettler *et al.* 1973), in the north-central United States (Beeman *et al.* 1982) and in Minnesota (Sumner *et al.* 1988).

In Ontario, although malathion has, in several cases, failed to control Indian meal moth in grain storage bins (Bereza pers. communication), the insecticide is still recommended. The objective of this study was to document the degree and extent of malathion resistance in Indian meal moth populations found in southern Ontario.

Materials and Methods

During 1988 and 1989, samples of Indian meal moth populations were collected from Blenheim, Leamington, Merlin, Midland, Wallaceburg, and Walton. A minimum of 25 larvae were obtained from each location. An insecticide-susceptible, laboratory strain was obtained from the Agriculture Canada stored-products laboratory in Winnipeg. All populations were reared through 5 generations on diet of wheat grain (45%), wheat germ (25%), wheat bran (15%), Brewer's yeast (5%), honey (5%) and glycerol (5%) at 28±2°C, 70±5% RH and a 16:8 hour photoperiod (Imura and Sinha 1986). The ingredients were assumed to be insecticide-free.

The dorsum of fifth instars were treated topically using a hand-held microapplicator with 1 µL of solution, containing technical grade malathion (96.6% purity), dissolved in analytical grade acetone (Sumner *et al.* 1988). For the susceptible and Midland strain, five doses were applied to three groups of 20 larvae for each dose. A discriminating dose of 20 µg/larva was applied to three replicates of 20 larvae for each field population. For each experiment an acetone-treated control group of larvae was used. Each group of treated larvae was placed in a petri dish (50x9 mm polystyrene with snap top lids) containing a small amount of wheat bran as a food source. Mortality was assessed after 92 hrs at 25°C. Probit analysis of the mortality data of the laboratory strain followed the maximum-likelihood method of Finney (1971).

Results and Discussion

The LD_{50} [95% confidence limits] was 2.9 [2.4, 3.5] µg/larva for the susceptible strain. The equation of the probit line derived was $Y = -4.14 + 3.69X$, where Y = probit of corrected percent mortality and X = Log(dose). These results agree with those of Zettler *et al.* (1973), Beeman *et al.* (1982) and Sumner *et al.* (1988) who reported LD_{50}'s of 3.3, 1.17 and 1.6 µg/larva respectively.

Mortality at lower doses in the Midland population was variable and the highest dose tested (400 µg/larva) resulted in only 68% mortality. The LD_{50} [95% confidence limits] was 17.8 [6.93, 45.8] µg/larva for the Midland population. The equation of the probit line was $Y = 3.53 + 0.45X$. The discriminating dose used was approximately 10 times the average of reported LD_{50} values for susceptible strains. The percent mortality for each strain at the discriminating dose is shown in Table I.

TABLE I. Percent mortality of several populations of Indian meal moth after topical application of a discriminating dose of technical malathion.

Sample location	% Mortality
	(at 20 µg/larva)
Midland	18.3
Blenheim	25.0
Merlin	6.0
Walton	15.0
Wallaceburg	3.0
Leamington	50.0
Susceptible	100.0
	(at 400 µg/larva)
Midland	63.3

All wild populations tested from southwestern Ontario were at least 10-fold resistant to malathion by comparison with the average of reported LD_{50} values for susceptible strains. Resistance is also demonstrated by the shallow slope of the probit line for the Midland strain. Malathion resistance in Indian meal moth appears to be highly specific to malathion (Zettler 1974) and is probably the result of increased levels of esterases (Zettler 1974). Esterase levels are controlled by a single autosomal gene, inherited as a single dominant trait (Beeman and Schmidt 1982). Little or no cross-resistance to other organophosphorous or synergized-pyrethrin insecticides has been reported in North America (Zettler *et al.* 1973, Zettler 1982, Beeman *et al.* 1982, Sumner *et al.* 1988).

Presently, only malathion is recommended to growers for grain-bin treatments in Ontario. Synergized pyrethrins are the only alternative insecticides registered for use in Canada. Other products, however, such as chlorpyrifos-methyl and pirimiphos-methyl are registered in the United States and have been tested in Canada and shown to be effective (White and Sinha 1990, White 1988). My results indicate that a programme to re-evaluate synergized pyrethrins and to assist in registration of effective, alternative materials is important for Ontario grain storage.

Acknowledgements

This project was supported by the Ontario Ministry of Agriculture and Food, through the Pest Management Fund. The technical assistance of T. Phibbs, Ridgetown College of Agricultural Technology is gratefully acknowledged. Field strains of Indian meal moth were supplied by Sellen's Grain Services Ltd., Thamesville, and the Canada Grain Commission, Chatham. The susceptible strain was donated by Agriculture Canada, Winnipeg. Malathion samples were obtained from Cynamid Canada Ltd. T. James, University of Guelph, kindly offered the computer software for probit analysis. Critical review of the manuscript by Dr. G.A. Surgeoner and Dr. R.E. Pitblado is appreciated.

References

Beeman, R.W. and B.A. Schmidt. 1982. Biochemical and genetic aspects of malathion-specific resistance in the Indian Meal moth (Lepidoptera: Pyralidae). Journal of Economic Entomology, 75: 945-949.

Beeman, R.W., W.E. Spiers, and B.A. Schmidt. 1982. Malathion resistance in Indian meal moths (Lepidoptera: Pyralidae) infesting stored corn and wheat in the North-central United States. Journal of Economic Entomology, 75: 950-954.

Bereza, K. 1986. Insects in Farm Stored Grain. Publication 229, Ontario Ministry of Agriculture and Food. AGDEX 110/623. 12 pp.

Cogan, P.M. 1982. A method for the rapid detection of malathion resistance in *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) with further records of resistance. Journal of Stored Products Research, 18: 121-124.

Finney, D.J. 1971. Probit Analysis. Cambridge University Press, London. 333 pp.

Imura, O. and R.N. Sinha. 1986. Bioenergetics of the Indian meal moth, *Plodia interpunctella* (Lepidoptera: Pyralidae). Annals of the Entomological Society of America, 79: 96-103.

Madrid, F.J. and R.N. Sinha. 1982. Feeding damage of three stored-product moths (Lepidoptera: Pyralidae) on wheat. Journal of Economic Entomology, 75: 1017-1020.

Madrid, F.J., N.D.G. White, and R.N. Sinha. 1983. Effects of malathion dust on Indian meal moth and almond moth (Lepidoptera: Phycitidae) infestation of stored wheat. Journal of Economic Entomology, 76: 1401-1404.

Sinha, R.N. and F.L. Watters. 1985. Insect pests of flour mills, grain elevators, and feedmills and their control. Research Branch, Agriculture Canada. Publication 1776. Canadian Government Publishing Centre, Ottawa. 290 pp.

Sumner, W.A. II, P.K. Harein, and Bh. Subrahanyam. 1988. Malathion resistance in larvae of some Southern Minnesota populations of the Indian meal moth, *Plodia interpunctella* (Lepidoptera: Phycitidae), infesting bulk-stored shelled grain. The Great Lakes Entomologist, 21: 133-137.

White, N.D.G. 1988. Residual activities of insecticides on freshly harvested and previously stored wheat, and on various carriers exposed to concrete surfaces. Proceedings of the Entomological Society of Ontario, 119: 35-42.

White, N.D.G. and R.N. Sinha. 1990. Impact of chlorpyrifos-methyl on oat ecosystems in farm granaries. Journal of Economic Entomology (in press).

Zettler, J.L. 1974. Esterases in a malathion-susceptible and a malathion-resistant strain of *Plodia interpunctella* (Lepidoptera: Pyralidae). Journal of the Georgia Entomological Society, 9: 207-213.

Zettler, J.L. 1982. Insecticide resistance in selected stored-product insects infesting peanuts in the Southeastern United States. Journal of Economic Entomology, 75: 359-362.

Zettler, J.L., L.L. McDonald, L.M. Redlinger, and R.D. Jones. 1973. *Plodia interpunctella* and *Cadra cautella* resistance in strains to malathion and synergized pyrethrins. Journal of Economic Entomology, 66: 1049-1050.

Received 25 September 1989; accepted 19 December 1989

INCIDENCE OF *IXODES COOKEI* (ACARI: IXODIDAE) ON GROUNDHOGS, *MARMOTA MONAX*, IN SOUTHWESTERN ONTARIO

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Abstract *Proc. ent. Soc. Ont.* 121:105-110

The incidence of *Ixodes cookei* Packard (Acari: Ixodidae) on groundhogs (*Marmota monax* (L.)) in southwestern Ontario was investigated. Approximately 38% of 318 groundhogs collected from May to August, 1985-1987, were infested with *I. cookei*. The incidence of these ticks on male groundhogs was highest in May, whereas the incidence of ticks on female groundhogs was highest in late summer. Larvae, nymphs and adults occurred on groundhogs from May to August. Number of nymphs and adults did not change significantly over this period but larvae were more numerous in August (26.2/infested animal) than in other months (1.6-8.8 per infested animal). Ticks were not concentrated in any particular area on the groundhogs. There was no evidence of engorgement by adult males. Apparently *I. cookei* occurs primarily in the burrow habitat. This behaviour results in little contact with people and results in a low incidence of human infection with Powassan virus.

Introduction

Ticks of the species *Ixodes cookei* are the major vector of Powassan virus, McLean and Donohue (1959) (Flaviviridae: Flavivirus) (McLean *et al.* 1964, 1966, 1967). In man, Powassan virus infection can cause encephalitis (McLean and Donohue 1959; Goldfield *et al.* 1973), meningoencephalitis (Smith *et al.* 1974; Rossier *et al.* 1974) or meningitis (Deibel *et al.* 1975, 1979). Since the disease was discovered in 1958 (McLean and Donohue 1959), there have been 19 confirmed human cases in North America, with 4 resultant deaths (Artsob 1989). The ticks feed on a variety of rodents and carnivores (Bishopp and Trembley 1945; Gregson 1956) but are commonly collected from groundhogs (*Marmota monax* (L.)) (Bishopp and Trembley 1945; Gregson 1956; McLean *et al.* 1964, 1966). In southern Ontario, haemagglutination-inhibition antibodies to Powassan virus indicated past infection in approximately 23% of groundhogs (Artsob *et al.* 1984). Although this serological evidence indicates wide-spread viral activity in Ontario, the disease is relatively rare in humans despite the common occurrence of groundhogs near human habitations.

Our objective was to study the biology of *I. cookei*, so as to explain why the high activity of the virus in groundhogs does not result in a higher number of human cases of Powassan encephalitis.

Materials and Methods

Groundhogs were collected within a 40 km radius of Guelph, Ontario over 3 summers to determine the proportion that were infested with *I. cookei*, and the relative numbers of larvae, nymphs and adults per groundhog.

Three hundred and eighteen were collected primarily during the late spring and summer of 1985-1987. The majority were obtained from hunters who shot them as they foraged in pastures. Hunters were provided with clean plastic bags and they prevented the escape of parasites by placing the carcasses into the bags within minutes of death. Bags were sealed, labelled by locality and returned to the laboratory within 24 hours. Bagged animals were refrigerated (4°C) until examined, usually within 1-3 days of submission. Less than 20 animals were collected as fresh road kills (no rigor mortis) and processed in the same manner as animals which had been shot.

Each groundhog was sexed, and the hair and skin examined for *I. cookei*. An infested groundhog was defined as having at least one tick. Wandering ticks were removed with forceps and attached ticks were excised by cutting into the skin around the mouthparts of the embedded tick. Site of tick attachment was recorded for 6 dorsal body areas (head, shoulder, back, tail, fore legs, hind legs) and 6 ventral body areas (head, chest, belly, tail, fore legs, hind legs). Ticks collected from each groundhog were placed into clear polystyrene vials and later counted and classified according to instar. Adult ticks were sexed. The presence of other ectoparasites was also recorded.

Data were analyzed using ANOVA and Duncan's Multiple Range Test procedures. The incidence of ticks on groundhogs was analyzed using an ANOVA (arcsine-transformed data) designed as a 2-way factorial, using sex of the groundhog as the qualitative variable, month as the quantitative variable, and year as the block effect.

Results

Incidence of Ticks on Groundhogs. All ticks recovered were *I. cookei*. The infestation rates over the 3 years (38.5, 37.5 and 36.4%) were not significantly different ($p \geq 0.05$, ANOVA). The sex ratio of the groundhogs we obtained was approximately 1:1 (47% males, 53% females). There was a significant linear interaction ($p \leq 0.05$, ANOVA) between the sex of the groundhogs and monthly infestation rate. Monthly infestation rates (for all years combined) were lowest among female groundhogs in May (22.7%) and increased later in the season (43.8%) (Table I). Infestation of male groundhogs, however, peaked in May (61.5%) and declined thereafter (Table I).

Only 21 groundhogs were collected from September to April in the present study. Ten nymphal ticks and an adult female were removed from 2 of 15 groundhogs caught in April. No ticks were found on a groundhog obtained in March or on five obtained in September.

Other ectoparasites. Adult fleas, *Oropsylla arctomys* (Baker) (Siphonaptera: Ceratophyllidae), were recovered from 81.1% of 104 groundhogs examined from April to August in 1986 and from 78.4% of 66 groundhogs collected in 1987. On the flea-infested groundhogs the average population of fleas per animal of 9.7 ± 1.1 SE (range 1-67) in 1986 was not significantly different (ANOVA; $p \geq 0.05$) from 8.1 ± 1.0 SE (range 1-32) in 1987. Laelapid mites of the species *Androlaelaps fahrenholzi* (Berlese) (Acari: Mesostigmata), and staphylinid beetles of the genus *Atheta* were also recovered from groundhog hair, although they were not counted. Voucher specimens have been deposited in the University of Guelph entomological collection and the Canadian National Collection at the Biosystematics Research Centre in Ottawa.

Number and Life Stage Distribution of Ticks on Infested Groundhogs. Larval, nymphal and adult ticks were collected from infested groundhogs each year during May (Table II). They were likely ticks which had overwintered.

Throughout the study, more larvae than nymphs or adults (ANOVA; $p \leq 0.05$) (Table II) were collected. Ninety-one percent of the 98 adult ticks recovered from groundhogs were female. Males were rarely recovered from groundhogs, and were never found engorging on

these animals. The numbers of nymphs and adults on the groundhogs did not differ over time ($p \geq 0.05$, ANOVA) (Table II). However, more larval ticks were present in August ($p \leq 0.05$, ANOVA).

TABLE I. Monthly incidence of *Ixodes cookei* (Acari: Ixodidae) on *Marmota monax* in southwestern Ontario, 1985-1987.

Sex of Groundhogs	Percentage Infested[1]				
	May	June	July	August	Mean
Female	22.7 (10/44)	31.8 (14/44)	38.1 (24/63)	43.8 (7/16)	32.9
Male	61.5 (24/34)	44.7 (17/38)	38.3 (18/47)	24.0 (6/25)	43.6

[1] Ratios in brackets are the number of tick-infested groundhogs/number examined. Interaction between sex of groundhog and monthly infestation rate was significant ($p \leq 0.05$, ANOVA).

Almost 78% of the infested groundhogs had 10 or fewer ticks (Table III). However, 11.7% had ≥21 ticks per animal. Adult ticks never exceeded 8 per animal (Table II). Nymphal infestation levels were higher (Table III), reaching a maximum of 27 per animal (Table II). Larval infestations were highest (Table III), with a maximum of 124 per animal (Table II).

Site of Attachment. Approximately 19% of the 1427 *I. cookei* recovered from groundhogs were attached. Forty-two percent of them were located on the dorsal half of the groundhogs, and 58% on the ventral half. Ticks were not concentrated in any of the 6 ventral or dorsal body regions examined, indicating that *I. cookei* are not site-specific.

Discussion

The 38% infestation rate of groundhogs with *I. cookei* agrees with previous reports of 29 to 50% in Ontario (McLean *et al.* 1966; Ko 1972; Artsob *et al.* 1984). Cohn *et al.* (1986) reported a 25% infestation rate among groundhogs collected from New York State. The incidence of *Oropsylla arctomys* and the presence of *Androlaelaps fahrenholzi* from our study also are similar to those reported by Cohn *et al.*(1986). The higher incidence of tick infestation among male groundhogs in May (61.5%) may be attributed, in part, to increased inter-burrow movement at this time when males disperse in search of mates. Movement of females is more restricted than that of males (Grizzell 1955).

Because males of *I. cookei* apparently do not feed, this eliminates 50% of the adult population as potential transmitters of Powassan virus. In most genera of Ixodidae, both sexes must feed on a host for several days before copulation occurs. However, many

individuals of *Ixodes* spp. can copulate while unfed, and often occur within the nest or burrow of their host (Oliver 1974).

TABLE II. Number (mean ± SE) of *Ixodes cookei* (Acari: Ixodidae) on infested *Marmota monax* (N-120) in southwestern Ontario (1985-1987).

Month	No. of Groundhogs	Number of Ticks[1]		
		Larvae	Nymphs	Adults[2]
May	34	1.6 ± 0.6[a] (0-14)[1]	1.4 ± 0.3[a] (0-8)	0.9 ± 0.3[a] (0-8)
June	31	8.8 ± 3.5[a] (0-74)	2.6 ± 1.0[a] (0-27)	0.9 ± 0.2[a] (0-5)
July	42	7.9 ± 3.1[a] (0-102)	3.0 ± 0.8[a] (0-26)	0.8 ± 0.2[a] (0-5)
August	13	26.2 ± 11.6[b] (0-124)	1.1 ± 0.5[a] (0-5)	0.4 ± 0.1[a] (0-1)
Seasonal Mean[3]	120	8.4 ± 2.0[a]	2.3 ± 0.4[b]	0.8 ± 0.1[b]

[1] Numbers in brackets represent the range in tick numbers per groundhog. Monthly means in a column followed by the same letter do not differ significantly ($p \geq 0.05$, ANOVA, Duncan's Multiple Range Test).
[2] Ninety-one percent of adults were female.
[3] Seasonal means followed by the same letter do not differ significantly ($p \geq 0.05$, ANOVA, Duncan's Multiple Range Test).

The low number of groundhogs collected in March, April and September (N=21) reflects the duration of the hibernation period. In Ontario, most groundhogs enter hibernation in September and emerge on warm sunny days in late March . Even after first emergence in the spring, groundhogs may remain underground during periods of cold weather (DeVos and Gillespie 1960). The recovery of nymphs from groundhogs shot in April has not been previously reported. Ko (1972) did not find *I. cookei* on groundhogs caught in March (N=5) or September (N=9), although he found one adult female from animals collected in April (N=39). The low activity of *I. cookei* in early spring and throughout the autumn months reduces the potential contact of humans with this tick.

The higher number of larvae in August probably resulted from eggs which were laid in late spring. Ko (1972) reported a similar increase in larval numbers in August. At 29°C, approximately 31 days are required to initiate hatch in eggs of *I. cookei*, while at a cooler temperature of 15°C the incubation period is extended to approximately 100 days (Farkas and Surgeoner 1990).

TABLE III. Percent of 120 groundhogs in southwestern Ontario with various infestations of larvae, nymphs, and adults of *Ixodes cookei* (1985-1987)

Infestation Level (tick per animal)	Percent of Groundhogs Invested at Designated Level by			
	All Stages	Larvae	Nymphs	Adults
1 - 10	77.5	32.5	58.3	45.8
11 - 20	10.8	6.7	2.5	0.0
21 - 40	2.5	1.7	1.7	0.0
41 - 60	2.5	1.7	0.0	0.0
61 - 80	3.3	3.3	0.0	0.0
81 - 100	1.7	0.8	0.0	0.0
101 - 130	1.7	1.7	0.0	0.0

Groundhogs spend most of their time either resting or sleeping in dens, and even during times of peak activity, only an hour or two is spent above ground each day (Grizzell 1955). The number of ticks falling off animals in the burrows as compared with outside in the vegetation is likely proportional to the time the hosts spend in the two environments. This suggests that *I. cookei* ticks are primarily restricted to burrows, where activities such as host attachment, and egg laying take place. The occasional heavy infestations of groundhogs by larval ticks probably result from contact with a newly-hatched egg mass within a burrow.

In the present study, *I. cookei* was never recovered from clothing, although 2 to 3 hours were usually spent each week in fields where groundhogs with high infestation rates had been shot during the summer. This supports the hypothesis that these ticks are primarily restricted to burrows. The fact that *I. cookei* could not be collected by flagging in endemic areas (Ko 1972), but was recovered by inserting a cloth-covered plumber's snake into burrows (M.A. Grayson, New York State Department of Health, personal communication) also supports this hypothesis. The restriction of *I. cookei* to burrows minimizes the risk of them attaching to people, thereby reducing the probability of *I. cookei* transmitting Powassan virus to humans.

Acknowledgements

We thank Karen Petrik and Peter Sinnott for their assistance. We also acknowledge the identification of specimens by E. E. Lindquist, K. W. Wu and J. M. Campbell of the Biosystematics Research Centre of Agriculture Canada, and T. D. Galloway of the University of Manitoba. This research was funded through a Postgraduate Scholarship to M. J. Farkas from the Natural Sciences and Engineering Research Council of Canada. We also thank the Ontario Ministry of Agriculture and Food for technical support.

References

Artsob, H. 1989. Powassan encephalitis. *In*: The Arboviruses: Epidemiology and Ecology. Volume IV. T.P. Monath (ed.). CRC Press, pp. 20-49.

Artsob, H., L. Spence, G. Surgeoner, J. McCreadie, J. Thorsen, C. Th'ng and V. Lampotang. 1984. Isolation of *Francisella tularensis* and Powassan virus from ticks (Acari: Ixodidae) in Ontario, Canada. Journal of Medical Entomology, 21: 165-168.

Bishopp, F.C. and H.L. Trembley. 1945. Distribution and hosts of certain North American ticks. Journal of Parasitology, 31: 1-54.

Cohn, D.L., H.N. Erb, J.R. Georgi and B.C. Tennant. 1986. Parasites of the laboratory woodchuck (*Marmota monax*). Laboratory Animal Science, 36: 298-302.

Deibel, R., T.D. Flanagan and V. Smith. 1975. Central nervous system infections in New York State. New York State Journal of Medicine, 75: 2337-2342.

Deibel, R., S. Srihongse and J.P. Woodall. 1979. Arboviruses in New York State. American Journal of Tropical Medicine and Hygiene, 28: 577-582.

De Vos, A. and D.I. Gillespie. 1960. A study of woodchucks on an Ontario farm. Canadian Field-Naturalist, 74: 130-145.

Farkas, M.J. and G.A. Surgeoner. 1990. Developmental times and fecundity of *Ixodes cookei* Packard (Acari: Ixodidae) under laboratory conditions. Canadian Entomologist, 122. (in press).

Goldfield, M., S.M. Austin, H.C. Black, B.F. Taylor and R. Altman. 1973. A non-fatal human case of Powassan virus encephalitis. American Journal of Tropical Medicine and Hygiene, 22: 78-81.

Gregson, J.D. 1956. The Ixodoidea of Canada. Canada Department of Agriculture Publication 930. Ottawa, Ontario. 92 pp.

Grizzell, R.A. Jr. 1955. A study of the southern woodchuck, *Marmota monax monax*. American Midland Naturalist, 53: 257-293.

Ko, R.C. 1972. Biology of *Ixodes cookei* Packard (Ixodidae) of groundhogs (*Marmota monax* Erxleben). Canadian Journal of Zoology, 50: 433-436.

McLean, D.M. and W.L. Donohue. 1959. Powassan virus: Isolation of virus from a fatal case of encephalitis. Canadian Medical Association Journal, 80: 708-711.

McLean, D.M., J.M. Best, S. Mahalingam, M.A. Chernesky and W.E. Wilson. 1964. Powassan virus: Summer infection cycle. Canadian Medical Association Journal, 91: 1360-1362.

McLean, D.M., P.A. Smith, S.E. Livingstone, W.E. Wilson and A.G. Wilson. 1966. Powassan virus: Vernal spread during 1965. Canadian Medical Association Journal, 94: 532-536.

McLean, D.M., C. Cobb, S.E. Gooderham, C.A. Smart, A.G. Wilson and W.E. Wilson. 1967. Powassan virus: Persistence of virus activity during 1966. Canadian Medical Association Journal, 96: 660-664.

Oliver, J.H. Jr. 1974. Symposium on reproduction of arthropods of medical and veterinary importance. IV. Reproduction in ticks (Ixodoidea). Journal of Medical Entomology, 11: 26-34.

Rossier, E., R.J. Harrison and B. Lemieux. 1974. A case of Powassan virus encephalitis. Canadian Medical Association Journal, 110: 1173-1175.

Smith R., J.P. Woodall, E. Whitney, R. Deibel, M.A. Gross, V. Smith and T.F. Bast. 1974. Powassan virus infection. American Journal of Diseases of Children, 127: 691-693.

Received 21 August 1989; accepted 5 November 1990

EFFECTS OF DENSITY OF IMPORTED CABBAGEWORM LARVAE ON CAULIFLOWER YIELD AND MARKETABILITY

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Proc. ent. Soc. Ont. 121:111-113

The imported cabbageworm, *Artogeia rapae* (L.) (Lepidoptera: Pieridae), is the most abundant and important pest of cole crops in Ontario (Harcourt *et al.* 1955). Larvae damage plants indirectly by removing foliage which can result in smaller heads or directly by contaminating the heads with frass, feeding damage, or the larva itself (Harcourt 1978).

The relationship between density of imported cabbageworm larvae and yield of cauliflower should be determined before a pest management program is established. Data that relates larval density to damage exist more for cabbage (Samson and Geier 1983, Shelton *et al.* 1982) than for cauliflower (Stewart and Sears 1988).

The objectives of this study were to determine the relationship between density of imported cabbageworm larvae and marketability of cauliflower grown in a greenhouse or field cages, and to compare these results with published data from field studies for cabbage and cauliflower.

Cauliflower, cv 'Polar Express', spaced at 0.5 m within a row and 0.9 m between rows, were infested from head formation to harvest with 0, 1, 2, 3, 4, or 5 third or fourth instar larvae in the greenhouse (4 replicates per treatment; completely randomized design) or 0, 1, 2, or 3 third or fourth instar larvae in field cages (up to 7 plants per replicate; 3 replicates per treatment; randomized complete block design). These densities fall within the range normally seen in the Guelph area (Stewart 1987). Each larva was placed individually at the base of a leaf. Plants were checked every three days for the greenhouse experiment and every seven days for the field cage experiment to ensure that the appropriate density was maintained. Larvae that were missing, had died, or pupated were removed and replaced with live larvae of a similar age.

Cauliflower heads were harvested when they exceeded a diameter of 10 cm and the head appeared to be opening prior to the expansion of the influorescence (bolting). Data on weight and diameter of heads, and the proportion of heads not marketable were recorded at harvest. Heads were considered not marketable if they were contaminated with larvae, pupae, or frass, or if they had any feeding damage.

The data were analyzed by ANOVA (SAS Institute Inc. 1985). Effects of increased densities of larvae on head weight, diameter, or marketability were compared using a protected LSD ($p=0.05$). All proportions (P) were transformed (arcsine $\sqrt{P}$) before analysis.

An average of 67.3% of the larvae were replaced every three days to maintain the population. No statistical differences were found among densities with respect to the rate of replacement.

Defoliation by larvae at densities of three per plant under field conditions and five per plant under greenhouse conditions did not affect head weight or diameter (Table I). Slopes of the regressions of head weight (y_{wt}) and head diameter (y_{dia}) on larval density ($x = \sqrt{n}$ where n was the number of larvae) were not significantly different from zero for plants

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grown in the greenhouse (y_{wt} = 296 + 18.1x; s.e. slope = 21.3 and y_{dia} = 12.5 + 0.3x; s.e. slope = 0.4) or in field cages (y_{wt} = 656 - 16.4x; s.e. slope = 89.9 and y_{dia} = 17.7 - 0.3x; s.e. slope = 1.1). The lack of significant differences in head weight and diameter at these densities is not surprising. Samson and Grier (1983) found that seven imported cabbageworm larvae per plant feeding from nine days after transplanting did not affect the yield of cabbage whereas the yield of cabbage infested with 34 larvae per plant 20 days after transplanting was reduced by 34%.

TABLE I. Impact of the imported cabbageworm on the yield and marketability of cauliflower, cv 'Polar Express'.

	No. larvae/ plant	No. plants infested	Yield		Marketability[1] %
			Mean head weight (g)	Mean head diameter (cm)	
Greenhouse	0	3	276.2a±34.7[2]	12.2a±0.7[2]	100a± 0[2]
	1	4	359.3a±20.1	13.3a±0.5	50b±29
	2	4	329.6a±47.0	13.5a±0.6	0c± 0
	3	4	277.2a±21.2	12.2a±0.5	0c± 0
	4	4	361.4a±54.6	13.8a±1.3	25bc±25
	5	4	323.7a±40.6	12.8a±1.1	0c± 0
Field Cages	0	6	619.4a±22.3	17.3a±0.5	100a± 0
	1	9	679.2a±62.0	17.7a±0.7	61b±21
	2	13	742.6a±96.4	18.7a±1.0	32b± 9
	3	13	515.5a±54.9	15.9a±0.7	23b±15

[1] Heads with a diameter of more than 10 cm and free of larvae, frass, and feeding damage.
[2] Values in a column for each experiment followed by the same letter are not significantly different (P = 0.05; protected LSD).

Equations that describe the relationship between marketability and density of larvae were determined by least squares regression analysis. Linear equations best described this relationship for the greenhouse (y = 37.1x, r^2 = 0.730) and field cages (y = 38.4x, r^2 = 0.992) where y = proportion of heads not marketable and x = $\sqrt{n}$ where n was the number of larvae. Shelton *et al.* (1982) found that densities equivalent to 0.8-1.3 imported cabbageworm larvae per plant feeding from head formation to harvest reduced the marketability of cabbage by 7.5% (data average of 1979 and 1980). Using the regression equation from a previous study (Stewart and Sears 1988), the equivalent of 0.35 imported cabbageworm larvae feeding from head formation to harvest reduced the marketability of cauliflower by 7.5%. The regression equations derived from this study indicated that a 7.5% decrease in the marketability of heads could be expected if the density of imported cabbageworm larvae from head formation to harvest was only 0.17 larvae per plant in the greenhouse and 0.18 larvae per plant in field cages. Estimates based on the greenhouse (0.17 larvae per plant) and field cage (0.18 larvae per plant) study are expected to be lower than the estimates of field studies (0.35 larvae per plant) (Stewart and Sears 1988). Insect densities from field samples are averages which could include plants with no larvae. The greenhouse and cage experiments were based on known numbers of larvae feeding on each plant from head formation to harvest.

Acknowledgements

The technical assistance of R. McGraw, D. Kitchen, and K. Ferguson is gratefully acknowledged. Support for this research was supplied by Agriculture Canada and the Ontario Ministry of Agriculture and Food. This is Contribution No. 702, Charlottetown Research Station, P.O. Box 1210, Charlottetown, Prince Edward Island.

References

Harcourt, D.G. 1978. Cabbageworm. Ontario Ministry of Agriculture and Food, Agdex 252/625, 3 pp.

Harcourt, D.G., R.H. Backs, and L.M. Cass. 1955. Abundance and relative importance of caterpillars attacking cabbage in eastern Ontario. Canadian Entomologist, 87: 400-406.

SAS Institute Inc. 1985. Procedures Guide for Personal Computers, Version 6 Edition. Cary, North Carolina. 373 pp.

Samson, P.R. and P.W. Geier. 1983. Induction of crop damage by the cabbage white butterfly, *Pieris rapae* (Lepidoptera: Pieridae), on cabbage. Protection Ecology, 5: 199-223.

Shelton, A.M., J.T. Andaloro, and J. Barnard. 1982. Effect of cabbage looper, imported cabbageworm, and diamondback moth on fresh market and processing cabbage. Journal of Economic Entomology, 75: 742-745.

Stewart, J.G. 1987. Economic impact of the imported cabbageworm, cabbage looper, and diamondback moth on cauliflower in southern Ontario. Ph.D. Thesis, University of Guelph, Guelph, Ontario. 113 pp.

Stewart, J.G.G. and M.K. Sears. 1988. Economic threshold for three species of lepidopterous larvae attacking cauliflower grown in southern Ontario. Journal of Economic Entomology, 81: 1726-1731.

Received 26 July 1989; accepted 19 March 1990

MARKETABILITY OF CAULIFLOWER PROTECTED WITH PERMETHRIN APPLIED AT INTERVALS DETERMINED BY HEAD FORMATION

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Proc. ent. Soc. Ont. 121:115-117

Cauliflower heads graded as Canada No. 1 must be white or creamy-white in colour and free of frass or larvae of imported cabbageworm (ICW), *Artogeia rapae* (L.) (Lepidoptera: Pieridae), cabbage looper (CL), *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae), and diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae). Although growers tie the outer leaves of the plant above the developing head when it is 6 to 8 cm in diameter, about one week before harvest, to prevent discolouration (Anonymous 1986), quality of cauliflower can still be reduced by contamination of the head with larvae, frass, and/or feeding damage (Harcourt 1963). The optimum time to apply an insecticide to eliminate these three species of larvae on cauliflower is not well understood.

Use of an action threshold based on larval densities, such as the one proposed for cabbage by Shelton *et al.* (1982), may not be as appropriate for cauliflower as a single insecticide application at some point between head formation and harvest. However, marketability may be reduced by larvae and/or frass of lepidopterous larvae not controlled by insecticide applications delayed until after wrapper leaves are tied. The objectives of this study were therefore to determine the most appropriate time, relative to head formation, to apply an insecticide and to determine if wrapper leaves protected larvae within a tied head of cauliflower from the insecticide.

Seedlings, cv. 'Andes', were transplanted at the Cambridge Research Station on 23 June 1986. Six treatments were replicated 4x in a randomized complete block design: a non-treated control, and applications of permethrin, 140 g a.i./ha, at head formation (14 August), and 8 days (22 August), 14 days (28 August), 19 days (2 September), and 26 days (9 September) after head formation. The number of degree-days (α=5°C) accumulated from head formation to harvest was also recorded using an Omnidata TA51 °C Phenological Development Monitor (Omnidata International Inc., Logan, Utah). The number of larvae of ICW, CL, and DBM were counted weekly on 20 plants randomly selected in each treatment, starting at head formation (14 August) and continuing until harvest (16 September). Larval densities were converted to Cabbage Looper Equivalents (CLE) using the formula of Shelton *et al.* (1982):

1 CLE = 1.0 CL = 1.5 ICW = 20 DBM

Heads were tied on 5 September (tie-up), about two weeks prior to harvest. Plants were harvested on 16 September and head diameter and marketability were measured. Heads were considered marketable if they were free of larvae, not contaminated with frass, and showed no signs of feeding damage. The number of live ICW, CL, and DBM larvae were counted on tied leaves and in the head region of plants sprayed on 2 September (3 days prior to tie-up), 9 September (4 days after tie-up), and on plants of the non-treated control to determine the efficacy of permethrin.

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The number of CLE per plant, head diameter, and marketability were analyzed using an ANOVA procedure (SAS Institute Inc. 1985). Main effect treatment means, significant at $P \leq 0.05$, were compared using a protected Least Square Differences (LSD) mean separation test (SAS Institute Inc. 1985). Proportions (p) were transformed to arc sin $\sqrt{p}$ before analysis.

Imported cabbageworms and DBM respectively comprised 91% and 9% of the population of lepidopterous larvae in the non-treated plots from head formation to harvest. Although the average number of CLE per plant from head formation to harvest did not differ statistically among the six treatments (Table I), numbers tended to be lower in plots sprayed 8 days after head formation compared with plots sprayed later in the season. The number of larvae in the check plots was 2.87 CLE/plant at head formation, peaked at 5.18 CLE/plant on 28 August, then slowly declined to 1.69 CLE/plant on 11 September. The number of larvae in plots sprayed at head formation declined from 3.6 CLE/plant on 14 August to 0.1 CLE/plant on 21 August then gradually increased to 1.6 CLE/plant prior to harvest (11 September). Densities of larvae on plants sprayed 8, 14, 19, or 26 days after head formation declined immediately after treatment and then remained below 0.2 CLE/plant until harvest.

TABLE I. Mean density of larvae and yield of cauliflower, cv. 'Andes', sprayed with permethrin at intervals relative to head formation.

Permethrin[1] relative to head formation	Degree-days[2] from head formation	No. heads examined	No. CLE/ plant/week -planting to harvest	Head Diameter (cm)	Marketability[3] (%)
Non-treated control	-	42	2.93	11.7	39.2
0 days	0	43	1.51	13.1	50.5
8 days	85	39	2.03	12.2	90.0
14 days	113	42	3.16	12.8	64.8
19 days	131	40	2.52	12.1	71.9
26 days	166	30	2.84	11.4	50.6
LSD (P=0.05)			1.91	1.64	25.1

[1] Permethrin at 140 g a.i./ha
[2] Base temperature = 5°C
[3] Heads were considered marketable if they were free of larvae and showed no signs of frass or feeding damage. Marketability converted to arc sin $\sqrt{p}$ before analysis.

The population of larvae was composed primarily of ICW and the peak on 28 August corresponded to the peak for the third generation of this species. Populations on plants sprayed at head formation and 8 days after head formation were reduced before this peak in larval density. Applications of permethrin 14, 19, or 26 days after head formation therefore did not have the same impact as the other treatments because ICW populations were declining naturally. However, the effectiveness of permethrin was lost in plants treated at head formation and larval populations increased to about 2 CLE/plant at harvest as females were still laying eggs on the cauliflower.

Head diameters were not statistically different (Table I). Plants from the non-treated control, and those sprayed at head formation, 14, or 26 days after head formation produced fewer marketable heads than plants sprayed 8 days after head formation (Table I). Reduction in marketability was due to contamination by frass rather than the presence of larvae (data not shown). Permethrin applied 8 days after head formation produced the greatest marketability, equivalent to that achieved using biweekly sprays (Stewart and Sears 1988).

Although linking insecticide application to an interval relative to head formation rather than the number of larvae on the crop could reduce the number of insecticide applications needed during a growing season, such timing does not consider the presence or absence of larvae, the stage of growth of the plant, or climatic conditions. A principle of integrated pest management is application of control measures only when needed. Further studies should therefore be undertaken to determine an acceptable threshold for lepidopterous larvae on cauliflower relative to head formation so that effective control decisions may be made.

Densities of larvae (CLE/plant) on plants sprayed 19 days after head formation (3 days before tie-up), 26 days after head formation (4 days after tie-up), and on the control plants were similar (5.5 ± 0.77, 5.87 ± 1.42, 5.18 ± 1.52, respectively) on 28 August, one week before tie-up. At harvest, significantly more larvae were found on the non-treated control plants (0.77 ± 0.18 CLE/plant) than on plants sprayed 3 days (0.1 ± 0.08 CLE/plant) before tie-up or 4 days (0.04 ± 0.02 CLE/plant) after tie-up. Equal numbers of larvae at harvest on plants sprayed 3 days prior to and 4 days after tie-up suggests that permethrin controlled larvae within the tied leaves of cauliflower. Permethrin will then be an effective treatment should an action threshold be exceeded after tie-up.

Acknowledgements

The technical assistance of R. McGraw, D. Kitchen, K. Ferguson is gratefully acknowledged. Thanks are also extended to M. Hardman for suggestions relating to a previous draft of this manuscript. Financial assistance for this project was provided by the Ontario Ministry of Agriculture and Food and by Agriculture Canada. This is Contribution No. 698, Charlottetown Research Station, P.O. Box 1210, Charlottetown, Prince Edward Island, Canada.

References

Anonymous. 1986. Vegetable Production Recommendations. Ontario Ministry of Agriculture and Food, Publication 363, Agdex 250/13, p. 32-35.

Harcourt, D.G. 1963. Biology of cabbage caterpillars in eastern Ontario. Proceedings of the Entomological Society of Ontario, 93: 61-74.

SAS Institute Inc. 1985. SAS Procedures Guide for Personal Computers, Version 6 Edition. Cary, N.C. 373 pp.

Shelton, A.M., J.T. Andaloro, and J. Barnard. 1982. Effects of cabbage looper, imported cabbageworm, and diamondback moth on fresh market cabbage and processing cabbage. Journal of Economic Entomology, 75: 742-745.

Stewart, J.G.G. and M.K. Sears. 1988. Economic threshold for three species of lepidopterous larvae attacking cauliflower grown in southern Ontario. Journal of Economic Entomology, 81: 1726-1731.

Received 19 December 1989; accepted 14 March 1990

TOXICITY OF SELECTED INSECTICIDES TO ADULT *HOLCOTHORAX TESTACEIPES* (HYMENOPTERA: ENCYRTIDAE), AN IMPORTED PARASITOID OF *PHYLLONORYCTER BLANCARDELLA* (LEPIDOPTERA: GRACILLARIIDAE)

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Proc. ent. Soc. Ont. 121:119-122

The spotted tentiform leafminer (STLM), *Phyllonorycter blancardella* (F.) is an introduced pest of apple in eastern North America (Pottinger and LeRoux 1971; Johnson *et al.* 1976). Current recommendations in Ontario for control of STLM include the use of the pyrethroids permethrin, fenvalerate and deltamethrin, and the carbamate methomyl (OMAF 1989). As a result of intensive chemical control programmes over the past several years, STLM has developed resistance to commonly used orchard insecticides in Ontario (Pree *et al* 1980; Pree *et al.* 1986; Marshall and Pree 1986). The use of biological control agents must be explored to provide alternatives to chemical insecticides.

Holcothorax testaceipes (Ratzeburg) is an important egg-larval endoparasitoid of *Phyllonorycter ringoniella* Matsumura, a leafmining pest of apple in Japan (Sekita and Yamada 1979) which was introduced into southern Ontario in 1983 for control of STLM. Subsequent field observations indicate the *H. testaceipes* is established on STLM. Because adult *H. testaceipes* of the overwintering generation emerge from mid-May to early June (unpublished data), they could be exposed to permethrin or methomyl applied to control STLM and to azinphosmethyl or phosmet applied to control the plum curculio, *Conotrachelus nenuphar* (Herbst). Adult emergence of subsequent generations of parasitoids could coincide with applications of organophosphorous insecticides to control the codling moth, *Cydia pomonella* (L.), and the apple maggot, *Rhagoletis pomonella* (Walsh). Thus, if *H. testaceipes* is released into commercial apple orchards in Ontario, it will be exposed to sprays and/or residues of several insecticides. As part of an assessment of this parasitoid in Ontario orchards, this study was conducted to determine the toxicity of methomyl (Lannate® 215 g a.i./L), permethrin (Ambush® 90.8% tech.), azinphosmethyl (Guthion® 96.7% tech.), and phosmet (Imidan® 96.7% tech.) to adult *H. testaceipes*.

Leaves containing overwintering STLM were collected between 6 September and 18 October 1985 and between 19 and 25 October 1986 from the University of Guelph Research Orchard, Guelph, Ontario. Pupal masses of the polyembryonic *H. testaceipes* were dissected from the leaves and stored at 2°C for 4 months. To obtain adults, pupal masses were removed from cold storage and held in a 6-litre plastic container maintained at 23 ± 1°C and 16hL:8hD. Once emerged, parasitoids were trapped and stored at 5 ± 1°C for < 24 h in a 5-litre plastic container supplied with a 25% honey solution. Tests were conducted with females which, while searching for host eggs, would likely spend more time than males on the leaf surface with insecticide residues, which could increase mortality of the parasites.

The rate per unit area (g a.i./ha) as recommended by OMAF (1989) for each insecticide was selected for the initial treatment. The deposit per unit area was calculated and the parasitoids were exposed to this amount of residue. If parasitoid mortality exceeded 50% within 5 h post-treatment, lower concentrations of the insecticide were tested. After dilution to the desired concentrations, insecticides were applied in 1 ml aliquots to filter paper (Whatman No. 41, 90 mm diameter) and allowed to dry for 1-2 h in a fume hood. Adult parasitoids were exposed to the dry residues by placing them on the treated filter paper in ventilated disposable petri dishes (28 mm high x 90 mm diam). Two holes (10 mm diam)

were cut into the side wall of each dish; one was plugged with a wet cotton wick while the other, used for introducing insects into the test chamber, was plugged with a cork.

A test for each insecticide consisted of five treatment doses and a solvent control. To determine if the compounds had any fumigant effects, a second set of tests was conducted using identical doses of insecticides as above. However, the parasitoids were prevented from contacting the insecticide residues by a fine-mesh screen halving the petri dish horizontally. In both types of tests, each treatment dose was replicated 5-6 times and each replicate consisted of a petri dish containing 10 female parasitoids < 24 h old. Tests were conducted at 23 ± 1°C, 70% RH and continuous light. Mortality was recorded 12 h post-treatment except for the test of fumigant effects where mortality was checked 3 h post-treatment. Moribund individuals, still capable of moving legs, wings, or antennae when prodded, were considered dead. For data analysis, the treatment doses were g a.i./ha and SAS probit analysis (SAS Institute 1985) was used to generate the weighted linear regression of probits on logarithms of the doses using the maximum likelihood procedure described by Finney (1971). Toxicity ratios of each insecticide were calculated by dividing the recommended field rate by the LD_{50} for that insecticide.

All 50 parasitoids, used to examine fumigant effects, were alive 3 h post-treatment and it was concluded that there was no fumigant activity by the four compounds tested. Mortality in the controls for methomyl, permethrin, azinphosmethyl and phosmet was 15.1, 4.2, 3.9 and 3.7, respectively, averaging 6.7%. When only the LD_{50}'s were considered, the two organophosphorous insecticides were the least toxic insecticides tested (Table I). However, susceptibility of the parasitoid should be related to the rate of use of the insecticides in the field. Although female parasitoids were susceptible to all four insecticides, permethrin and phosmet were the least toxic with toxicity ratios of 2.2; methomyl was most toxic with a toxicity ratio of 26.2. Of the two organophosphorous insecticides, azinphosmethyl was more toxic to *H. testaceipes* than phosmet. The slopes of the straight lines, estimated by probit regression, were steepest for methomyl and permethrin (Table I). This indicates that, for a given increase in residue, methomyl and permethrin would cause a higher mortality of *H. testaceipes* than azinphosmethyl and phosmet. The LD_{50}'s for azinphosmethyl and phosmet were associated with wide fiducial limits which indicated large variation in response of female *H. testaceipes* to these insecticides (Table I).

TABLE I. Toxicity of residues of four insecticides to *Holcothorax testaceipes*.

Insecticide	No. Treated	RFD[1]	LD_{50} (g a.i./ha)	95% CL[2]	Slope of probit line (± SE)	Toxicity[3] ratio
Methomyl	332	1451	55.29	26.25- 83.91	2.08±0.32	26.2
Permethrin	300	200	90.76	38.05- 136.14	1.01±0.14	2.2
Azinphos-methyl	380	1050	265.54	85.21- 540.19	0.48±0.03	4.0
Phosmet	450	1875	835.27	539.64-1248.82	0.78±0.08	2.2

[1] RFD = recommended field dose
[2] 95% CL = 95% fiducial limits for LD_{50}
[3] Toxicity ratio = RFD/LD_{50}

Van Driesche *et al.* (1985) demonstrated that azinphosmethyl was significantly more toxic to *Sympiesis marylandensis* (Girault) than to its host *Phyllonorycter crataegella* (Clemens). Weires *et al.* (1982) reported similar results for *Pholetesor ornigis* (Weed), a braconid parasitoid collected from STLM in western New York and also found that parasitoid was very susceptible to methomyl. Trimble and Pree (1987) concluded that *Pholetesor ornigis* in Ontario had developed low levels of resistance to permethrin and methomyl during 5-7 years of use of the chemicals. They also showed that *P. ornigis* remained susceptible to azinphosmethyl although its host had developed 170-fold resistance to this insecticide.

Our tests, using insecticide residues on filter paper, only approximate the discontinuous residues found on treated foliage in the field. Additional studies are required to elucidate the response of the parasitoid to foliar residues under field conditions.

References

Finney, D.J. 1971. Probit Analysis. 3rd Edition. Cambridge University Press. 318 pp.

Johnson, E.F., J.E. Laing, and R. Trottier. 1976. The seasonal occurrence of *Lithocolletis blancardella* (Gracillariidae), and its major natural enemies in Ontario apple orchards. Proceedings of the Entomological Society of Ontario, 107: 31-45.

Marshall, D.B. and D.J. Pree. 1986. Effects of Pyrethroid insecticides on eggs and larvae of resistant and susceptible populations of spotted tentiform leafminer. Canadian Entomologist, 118: 1123-1130.

OMAF. 1989. Fruit Production Recommendations. Publication 360. Ontario Ministry of Agriculture and Food, Toronto.

Pottinger, R.P. and E.J. LeRoux. 1971. The biology and dynamics of *Lithocolletis blancardella* (Lepidoptera: Gracillariidae) on apple in Quebec. Memoirs of the Entomological Society of Canada, No. 77. 437 pp.

Pree, D.J., E.A.C. Hagley, C.M. Simpson, and A. Hikichi. 1980. Resistance of the spotted tentiform leafminer, *Phyllonorycter blancardella* (Lepidoptera: Gracillariidae), to organophosphorus compounds in southern Ontario. Canadian Entomologist, 112: 469-474.

Pree, D.J., D.B. Marshall, and D.E. Archibald. 1986. Resistance to pyrethroid insecticides in the spotted tentiform leafminer, *Phyllonorycter blancardella* (Lepidoptera: Gracillariidae), in southern Ontario. Journal of Economic Entomology, 79: 318-322.

SAS Institute Inc. 1985. SAS User's Guide: Statistics, Version 5. SAS Institute Inc., Cary, N.C. 956 pp.

Sekita, N. and M. Yamada. 1979. Studies on the population of the apple leafminer *Phyllonorycter ringoniella* Matsumura. III. Some analyses of the mortality factors operating upon the population. Japanese Journal of Applied Entomological Zoology, 14: 137-148.

Trimble, R.M. and D.J. Pree. 1987. Relative toxicity of six insecticides to male and female *Pholetesor ornigis* (Weed) (Hymenoptera: Braconidae), a parasite of the spotted tentiform leafminer, *Phyllonorycter blancardella* (Fabr.) (Lepidoptera: Gracillariidae). Canadian Entomologist, 119: 153-157.

Van Driesche, R.G., J.M. Clark, M.W. Brooks, and F.J. Drummond. 1985. Comparative toxicity of orchard insecticides to the apple blotch leafminer, *Phyllonorycter crataegella* (Lepidoptera: Gracillariidae), and its Eulophid parasitoid, *Sympiesis marylandensis* (Hymenoptera: Eulophidae). Journal of Economic Entomology, 78: 926-932.

Weires, R.W., J.R. Leeper,W.H. Reissig, and S.E. Lienk. 1982. Toxicity of several insecticides to the spotted tentiform leafminer (Lepidoptera: Gracillariidae) and its parasite, *Apanteles ornigis*. Journal of Economic Entomology, 75: 680-684.

Received 13 June 1989; accepted 17 July 1990

BUGWATCH: A MICROCOMPUTER-BASED MONITORING PROGRAM FOR PESTS OF APPLES AND PEACHES IN ONTARIO

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Proc. ent. Soc. Ont. 121:123-126

BUGWATCH is a microcomputer-based pest-monitoring program for apples and peaches designed for use by Ontario Ministry of Agriculture and Food pest management specialists and scouts (Yee and Yee 1989a). BUGWATCH monitors pest development and population size (via insect numbers monitoring devices) on a pest-by-pest and site-by-site basis. The current list of apple pests consists of apple maggot *Rhagoletis pomonella* (Walsh), codling moth *Cydia pomonella* (L.), oblique banded leafroller *Choristoneura rosaceana* (Harris), red banded leaf roller *Argyrotaenia velutinana* (Walker), spotted tentiform leafminer *Phyllonorycter blancardella* (Fabr.), *Pholetesor* (=*Apanteles*) *ornigis* (Weed), and European red mite *Panonychus ulmi* (Koch). The single peach pest is oriental fruit moth *Cydia molesta* (Busck). Users enter weather data and data from insect monitoring devices, and from that information BUGWATCH produces summaries of lifestage development and trap catches. Associated utility programs help the BUGWATCH manager maintain the system on the microcomputer. The general user does not use these utility programs. All programs are written in Turbo Pascal 3.0 (Borland 1985). The programs run on an IBM-PC/XT with math coprocessor and CGA graphics adapter operating under PC-DOS 2.10 (trademarks of International Business Machines, IBM 1983). Our note introduces the system to prospective users and researchers.

BUGWATCH can do the following:

(1) accept user-entered data and store it in proper files,
(2) summarize field insect captures,
(3) calculate pest lifestage and percent development of the current lifestage from weather data (Harcourt and Yee 1982),
(4) calculate simple summary statistics on trap count data,
(5) print text reports, and
(6) produce on a printer graphs of trap count versus time.

The user operates the program by selecting a task from the menu. Within a specific task the program prompts the user to enter a selection code (such as a date) and the corresponding data. This allows flexibility in data entry (e.g. temperatures may be entered by date in any order) and serves to remind the user what data are required (Yee and Yee 1989c). For convenience, batch processing of printing and developmental calculations occurs.

UTILITY is a program which assists the BUGWATCH manager to maintain the BUGWATCH pest and site data files by automating the following tasks:

(1) adding a new monitoring site,
(2) enabling or disabling data collection at a site,
(3) deleting a monitoring site,
(4) modifying (to a limited extent) the developmental rate function for a pest,
(5) initializing the data files for a site, and
(6) displaying site identification and information on data collection at a given site.

Operating information is available in the User and Manager Guides (Yee and Yee 1989c). Other utility programs help the BUGWATCH manager install the system, initialize the data files at the beginning of the season, and remove old files at the end of the season (Yee and Yee 1989b).

Ontario Ministry of Agriculture and Food pest management specialists have reported that BUGWATCH is easy to use and has a short response time. The batch processing facility allowed workers to leave the terminal while the program was running. Reports were produced more easily than with previous systems and turn-around time was reduced allowing pest management specialists to spend more time in the field. Table I shows system performance on an IBM-PC/XT. Performance on IBM-PC compatible systems can vary from these values.

Table I. Performance times of various operations associated with BUGWATCH[1]

Item	Time
Learning time	less than 30 minutes; independent of the number of sites
Response to data entry	
selecting a site	immediate
selecting trap file	variable, but less than 5 seconds
saving trap file	variable, but less than 5 seconds
selecting weather file	2 to 3 seconds
saving weather data	2 to 3 seconds
Calculation phase	30 minutes
Printout	
lifestage report	1 minute each
regional report	2 minutes each
graphs	2 minutes each

[1] Response and calculation times were obtained using an IBM-PC/XT with a math coprocessor chip and a 10 Mb hard disk running PC-DOS 2.10. Print times were obtained using an Epson FX-100 printer. There were 81 monitoring sites, almost half of which gathered weather data.

BUGWATCH, associated utility programs, and sample data files are available to all researchers. Both Pascal source and IBM-PC executable files are provided. Persons wishing to obtain the programs should send two 5.25 inch, double-sided, double-density, 360K formatted diskettes and a diskette mailer to either author.

Disclaimer

Mention of commerical products does not imply endorsement on the part of the authors, Agriculture Canada or Brock University.

Acknowledgements

An Ontario Ministry of Agriculture and Food service contract supported S. Yee's work. We thank P. Goodwin and K. Kerr of the Ontario Ministry of Agriculture and Food for their assistance.

References

Borland International. 1985. Turbo Pascal version 3.0 Reference Manual. Borland International, Inc., 4585 Scotts Valley Drive, Scotts Valley, CA, USA 376 pp.

Harcourt, D.G. and J.M. Yee. 1982. A polynomial algorithm for predicting the duration of insect lifestages. Environmental Entomology, 11: 581-584.

IBM. 1983. Disk Operating System by Microsoft Corp. version 2.10. International Business Machines, Boca Raton, FL, USA

Yee, J.M. and S. Yee. 1989a. BUGWATCH - Program reference manual. Research Branch, Agriculture Canada. Technical Bulletin 1989-4E. 27pp. + 3 appendices

Yee, J.M. and S. Yee. 1989b. BUGWATCH - Utilities reference manual. Research Branch, Agriculture Canada. Technical Bulletin 1989-7E. 20pp. + 3 annexes

Yee, J.M. and S. Yee. 1989c. BUGWATCH - User and manager guides. Research Branch, Agriculture Canada. Technical Bulletin 1989-8E. Part 1 26pp., Part 2 6pp., Part 3 21pp.

Received 6 March 1989, accepted 10 March 1990

PRESIDENT'S PRIZES* AND STUDENTS' PAPERS, 1990

The Society congratulates Carol Ramey and David Clements for their exemplary presentations at the 127th Annual meeting, held in Sault Ste. Marie on 19-21 October 1990 which resulted in their both being awarded the President's Prize at the banquet.

The Society also congratulates the other student participants in the meetings for their excellent presentations.

Abstracts of all student presentations are given below.

PRESIDENT'S PRIZES

HOST IDENTIFICATION AND OVIPOSITION BEHAVIOUR OF A PARASITIC WASP, *EURYTOMA OBTUSIVENTRIS* (HYMENOPTERA: EURYTOMIDAE)

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Proc. ent. Soc. Ont. 121:127

Eurytoma obtusiventris Gahan parasitizes larvae of the fly, *Eurosta solidaginis* (Fitch), which live in galls formed on goldenrods (*Solidago* spp.). Female wasps have available both *Solidago*-based and *Eurosta*-based cues to find their hosts. To identify important cues, I offered female *E. obtusiventris* a choice of plants for oviposition in a 0.8 m^3 cage. In the absence of host larvae, females landed more often and spent more time on *Solidago altissima* L. than *Solidago canadensis* L. or *Aster novae-angliae* L. Female wasps preferred stems of *S. altissima* with host larvae to those without, even when galls had not yet begun to form. However, females spent a significant amount of time exploring stems of *S. altissima* which did not contain hosts. Wasps repeatedly inserted the ovipositor while exploring the goldenrods. These insertions probably were sensory, and were always brief (<30 s) while insertions for oviposition were significantly longer (>5 min). Females oviposited only on plants containing host larvae.

THE APPLE RUST MITE *ACULUS SCHLECHTENDALI* (ACARI: ERIOPHYIDAE): A BENEFICIAL PEST

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Proc. ent. Soc. Ont. 121:127

Phytophagous arthropods are nearly always regarded as pests when they attack plants grown agriculturally. However, allowing certain pest species to survive may reduce the abundance of other pest species. Although the apple rust mite, *Aculus schlechtendali* (Nal.), is a phytophagous pest, it seldom reaches damaging populations. It has been suggested by some researchers that *A. schlechtendali* can improve control of the European red mite, *Panonychus ulmi* (Koch) through competition and by acting as an alternative host for predators. By simulating the orchard mite system, I found further support for the potential role of *A. schlechtendali* as an alternative host. Furthermore, the simulation demonstrated that the presence of *A. schlechtendali* could help to mediate potential harmful interactions between the major predators of phytophagous mites. Stigmaeid (*Zetzellia mali* (Ewing)) and

phytoseiid (*Typhlodromus caudiglans* (Schuster)) predatory mites tend to displace one another as prey decline. By maintaining both predators at higher levels, *A. schlechtendali* could provide a cushion against outbreaks of *P. ulmi*. Applying these simulation results to managed orchards is difficult because the "beneficial" mites, particularly *A. schlechtendali*, are less tolerant to pesticides than *P. ulmi*, but as management protocols seek to further reduce pesticide use, *A. schlechtendali* may come to play a useful role.

STUDENTS' ABSTRACTS

THE INFLUENCE OF SIZE ON THE THORACIC TEMPERATURE OF HOVERING MALE HORSEFLIES, *HYBOMITRA ARPADI* (DIPTERA: TABANIDAE)

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Proc. ent. Soc. Ont. 121:128

Male *Hybomitra arpadi* (Szilàdy) are active in the Churchill, Manitoba region for approximately 2-3 weeks in early July. Males hover while aggregating within mating arenas defined by the structure of the surrounding vegetation, and attempt to mate with female *H. arpadi* by pursuing passing insects. Aggregation begins between 0800-0900 and continues until approximately 1900 during which time thoracic temperatures of males ranged from 35.0-43.0°C and shaded ambient temperatures ranged from 12.5-30°C. Thoracic temperatures of males remain higher than ambient temperatures and show less variance than ambient temperatures suggesting that thoracic temperature may indicate the temperature constraints males experience during aggregation. A synthetic descriptor of fly size, created using principal component analysis, explained 70% of the variance in the size variables used in the analysis. Preliminary regression analyses using morphometric and weight measures as well as the synthetic size variable, as indicators of fly size, show a significant but weak relationship with thoracic temperatures.

SEROTONERGIC CONTROL OF PHAGOCYTOSIS IN HAEMOCYTES OF THE COCKROACH, *PERIPLANETA AMERICANA* (DICTUOPTERA: BLATTIDAE)

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Proc. ent. Soc. Ont. 121:128

Recent results indicate serotonin (5-HT) is involved with phagocytosis in haemocytes of the American cockroach, *Periplaneta americana* (L.). Assays of survival show that the defense system of the cockroaches is enhanced (increased survival) in the presence of 5-HT. A mammalian 5-HT receptor antagonist, ketanserin, blocked the 5-HT-mediated increase in survival of the cockroaches. The data suggest that a 5-HT receptor must be important in controlling a part of the defense system in cockroaches. I have assayed the effect of 5-HT on phagocytosis using stained bacteria. The results show that 5-HT increased phagocytosis and this effect was abolished by the mammalian 5-HT antagonists, ketanserin and mianserin. Thus, the assays of phagocytosis corroborated the findings of the studies of survival.

In vertebrates, catecholamines are known to increase the phagocytic activities of macrophages and neutrophils via the adenylate cyclase system. A time-course for phagocytosis in cockroach haemocytes shows a 5-HT-mediated increase in cAMP in the first minute. This was followed by a decline to control levels at 5 minutes. A similar, transient increase in cAMP is found in higher animals.

THE EFFECT OF HOST ENCOUNTER RATE ON FECUNDITY OF *GELIS TENELLUS* (HYMENOPTERA: ICHNEUMONIDAE)

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Proc. ent. Soc. Ont. 121:129

Gelis tenellus (Say) is a hyperparasitic ichneumonid wasp that attacks the cocooned larvae of *Cotesia melanoscela* (Ratzeburg). *C. melanoscelus* is a primary parasitoid that has been used in inundative release programs for control of gypsy moth. By killing primary parasitoids, *G. tenellus* may play an important role in gypsy moth population dynamics. Experiments were designed to assess the ovipositional response of female *G. tenellus* when they encountered host cocoons at differing rates. Female *G. tenellus* were provided with the same number of hosts but at different rates of encounter. One group received 2 hosts every day while a second group received 6 hosts every third day. The group that received a daily supply of hosts produced significantly more eggs than those encountering hosts every third day. Superparasitism by *G. tenellus* was common under both encounter rates. This may be a function of the restricted environment and prolonged exposure periods to hosts. *G. tenellus* may regulate its egg production in response to environmental cues, or conversely, egg production may be limited by its access to a protein source. Experiments involving encounter rate may offer insight into the response of populations of *G. tenellus* to an inundative release of *C. melanoscela.*

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SYSTEMATICS OF THE NEW WORLD SPECIES OF THE *RACHISPODA LIMOSA* GROUP (DIPTERA: SPHAEROCERIDAE)

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Proc. ent. Soc. Ont. 121:129

The subgenus *Leptocera* (*Rachispoda*) Lioy is a cosmopolitan group of over 100 species of sphaerocerid flies, with approximately 40 species described to date from the New World. *Rachispoda* may be divided into three broadly defined species groups, based on the chaetotaxy of the scutellum. One of these groups is the *Rachispoda limosa* (Fallén) group. Prior to 1990, only four species of this group were described from the New World: *Rachispoda limosa*, *R. frosti* Johnson, *R. hoplites* Spuler (North America), and *R. maculinea* Richards (South America). This study has described ten new species in this group (three Nearctic, seven Neotropical). A hypothesis is presented for the phylogeny of the group and

the zoogeography of the species is examined in light of this hypothesis. The *limosa* group appears to be polyphyletic, comprising two monophyletic groups of species. The Nearctic species are monophyletic, although potential Nearctic-Palearctic sister group relationships within this group must still be evaluated. The second monophyletic group comprises the Neotropical species, with three plesiomorphic species restricted to the northern Andes, and four apomorphic species distributed in lowland regions in northeastern South America and Central America. Two additional species of questionable affinity remain unplaced pending further study.

THE SPHAEROCERIDAE (DIPTERA) OF ST. JOSEPH ISLAND

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Proc. ent. Soc. Ont. 121:130

Between April 1987 and December 1989 pan traps were set in both a cedar swamp and in a mixed hardwood forest near Hilton Beach on St. Joseph Island, Ontario. The Sphaeroceridae were removed from the trap samples, mounted and identified to species. Species caught included rare *Xenolimosina phoba* Marshall and *Xenolimosina sicula* Marshall. Based on the known biogeography of the species caught I conclude that St. Joseph Island appears to be a transitional zone for Boreal and Carolinian fauna.

COLOUR RESPONSE OF LARCH CONE FLY, *STROBILOMYIA LARICIS* (DIPTERA: ANTHOMYIIDAE)

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Proc. ent. Soc. Ont. 121:130

The colour response of the larch cone fly, *Strobilomyia laricis* Michelsen, is being studied in order to develop an effective monitoring system for this pest. Studies on the colour preference and the factors that affect such preference have been initiated. Biotic factors such as sex, maturity, mating status and oviposition as well as abiotic factors such as spectrum quality, shape, size, background contrast, trap distance and height have been investigated. The experiments conducted in May and June 1990, near Kapuskasing in northern Ontario, examined the number of flies collected on traps of different colour, height and distance from the host tree. The female flies were dissected and their physiological status was determined. The response to colour of males and females, as well as that of mated and unmated females, have been compared and differences noted. These results indicate that the development of an effective colour trap to monitor this pest in seed orchards must take into account colour, presentation of the traps, and the physiological, sexual, and age of the trapped flies.

FIELD SELECTION FOR PYRETHROID RESISTANCE IN SPOTTED TENTIFORM LEAFMINER, *PHYLLONORYCTER BLANCARDELLA* (LEPIDOPTERA: GRACILLARIIDAE)

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Proc. ent. Soc. Ont. 121:131

Field selections with multiple, low-dose applications of a pyrethroid insecticide were conducted in an apple orchard at Smithfield, Trenton from 1988 to 1990 for resistance in spotted tentiform leafminer, *Phyllonorycter blancardella* (F.) to understand the development of resistance in this species. The leaf-dip method was used to evaluate the resistance/tolerance of larval populations of *P. blancardella*. A field population of *P. blancardella* from an apple orchard not sprayed with pyrethroids in Picton was used as a susceptible strain. After nine selections, the populations from the pyrethroid-sprayed orchard showed 3.4- and 11.1-fold resistance/tolerance to PP_{321} at LC_{50} and LC_{90}, respectively. Laboratory bioassay results further supported that tissue-feeding larvae are not controlled by insecticide application but that the sap-feeding larvae are so controlled in the field. In this study, *P. blancardella* developed less resistance than would be predicted by results obtained by other researchers using high-dose selection. The strategy for *P. blancardella* control with pyrethroid is being explored.

COMPETITION BETWEEN THE COLORADO POTATO BEETLE, *LEPTINOTARSA DECEMLINEATA* (COLEOPTERA: CHRYSOMELIDAE), AND THE POTATO LEAFHOPPER, *EMPOASCA FABAE* (HOMOPTERA: CICADELLIDAE), ON POTATO

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Proc. ent. Soc. Ont. 121:131

Field observations indicate a negative correlation between numbers of Colorado potato beetles (CPB) and potato leafhoppers (PLH) on potato. Evidence for interspecific competition was obtained by measuring changes in growth, development and feeding behaviour in the single and two-species situation. PLH feeds less on CPB damaged plants and both species can distinguish between damaged and undamaged plants. CPB gain less weight and have a lower emergence success on hopperburned plants. Chemical modification of the food source may be a cause for this competitive interaction. Plant samples with PLH damage, CPB damage, artificial defoliation and waterstress were analyzed for free amino acids using gas chromatography. It was found that CPB and PLH feeding affected the amino acid profile differently than artificial defoliation or waterstress suggesting that insect feeding caused more than a general stress reaction. The increase in free amino acids observed may be detected by insects with chemoreceptors or they may be precursors to inhibitory compounds such as alkaloids. This competitive interaction between the CPB and the PLH should be considered in a systems approach to potato pest management since it is unknown how new control methods such as Bt affect the dynamics of the whole potato pest complex.

THE EFFECTS OF A JUVENILE HORMONE ANALOGUE, S71639 ON COLORADO POTATO BEETLE, *LEPTINOTARSA DECEMLINEATA* (COLEOPTERA: CHRYSOMELIDAE), AND POTATO LEAFHOPPER, *EMPOASCA FABAE* (HOMOPTERA: CICADELLIDAE)

TRIKOESOEMANINGTYAS SANTOSO

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Proc. ent. Soc. Ont. 121:132

The treatment of the juvenile hormone analogue, 2-[1-methyl- 2-(2-phenoxy phenoxy) ethoxy] pyridine, or S71639, on last-instar larvae of Colorado potato beetle, *Leptinotarsa decemlineata* (Say), delayed the onset of pupation, caused the formation of deformed adults and prevented adult emergence. The morphogenetic activity of S71639 is modified by the time of application, concentration, and post-treatment temperature. S71639 also reduced hatchability when applied to eggs. The effect of S71639 on potato leafhopper, *Empoasca fabae* (Harris), is still under investigation.

MINERAL NUTRIENT ACQUISITION BY THE GALL OF *HEMADAS NUBILIPENNIS* (HYMENOPTERA: PTEROMALIDAE) ON THE LOWBUSH BLUEBERRY, *VACCINIUM ANGUSTIFOLIUM* (ERICACEAE)

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Proc. ent. Soc. Ont. 121:132

The chalcid wasp *Hemadas nubilipennis* Ashmead induces a multichambered gall on the vegetative shoots of lowbush blueberry, *Vaccinium angustifolium* Aiton. The gall wasps are known to alter structurally the growth form of attacked shoots, but little is known about how they physiologically alter their hosts.

Galls undergo three stages of development identified as initiation, growth and maturation. Galls in these three stages were collected near Sudbury, Ontario and analyzed for several mineral nutrients. Highest concentrations of nutrients, on a dry weight basis, accumulated in galls in the initiation stage. Concentrations of nutrients then decrease and stabilize as the galls enter the growth and maturation stages. Gall initiation occurs in the early spring when new plant growth and nutrient flow is greatest. The results indicate that galls act as physiological sinks as the larvae within direct the movement of nutrients from the host plant into the developing gall.

STRUCTURAL ALTERATIONS AND NUTRIENT DISTRIBUTION IN THE GALL OF *DIPLOLEPIS SPINOSA* (HYMENOPTERA: CYNIPIDAE)

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Proc. ent. Soc. Ont. 121:133

Diplolepis spinosa (Ashmead) induces a large multichambered gall on the stems of the cultivated rose *Rosa rugosa* Thunb. (Rosaceae). Galls from domestic roses in Sudbury, Ontario were used for histological studies of gall anatomy. Tissues of normal stems and leaves were compared to stems and leaves associated with galls. Levels of calcium and copper in mature gall tissues were compared to levels in normal leaves and stems.

Galls alter both the normal arrangement of vascular tissues, and the distribution of inorganic nutrients, within stems. Larvae of *D. spinosa* cause a redirection of vascular elements toward the larval chambers away from the apical meristem. As well, the larvae cause a lateral expansion of the stem pith and increase the proliferation of parenchyma cells adjacent to the larval chambers. Leaves distal to the gall are severely damaged.

It is hypothesized that vascular disruption is responsible for reduced levels of calcium in gall tissues and leaves distal to the gall. Increases in levels of copper in the gall, and gall-associated tissues, is related to an accumulation of organic compounds such as phenolics within the gall. The concentrations of copper in leaf tissues distal to the gall are toxic.

IN MEMORIAM

Dr. Hsien-Hua Cheng (1935-1990)

Dr. Hsien-Hua Cheng, Senior Research Scientist, Agriculture Canada, Research Station, Delhi, Ontario, passed away on May 27, 1990.

Dr. Cheng was born in San Dung Province, China, and came to Canada in 1963. He received his B.Sc. degree from the National Taiwan University in 1959. He obtained his M.Sc. and Ph.D. degrees in entomology from McGill University in 1965 and 1967. In 1967, he joined Agriculture Canada and began a very productive career as an entomologist.

In his service with Agriculture Canada, Dr. Cheng published over 50 research papers. Although best known for outstanding work on tobacco insect biology, ecology and control, his experience, knowledge and enthusiastic approach to research was invaluable in all aspects of entomology. An active collector and curator, Dr. Cheng developed and established over 60 drawers of tobacco and peanut insect specimens at Delhi. He contributed over 50 different species and rare and important species to the Insect Museum, Ottawa, for studies and reference.

In recent years, Dr. Cheng was involved with a tobacco technology exchange program with China. His contribution to China's agricultural development was recognized by the award of an Agricultural Medal in 1989. Dr. Cheng was the 18th recipient of this prestigious honour from China.

Dr. Cheng was a member of the Entomological Society of Ontario, Quebec, Canada and America; also of the Ontario Tobacco Committee, Crop Protection Committee and Entomology Section of Tobacco Workers in North America.

Dr. Cheng will be sadly missed and fondly remembered by those with whom he worked and also his many friends.

He is survived by his wife, Helen, his sons, Samuel and Edgar, and his daughters, Jane and Doris.

THANKS TO SPONSORS OF 1990 ANNUAL MEETING

The **Entomological Society of Ontario** is grateful for the support it received for the **127th Annual Meeting** held in Sault Ste. Marie on 19-21 October 1990 from the Forest Pest Management Institute and the scientific and technical staff.

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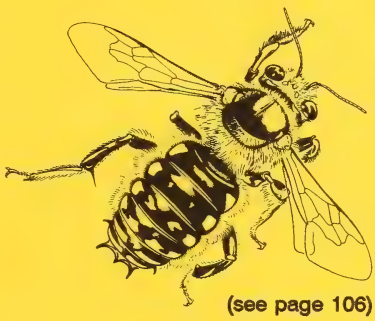

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Proceedings of the Entomological Society of Ontario Volume 122, 1991

FOLIAGE-FEEDING LEPIDOPTERA AND THEIR PARASITES RECOVERED FROM UNMANAGED APPLE ORCHARDS IN SOUTHERN ONTARIO

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Proc. ent. Soc. Ont. 122:1-7

Larvae of several species of Lepidoptera are observed each year in the spring feeding on the foliage of apple trees in unmanaged orchards in southern Ontario. Since many of these species occasionally assume pest status in commercial orchards and cause considerable damage (Hall 1929; Macnay and Creelman 1958; Hagley and Hikichi 1973), a survey was undertaken from 1982-1990 to determine (i) if changes in the species complex had occurred since the last survey in 1968-1972 (Hagley and Hikichi 1973), (ii) which species were most abundant, and (iii) levels of parasitism and the parasite guilds associated with each species.

Collections of larvae and pupae were made directly from apple foliage in the following areas of southern Ontario, *viz*: three sites in the Town of Lincoln; two sites each in Grey and Norfolk counties; and one site each in Brant, Durham, Northumberland, Simcoe and Wentworth counties and the Regional Municipality of Niagara. Collections were not made at all sites in each year. Larvae (2nd and 3rd instars) were reared initially in groups of 3-5 individuals and later, when mature, individually, on freshly cut apple shoots in 7 oz waxed paper cups at 24±1°C, 70-75% RH and a 16L:8hD photoperiod. The cut ends of the apple shoots were placed in water and the shoots replaced as needed. Mature field-collected larvae were similarly reared in individual containers. Pupae were placed individually in shell vials (2.3 cm int. diam. x 9.3 cm long) loosely stoppered with cotton and held under the same conditions as the larvae until adult host or parasite emergence occurred. All specimens of Lepidoptera and parasites recovered were identified by systematists at the Biosystematic Research Centre, Agriculture Canada, Ottawa, Ontario.

The species of spring feeders and their parasites obtained are given in Table I. Thirty-three species of Lepidoptera in seven families were recovered from 2196 larvae and pupae. In all years the most numerous Lepidoptera, which were recovered in orchards in all areas surveyed, were the oblique-banded leafroller, *Choristoneura rosaceana* (Harris) (49.7%); the eye-spotted budmoth, *Spilonota ocellana* (Dennis and Schiffermüeller) (21.0%); and the pale apple budworm, *Pseudexentera mali* Freeman (16.6%). Hagley and Hikichi (1973) previously reported that *C. rosaceana* and *S. ocellana* were present in most orchards in low numbers, and that *P. mali* was occasionally present. These authors suggested that these species had the potential to become serious pests of apple in Ontario. In 1989 a small amount of fruit injury due to *C. rosaceana* was observed in commercial orchards in Essex and Kent counties (Fisher *et al.* 1989), and in 1991 *C. rosaceana* was regarded as the primary pest of apple in Essex county (Huffman *et al.* 1991). Damage due to *C. rosaceana* was also reported in orchards on the Niagara peninsula in 1990 (McNeill *et al.* 1990), and in the Durham area in 1990 and 1991 (Clarke and Clarke 1990, 1991). *Spilonota ocellana* and *P. mali* must continue to be regarded as species with considerable pest potential. Ten other species of Lepidoptera observed by Hagley and Hikichi (1973) were not recovered in the present study, and five species observed in the present study were not recovered by Hagley and Hikichi (1973).

Hall (1929) reported ten species of tortricids and one gelechiid injurious to apple in Norfolk Co., and stated that *Archips argyrospilus* (Walker), *A.* (*Choristoneura*) *rosaceana* and *Pandemis*

limitata (Robinson), were the most numerous. In the present study *A. argyrospilus* and *P. limitata* were only occasionally recovered. Subsequently, Hikichi (1964) reported eighteen species of leafrollers on apple in Norfolk county, and stated that the species reported by Hall (1929) were also predominant in the 1940's and 1950's. Hikichi (1964) also noted that populations of the red-banded leafroller, *Argyrotaenia velutinana* (Walker), were increasing in Norfolk county. A total of 41 individuals of *A. velutinana* were recovered from four locations in 1989 and 1990 indicating that this species is currently of little importance. Macnay and Creelman (1958) listed forty-one species of spring feeding Lepidoptera, including *C. rosaceana* and *S. ocellana* as occasional pests of apple in Ontario. Macnay and Creelman (1958) did not list *P. mali*, *Coleophora tiliaefoliella* Clemens, *Orthosia hibisci* Guenée, *Hedya nubiferana* (Haworth) (=*H. variegana* Hübner), *Recurvaria nanella* (Denis and Schiffermüeller), or any *Sparganothis* sp. as occurring on apple in Ontario.

Twenty-four species of parasitic Hymenoptera in three families, and two species of parasitic Diptera in one family, were recovered. Ichneumonidae was the predominant parasitic group and accounted for 66.7% of the total number of species (n=71) recovered. Levels of parasitism were generally low and averaged 4.2% (n=616) for *C. rosaceana*; 5.7% (n=105) for *P. mali* and 10.0% (n=140) for *S. ocellana* during the survey period. *Itoplectis conquisitor* (Say) was the most frequently recovered parasite from *C. rosaceana* (27%) and *P. mali* (67%) and *Bassus* (=*Agathis*) *dimidiator* (Nees) from *S. ocellana*. The recovery of *Colpoclypeus florus* (Walker) from *C. rosaceana* and *S. ocellana* is reported for the first time from southern Ontario. This parasite was imported from France and released against *A. velutinana* in apple orchards near Simcoe, Norfolk Co., in 1967 (see Williamson 1967).

Highest levels of parasitism were observed in the *Coleophora* spp. (30.2%, n=63) and in the *Sparganothis* spp. (62.0%, n=21). The predominant parasites attacking *Coleophora* spp. were *Scambus* (*Scambus*) spp. (30%), and *Orgilus scabriculus* Nees (30%), and the primary species attacking *Sparganothis* spp. were *Triclistus* spp. (71%). Whether the efficacy of these parasites can be increased by augmentative releases must be determined by further study.

TABLE I. Species of Lepidoptera and their parasites recovered from unmanaged orchards in southern Ontario.[1]

Lepidoptera	Location and year collected	Parasites reared
Choreutidae		
Choreutis pariana (Clerck.)	A,1983; D,1983 J,1982; M,1984	
Coleophoridae		
Coleophora sacramenta Heinrich[2]	C,1983; E,1987	Hymenoptera Braconidae
C. pruniella (Clemens)	E,1988	*Orgilus scabriculus* Nees
C. tiliaefoliella Clemens	C,1983; D,1983	(C,1983) Ichneumonidae *Gelis* sp. (C,1983) *Scambus* (*Scambus*) sp. (C,1983) *S.* (*S.*) *decorus* Walley (C,1983)

TABLE I. - continued

Lepidoptera	Location and year collected	Parasites reared
Gelechiidae		
Dichomeris ligulella Hübner	G,1987	
Recurvaria nanella (Denis and Schiffermüeller)	K,1982; L,1982 M,1987	
Lymantriidae		
Orgyia leucostigma J.E. Smith	E,1987; G,1984 L,1987	
Lyonetiidae		
Bucculatrix pomifoliella Clemens	K,1989	
Noctuidae		
Amphipyra pyrimadoides Guenée	A,1986; B,1983,1987 G,1984,1986; M,1986,1987	
Orthosia hibisci (Guenée)	H,1983; L,1983	
Totricidae		
Archips argyrospilus (Walker)	D,1983; G,1987 K,1982,1988; M,1986	
A. negundanus (Dyar)	A,1984	
A. purpuranus (Clemens)	K,1982	Hymenoptera Braconidae *Macrocentrus nigridorsis* (Viereck) *Microgaster canadensis* (Muesbeck) *Oncophanes canadensis* (Muesbeck) (Above specimens reared by Putman (1942))
A. rosana (Linnaeus)	H,1984; M,1984	Hymenoptera Braconidae *Microgaster canadensis* (Muesbeck) Diptera Tachinidae *Phorocera erecta* Coquillet *Zenilla caesar* Aldrich (Above specimens reared by Putman (1942) from larvae on a privet-hedge and on *Caragana arborescens*)

TABLE I. - continued

Lepidoptera	Location and year collected	Parasites reared
Argyrotaenia mariana (Fernald)	B, 1982	
A. quadrifasciana (Fernald)	A,1984; B,1982; E,1984; K,1983	
A. velutinana (Walker)	A-M,1982-1990	Hymenoptera Trichogrammatidae *Trichogramma minutum* Riley (Reared by Garlick, 1955; Hikichi, 1962) Ichneumonidae *Phytodietus annulatus* (Provancher) (Reared by Hikichi, 1962)
Choristoneura rosaceana (Harris)	A-M,1982-1990	Hymenoptera Braconidae *Macrocentrus irridescens* (French) (A,1984). (Also reared from larvae on *Lonicera* sp. by Barron and Bisdee, 1984) Eulophidae *Colpoclypeus florus* (Walker) (E,1984,1990; K,1985) (Imported and released by A. Hikichi in Norfolk Co. in 1967) *Elachertus* sp. (K,1984) Ichneumonidae *Acropimpla alboricta* (Cresson) (A,1984) *Agrypon* sp. (E,1986) *Apophua simplicipes* (Chesson) (Reared by Barron and Bisdee, 1984) *Glypta* sp. (A,1987); (E,1985) *G. fumiferanae* (Viereck) (B,1987; E,1987) *Itoplectis conquisitor* (Say) (E,1984,1988) *Pimpla aequalis* Provancher (E,1987,1989) *Phytodietus* sp. (E,1985); (G,1984) *P. vulgaris* Cresson (E,1987)

TABLE I. - continued

Lepidoptera	Location and year collected	Parasites reared
Choristoneura rosaceana (Harris) - continued		*Scambus* (*Scambus*) *versicarius* (Ratzeburg) (E,1984) Trichogrammatidae *Trichogramma minutum* Riley (E,1984) Diptera Tachinidae *Actia interrupta* Curran. (E,1985) *Nilea* (*Pseudoperichaeta*) *erecta* (Coquillet) (I,1985)
Hedya chionosema (Zeller)	K,1982; M,1982	Hymenoptera Braconidae *Macrocentrus nigridorsis* Viereck (K,1982)
H. nubiferana (Haworth)	A,1983; E,1983 G,1987; M,1983	Hymenoptera Braconidae *Cotesia acaudus* Provancher (M,1983)
Olethreutes viburnana (McDunnough)	K,1983	
O. permundana (Clemens)	K,1985; L,1985	
Pandemis sp.	J,1985	Hymenoptera Ichneumonidae *Triclistus* sp. (J,1985)
Pandemis limitata (Robinson)	A,1985; D,1983 G,1984; M,1984	
P. probably *canadana* Kearfott	M,1988	
Platynota sp.	G,1986	
Pseudexentera mali Freeman	A-M,1982-1990	Hymenoptera Ichneumonidae *Diadema* sp. (L,1982) *Itoplectis conquisitor* (Say) (M,1984)
Sparaganothis diluticostana (Walsingham)	C,1989	
S. probably *directana* (Walker)	G,1984	

TABLE I. - continued

Lepidoptera	Location and year collected	Parasites reared
S. distincta[3] (Walsingham)	G,1984	Hymenoptera Ichneumonidae *Enytus* sp. (K,1982) *Triclistus* sp. (A,1984; C,1983)
S. reticulatana (Clemens)	A,1983,1984 K,1982,1983	Hymenoptera Ichneumonidae *Triclistus crassus* Townes (K,1982)
Spilonota ocellana (Denis and Schiffermüeller)	A-M,1982-1990	Hymenoptera Braconidae *Bassus* (=*Agathis*) *dimidiator* (Nees) (E,1987); (G,1983) Eulophidae *Colpoclypeus florus* (Walker) (E,1987); (J,1985) Ichneumonidae *Triclistus crassus* Townes (B,1982) Trichogrammatidae *Trichogramma minutum* Riley (Reared by Garlick, 1955)

[1] Orchard location (A=Ancaster, Wentworth Co.; B=Bowmanville, Durham Co.,; C=Clarksburg, Grey Co.; D=Collingwood, Simcoe Co.; E=Jordan Station, Town of Lincoln; F=Vittoria, Norfolk Co.; G=Louth, Town of Lincoln; H=Meaford, Grey Co.; I=Niagara-on-the-Lake, Regional Municipality of Niagara; J=St. Georges, Brant Co.; K=Simcoe, Norfolk Co.; L=Smithfield, Northumberland Co.; M=Vineland, Town of Lincoln).

[2] *Coleophora* spp. larvae not separated.

[3] *Sparganothis distincta* and *S. reticulatana* larvae not separated.

Acknowledgements

We thank J.M. Powers, B. Solymar, E. Gretsinger and M. Harrod for technical assistance; B. Ells (deceased), P. Fisher, K. Kerr, C. Thorpe, J. Uyenaka and J. Walker of the Ontario Ministry of Agriculture and Food, and J. Warner, Agriculture Canada, Smithfield Experimental Farm, for locating unmanaged orchards; and J.R. Barron, H.E. Bisdee, C.M. Yoshimoto, P.T. Dang, J-F. Landry, W.R.M. Mason, A. Mutuura, E.W. Rockburne, M.J. Sharkey and D.M. Wood of the Biosystematics Research Centre, Agriculture Canada, Ottawa, for specimen identifications.

References

Barron, J.R. and H.E. Bisdee. 1984. Hymenopterous parasites with Lepidoptera and sawfly hosts on *Lonicera* (Honeysuckle) in the Ottawa area. Canadian Entomologist, 116: 1345-1356.

Clarke, T. and A. Clarke. 1990. Ontario Ministry of Agriculture and Food, Weekly Horticultural Report, 90: 30-34.

Clarke, T. and A. Clarke. 1991. Ontario Ministry of Agriculture and Food, Weekly Horticultural Report, 91: 32-35.

Fisher, C., E. Tomecek, L. Huffman and T. Leuty. 1989. Ontario Ministry of Agriculture and Food, Weekly Horticultural Report, 89: 2-9.

Garlick, W.G.P. 1955. Faunal studies in an apple orchard not treated with insecticides. Annual Report Entomological Laboratory, Vineland Station, Ontario, Vol. 2, pp. 303-391.

Hagley, E.A.C. and A.A. Hikichi. 1973. The arthropod fauna in unsprayed apple orchards in Ontario. I. Major pest species. Proceedings of the Entomological Society of Ontario, 103: 60-64.

Hall, J.A. 1929. Apple leafrollers in Ontario. Report of the Entomological Society of Ontario, 1929, pp. 21-31.

Hikichi, A. 1962. Notes on mortality factors affecting the red-banded leafroller, *Argyrotaenia velutinana* (Wlkr.) (Lepidoptera: Tortricidae) in an unsprayed apple orchard in Ontario. Proceedings of the Entomological Society of Ontario, 92(1961): 180-182.

Hikichi, A. 1964. The status of apple leafrollers in Norfolk County, Ontario. Proceedings of the Entomological Society of Ontario, 94(1963): 38-40.

Huffman, L., T. Leuty, G. Ferguson and S. Khosla. 1991. Ontario Ministry of Agriculture and Food, Weekly Horticultural Report, 91: 2-9.

Macnay, C.G. and L.S. Creelman. 1958. List of insects and mites attacking tree fruits in Canada. Canadian Department of Agriculture, Science Service, Entomology Division. Research Notes, No. E12, 38 pp. Ottawa, Canada.

McNeill, B., K. Ker, G. Walker, W. Brown and J. Zimmerman. 1990. Ontario Ministry of Agriculture and Food, Weekly Horticultural Report, 90: 17-22.

Putman, Wm.L. 1942. Host plants and parasites of some lepidopterous larvae. Canadian Entomologist, 74: 219-223.

Williamson, G.D. 1967. Insect liberations in Canada. Parasites and predators 1967. Research Institute, Research Branch, Canada Department of Agriculture, Belleville, Ontario, 18 pp.

(Received 1 July 1991; accepted 6 December 1991)

SYNTHETIC VOLATILE LURES IMPROVE THE PERFORMANCE OF APPLE MAGGOT, *RHAGOLETIS POMONELLA* (DIPTERA: TEPHRITIDAE), TRAPS IN ONTARIO

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Abstract *Proc. ent. Soc. Ont.* 122:9-13

Field studies carried out over two years in Meaford and Trenton, Ontario showed that synthetic volatile lures increased apple maggot (AM), *Rhagoletis pomonella* (Walsh), catches on traps consisting of a yellow panel plus two red spheres by two to four times, compared to traps without lures. Traps baited with Consep® or Ladd® lures usually caught AM flies earlier in the season and when AM populations were low compared to unbaited traps. Ninety percent of the AM flies caught were on the red sphere part of the trap. More sensitive traps and improved treatment thresholds should increase the confidence in the AM monitoring system.

Introduction

Apple Maggot (AM), *Rhagoletis pomonella* (Walsh) (Diptera: Tephritidae), is a serious pest attacking apple fruit in eastern North America. In Ontario, a combination of red spheres and Pherocon® prebaited yellow AM panels is used to monitor AM flies in commercial orchards (Ontario Ministry of Agriculture and Food 1990). Control sprays are recommended as soon as any AM flies are caught in commercial orchards. The efficiency of AM traps has been improved by using synthetic apple volatiles which are attractive to both male and female AM flies (Reissig *et al.* 1982; Swift 1982). In New York State, red spheres baited with synthetic volatile chemicals were more effective than unbaited red spheres or yellow panels in attracting AM flies in commercial orchards (Reissig *et al.* 1985; Agnello *et al.* 1990). A threshold of five AM flies per volatile baited red sphere was suggested in New York State before control sprays were recommended (Agnello *et al.* 1990). The use of this threshold should reduce the number of control sprays required without increasing fruit injury. Warner and Smith (1989) reported Ladd® lures containing a 6-component mixture of synthetic apple volatile chemicals increased AM fly catches on traps used in abandoned orchards. However, the use of synthetic volatile lures has not been tested in commercial orchards in Ontario. This paper reports on the effectiveness of synthetic volatile lures, used in conjunction with the standard AM trap presently used in Ontario, to monitor AM in commercial and research orchards in Ontario.

Materials and Methods

A commercial orchard in Meaford, Ontario and research orchards at the Smithfield Experimental Farm (S.E.F.), Trenton, Ontario were used in this study. The Meaford orchard consisted of 50-year-old apple (*Malus domestica* Borkh.) trees cv. McIntosh and Northern Spy on seedling rootstocks. The S.E.F. orchards consisted of mature apple trees cv. McIntosh, Northern Spy, Delicious, Spartan, Paulared, Jonamac, and Jerseymac on size-controlling rootstocks. Orchard size was 17 ha in Meaford and varied from 0.25 to 1 ha in size at the S.E.F. The orchards were sprayed following an integrated pest management program (O.M.A.F. 1990).

The traps used were: (1) a standard trap consisting of a Pherocon® AM (Trece Incorporated, Salinas, California, U.S.A. 93915) yellow panel (14.0 x 23.0 cm) baited with ammonium acetate and casein hydrolysate and two 7.0 cm diameter unbaited red polyethylene spheres placed approximately 0.5 m to each side of the yellow panel; (2) a standard trap as described above except baited with a Consep® membrane biolure (Consep Membrane Inc., Bend, Oregon, U.S.A. 97708) containing butyl hexanoate attached to the top of each red sphere; and (3) a standard trap baited with a Ladd® (Ladd Research Industries, Burlington, Vermont, U.S.A. 05402) odour enhanced lure attached to the top of each red sphere. The Ladd® lure was tested only at the S.E.F. Disposable red polystyrene spheres (Olsen Products, Medina, Ohio, U.S.A. 44258) were used in the Meaford orchard instead of the polyethylene spheres. At the beginning of each trapping season the red spheres on all traps were coated with a brush-on formulation of tangle-trap (The Tanglefoot Company, Grand Rapids, Michigan, U.S.A. 49504).

In the Meaford orchard, 10 trees were chosen from the perimeter of the orchard. These were divided into five blocks (replicates), each with two trees. One trap was placed in each tree using a randomized complete block design. Traps were separated by approximately 40 m. At the S.E.F., the three traps were placed in trees along the outer row on each of two sides of 10 orchards using a randomized complete block design. Each row served as a replicated (20 replicates). Traps were separated by at least two trees and a minimum of 10 m. In both orchards, traps were hung approximately 1.5 m above ground level and foliage was removed from around the traps so that they were clearly visible from outside the tree canopy.

In the Meaford orchard, traps were put out on 28 June both years and removed 4 September, 1989 and 13 September, 1990. The yellow panels and lures were replaced once each year during the first week of August. At the S.E.F., traps were put out 23 June, 1989 and 17 July, 1990 and removed from the orchard at the end of August both years. Yellow panels were replaced every two weeks and lures were changes on 27 July, 1989 and 7 August, 1990.

Traps were checked twice a week and the number of AM flies caught on the red spheres and yellow panel was recorded separately for each sex. AM flies and other debris were removed from the trap surface on each trap check date. The surface of the traps remained sticky throughout the trapping season. After each inspection, when one or more AM flies were caught, traps were moved one position within each replicate to minimize the effect of location on trap performance. AM flies trapped in the Meaford orchard were saved (Warner and Smith 1989) and dissected under a binocular microscope and the presence of eggs was used as an indication of sexual maturity.

The number of AM flies trapped per date, starting at first AM fly catch, was subjected to analysis of variance using a randomized complete block design with date as a second blocking factor (Steel and Torrie 1980). For the S.E.F. data, when a significant "F" value was obtained ($P<0.05$), means were separated using Duncan's multiple range test ($P=0.05$).

Results

A total of 104 AM flies was trapped in 1989 and 160 in 1990 in the Meaford orchard. First catch occurred on 20 July, 1989 on a baited red sphere. In 1990, first catch occurred on 23 July on an unbaited red sphere. First catch on the baited traps occurred on 26 July, 1990. In both years, the Consep® membrane biolure increased AM fly catches compared to unbaited traps (Table I). AM fly catch was significantly increased ($P<0.01$) on the baited red spheres but was not affected on the yellow panel part of the trap.

TABLE I. Mean number of apple maggot flies caught per trap[x] at Meaford.

Year and lure	Red spheres			Yellow panel			Red spheres + yellow panel		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
1989									
Consep®	0.74a[y]	0.35	1.23a	0.02	0.03	0.05	0.75a	0.38	1.28a
No lure	0.14b	0.14	0.29b	0.02	0.02	0.03	0.15b	0.15	0.32b
S.E.[z]	0.13	0.07	0.13	0.02	0.02	0.02	0.11	0.08	0.13
1990									
Consep®	0.89	0.59a	1.47a	0.07	0.14	0.21	0.96	0.73a	1.69a
No lure	0.24	0.23b	0.49b	0.01	0.10	0.11	0.26	0.33b	0.60b
S.E.	0.18	0.07	0.21	0.03	0.06	0.06	0.19	0.05	0.23

[x] Traps checked twice a week. Data from 20 July to 4 September, 1989 and 23 July to 13 September, 1990.

[y] Means followed by the same letter within each column for each year are not significantly different using "F" test ($P=0.05$). Absence of letters indicates no significant difference. Each mean represents the average of 65 observations in 1989 and 70 observations in 1990.

[z] S.E. = standard error of means within each column for each year.

In 1989, 59 male and 35 female AM flies were trapped. In 1990, 85 males and 74 females were trapped. The number of females caught was larger on the baited traps than on unbaited traps ($P=0.12$ in 1989 and $P=0.004$ in 1990). Only five of the female flies did not have eggs in the abdominal cavity when dissected.

A total of 675 AM flies was trapped in 1989 and 2,996 in 1990 at the S.E.F. In both years, the Consep® membrane biolure increased AM fly catches compared to unbaited traps (Table II). In 1990, the Ladd® lure also significantly ($P<0.05$) increased AM fly catches compared to unbaited traps. The Consep® lure effect was significant ($P=0.05$) on the red spheres both years and on the yellow panel part of the trap only in 1989. The Ladd® lure effect was significant ($P=0.05$) on the red spheres only in 1990. The number of female AM flies caught was also greater in both years for traps baited with the Consep® lure compared to unbaited traps. In 1990, the Ladd® lure also significantly ($P<0.05$) increased female AM fly catches compared to unbaited traps.

TABLE II. Mean number of apple maggot flies caught per trap[x] at Smithfield Experimental Farm.

Year and lure	Red spheres			Yellow panel			Red spheres + yellow panel		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
1989									
Consep®	1.12a[y]	0.65a	1.77a	0.10	0.22	0.32a	1.22a	0.87a	2.09a
Ladd®	0.58b	0.32b	0.90b	0.06	0.18	0.24b	0.64b	0.50b	1.14b
No lure	0.28b	0.20b	0.48b	0.05	0.14	0.19b	0.32b	0.35b	0.67b
S.E.[z]	0.12	0.07	0.18	0.02	0.03	0.03	0.13	0.08	0.19
1990									
Consep®	4.6a	1.3a	5.9a	0.2	0.3	0.4	4.7a	1.6a	6.3a
Ladd®	3.3b	1.0a	4.3b	0.1	0.2	0.3	3.4b	1.2b	4.6b
No lure	1.5c	0.4b	2.0c	0.1	0.2	0.3	1.6c	0.7c	2.3c
S.E.	0.3	0.1	0.4	0.02	0.04	0.05	0.3	0.1	0.4

[x] Traps checked twice a week. Data from 26 June to 31 August, 1989 and 19 July to 30 August, 1990.

[y] Means followed by the same letter within each column for each year are not significantly different using Duncan's multiple range test (P=0.05). Absence of letters indicates no significant difference. Each mean represents the average of 173 observations in 1989 and 226 observations in 1990.

[z] S.E. = standard error of means within each column for each year.

In 1989, first AM fly catch occurred on baited traps in 17 of the 20 locations. At one location, baited and unbaited traps caught AM flies on the same date and at two locations, first catch occurred on unbaited traps. In 1990, first AM fly catch occurred on baited traps at 10 locations and on both baited and unbaited traps on the same date at the other 10 locations.

Discussion

The results of our experiments show the improved performance of AM traps baited with Consep® and Ladd® lures in Ontario. Two to four times more AM flies were caught on baited traps than on unbaited traps, depending on location and year. This is similar to the findings of Reissig *et al.* (1985) who reported that volatile baited red spheres were two to four times more effective than unbaited red spheres when used in commercial orchards in New York State. In our study, first AM fly catch usually occurred earlier with the baited traps. The baited traps were more sensitive when AM fly populations were low at the beginning and end of the season. Agnello *et al.* (1990) and Reissig *et al.* (1985) also concluded that volatile baited red spheres were more sensitive in detecting low AM populations than were unbaited traps. In addition, when numbers caught are higher, it is easier to determine peak periods of AM fly activity. The baited traps would be more useful than unbaited traps in a wide range of commercial orchards where AM populations are low. It is also clear that when trap performance is improved, the treatment threshold of one AM fly caught in a commercial orchard should be increased. Stanley *et al.* (1987) suggested a treatment threshold of two to five adults per trap using baited red spheres. This

was similar to a treatment threshold of five adults per baited trap proposed by Agnello *et al.* (1990) for New York State. No attempt was made in the present study to determine treatment thresholds.

It is the female AM which causes damage to the fruit. Although the number of female AM flies caught was less than the number of males, the lure effect was significant for the females. In the Meaford orchard, most female AM flies were gravid, regardless of date. The red spheres act as a fruit mimic eliciting a mating and oviposition type response (Prokopy 1968).

During the two years tested at Meaford and S.E.F., 90% of the AM flies caught were on the red sphere part of the traps. Using a baited red sphere trap with no yellow panel would provide savings in cost and labour compared to the standard trap presently used in Ontario (two red spheres + yellow panel). However, additional work needs to be carried out to evaluate the baited red sphere trap in Ontario and to determine a treatment threshold for this trap. More sensitive traps and improved treatment thresholds levels should increase the confidence in the AM monitoring system and help to reduce pesticide use for control of this pest.

Acknowledgements

We thank J.M. Cook for technical assistance in this study, and Anita Lajunen and Heather Scott for help in collecting trap catch data.

References

Agnello, A.M., S.M. Spangler and W.H. Reissig. 1990. Development and evaluation of a more efficient monitoring system for apple maggot (Diptera: Tephritidae). Journal of Economic Entomology, 83: 539-546.

Ontario Ministry of Agriculture and Food. 1990. Integrated pest management for apple orchards in Ontario. Queens Printer, Toronto, Ontario, 59 pp.

Prokopy, R.J. 1968. Visual responses of apple maggot flies, *Rhagoletis pomonella* (diptera: Tephritidae): orchard studies. Entomologia Experimentalis et Applicata, 11: 403-422.

Reissig, W.H., B.L. Fein and W.L. Roelofs. 1982. Field tests of synthetic apple volatiles as apple maggot (Diptera: Tephritidae) attractants. Environmental Entomology, 11: 1294-1298.

Reissig, W.H., B.H. Stanley, W.L. Roelofs and M.R. Schwarz. 1985. Tests of synthetic apple volatiles in traps as attractants for apple maggot flies (Diptera: Tephritidae) in commercial apple orchards. Environmental Entomology, 14: 55-59.

Stanley, B.H., W.H. Reissig, W.L. Roelofs, M.R. Schwarz and C.A. Shoemaker. 1987. Timing treatments for apple maggot (Diptera: Tephritidae) control using sticky sphere traps baited with synthetic apple volatiles. Journal of Economic Entomology, 80: 1057-1063.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. 2nd edition. McGraw-Hill, New York, 633 pp.

Swift, F.C. 1982. Field tests of visual and chemical lures for apple maggot flies. Journal of Economic Entomology, 75: 201-206.

Warner, J. and A. Smith. 1989. Apple maggot, *Rhagoletis pomonella* (Diptera: Tephritidae), response to traps, synthetic lures and adhesive in field tests in Ontario. Proceedings of the Entomological Society of Ontario, 120: 55-64.

(Received 22 July 1991; accepted 25 November 1991)

POLLINATION OF GREENHOUSE TOMATOES BY BUMBLE BEES IN ONTARIO

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Abstract *Proc. ent. Soc. Ont.* 122:15-19

The use of *Bombus* [*B. impatiens* and *B. bimaculatus* (Hymenoptera: Apidae)] introduced into greenhouses for pollination of tomatoes resulted in crop yields and quality equivalent to that from artificial (by hand-held buzzer for tomato pollination) pollination. Tomatoes receiving little to no pollination by *Bombus* set fewer tomatoes than those which were hand-pollinated.

Although the tomato (*Lycopersicon esculentum* Mill. Solanaceae) is mostly self-fertile, the flowers require agitation particularly sonication (Buchmann 1983, 1986) to release pollen from the poricidal anthers. In greenhouses, hand-held electric vibrators are often used to release pollen and bring about pollination. Recently, however, bumble bees (*Bombus terrestris* (L.)) have been found to be highly efficient pollinators of greenhouse tomatoes in Europe (Banda and Paxton 1991; van Ravestijn and van der Sande 1991). Because of the savings in labour costs and general reliability of bumble bees as pollinators in European greenhouses, interest has developed in using the same technology, but tailored to Canadian species of bumble bees (Plowright and Laverty 1987; Straver and Plowright 1991). With the above in mind, we conducted experiments with bumble bees in tomato greenhouses in Ontario to determine their efficacy as pollinators.

Materials and Methods

Two sets of experiments are reported herein. One was made in a commercial setting, the other at the Horticultural Research Institute of Ontario (H.R.I.O.) greenhouses at Vineland, Ontario.

Two greenhouses for commercial production of tomatoes were used. Both were located in the same complex operated by Robertson Greenhouses in Vineland Station, Ontario. The greenhouses were 1458 m^2 and 926 m^2. One colony of bumble bees, *B. impatiens* Cresson, in the larger house and *B. bimaculatus* Cresson in the smaller, was introduced into each house on 8 May, 1990. The bees were seen to have started pollinating activity by 10 May, 1990. One H.R.I.O. greenhouse, 200 m^2, was used with one colony of *B. impatiens* introduced on 8 May, 1990. The colonies were supplied by R.C. Plowright via Morse Growers' Suppliers, Leamington, Ontario. In all greenhouses the tomato plants were grown at 80 cm spacing in the rows.

At the start of the experiments the Beefsteak tomatoes (cultivar Caruso) were well grown. The inflorescences on experimental plants were marked with numbered flags as to those which had already completed blooming before the bumble bees were introduced versus those which bloomed in the presence of bumble bees. Two groups of 12 plants in two rows adjacent to each other were marked in each commercial greenhouse and two groups of 9 replicates (= plots), each of 6 plants

per plot, were marked in the H.R.I.O. greenhouses. One group received usual daily hand-held electric buzzer (*ca.* 30 Hz) (Agrarische Unie-Vulcaan, Aalsmeer, Netherlands) pollination of all inflorescences. The other group was buzzer pollinated daily until the bumble bees were introduced. Thereafter, the inflorescences remained untouched by buzzer. Thus, the treatments in the commercial houses were 2 groups of plants buzzer pollinated before bumble bees and, then after bumble bees were introduced, the same groups but buzzer and bumble bee pollinated *versus* bumble bee pollinated alone. In the H.R.I.O. greenhouse the colony almost died out in mid-June but was replaced on 2 July. Thus, in the H.R.I.O. greenhouse the treatments were one group of plants pollinated by bumble bees alone and one group by bumble bees and buzzer, but in three periods; 1 when the first colony of bumble bees was strong; 2 when it was weak; and 3 after it had been replaced by a strong colony. No data were collected from the H.R.I.O. greenhouses for tomatoes pollinated by buzzer alone before the introduction of the bumble bees.

As the tomatoes were harvested from the commercial greenhouse they were collected, measured by three diameters (d_1 = equatorial maximum, d_2 = equatorial minimum, and d_3 = calyx to stigmatic scar), weighed, and then squashed to obtain the seed count. The three diameters were used to calculate a measure of roundness as follows:

$$Roundness = \sum_{i=1}^{3} \left| 1 - \frac{d_i}{\bar{d}} \right| \quad \text{where} \quad d_i = \text{diameter}, \quad \bar{d} = \text{average diameter} \quad \frac{d_1 + d_2 + d_3}{3}$$

As the tomatoes were harvested from the H.R.I.O. greenhouse, they were counted, weighed, and graded.

Statistical analyses were by Analysis of Variance followed by Tukey's Studentized Range test, or by Chi-squared contingency tests.

Results and Discussion

Because we found no statistical differences between tomatoes harvested from the two commercial houses ($F_{3,329} = 1.27$; $p = 0.28$) we pooled the data (Table I). ANOVA indicates that the early set tomatoes were less round than the later set ones (Bb's vs. A's) but that buzzer pollination did not significantly change roundness after bumble bees were introduced (Ab vs. An). The weights of tomatoes showed no significant differences attributable to early or late set fruits nor to presence or absence of bumble bees. Seediness gives an indication of firmness of tomatoes of any given size (Banda and Paxton 1991). Although we did not measure firmness, we found that seediness was greater in the tomatoes pollinated by bumble bees alone than in those from other treatments (Table I).

The results from the H.R.I.O. greenhouses are consistent with the above (see also Straver and Plowright 1991). We found that the average weight of tomatoes produced during the three periods did not differ between treatments (Table II) even though the average weight produced between periods was significantly different with Period 2 producing lighter tomatoes (Table II). However, the number of tomatoes produced by the different treatments was highly significantly different in Period 2 when bumble bees were almost absent (Table II). Although few inferior grade (grade 2

and unmarketable) tomatoes were produced, particularly during the presence of healthy colonies of bumble bees, there were significantly more when the colony was weak, especially from plants which received no artificial pollination. The main difference was in the proportion of the crop graded as number 2 (Table II).

TABLE I. Roundness, weight, and seed count (means ± standard deviation) of tomato fruit set before (B) and after (A) introduction of bumble bees into two commercial greenhouses with two groups of plants receiving buzzer pollination (b) and no buzzer pollination (n).

Treatment	Group of 12 Plants	Roundness	Weight (gm)	Seed Count
Bb Buzzer alone	1	0.269±0.111 ab	152.61±56.43 ab	214.83± 99.18 a
Bb Buzzer alone	2	0.293±0.110 a	168.67±51.87 a	216.64±100.10 a
Ab Bumble bees and buzzer	1	0.221±0.082 c	138.97±35.06 b	227.96± 71.24 ab
An Bumble bees alone	2	0.248±0.097 bc	157.78±35.64 ab	254.73± 52.35 b
		$F_{3,327}$=6.32; p=0.004	$F_{3,328}$=4.98; p=0.0022	$F_{3,326}$=3.55; p=0.0149

Means followed by the same letter in any given column are not significantly different from one another (α = 0.05) by Tukey's Studentized Range Test.

The experimental results indicate that after the introduction of bumble bees into the greenhouses, the use of the electric buzzer for pollination had no additional effect. Banda and Paxton (1991) report similar but not entirely consistent results from two greenhouses for fruit set, fruit size, fruit weight, and seediness in cultivar Cleopatra in England as did van Ravestijn and van der Sande (1991) for fruit weight of beefsteak tomatoes in Venlo and round tomatoes in Naaldwijk in Holland.

Acknowledgements

We thank Robertson's Greenhouses for kindly providing a setting for our research. Philippe Casgrain greatly assisted in the systematic harvesting of the tomatoes. We are grateful to R.C. Plowright and P. Stickles for information on, and providing, the bumble bees. Enviroquest, Ltd., assisted with partial support for the work.

TABLE II. Number of tomatoes harvested, their total weight, average weight from 9 plots of 6 plants each, and grades (1, 2, and Unmarketable) in two experimental groups. Bumble bees and buzzer (b) and bumble bees alone (n) over three periods, 1 with healthy colony of bumble bees; 2 with few bumble bees; 3 with healthy colony of bumble bees.

Period	Treatment	Number of tomatoes produced per plot	Total weight (gm) of tomatoes produced per 6 plant plot	Average weight (gm) of individual tomatoes produced	Tomatoes according to grade (% of n)				
					1	2	Unm	n	χ^2
1	Bees & buzz	128.9 ± 10.1	19896.7 ± 1167.1	154.7 ± 6.9 a	96.1	3.4	0.5	1163	c
	vs.	F=0.15; p=0.70	F=0.18; p=0.68	F=1.43; p=0.25					
	Bees only	131.3 ± 15.6	19607.8 ± 1679.8	150.0 ± 9.7 a	95.4	4.5	0.1	1183	c
2	Bees & buzz	41.7 ± 7.4	5145.6 ± 819.3	123.8 ± 6.6 b	71.8	27.9	0.3	376	d
	vs.	F=10.52; p=0.005**	F=6.58; p=0.02*	F=0.72; p=0.41					
	Bees only	33.0 ± 3.3	4224.4 ± 699.5	127.5 ± 11.4 b	58.1	40.6	1.3	298	e
3	Bees & buzz	138.2 ± 23.8	21075.6 ± 3950.1	152.5 ± 9.6 a	92.1	6.3	1.6	1242	f
	vs.	F=4.43; p=0.06	F=2.57; p=0.13	F=0.38; p=0.55					
	Bees only	158.4 ± 17.4	23633.3 ± 2697.7	149.4 ± 11.7 a	93.0	5.8	1.2	1440	f

* significantly different

** highly significantly different

Means followed by the same letters (a,b) are not significantly different at $\alpha = 0.05$ by Tukey's Studentized Range test; ANOVA F=18.49; $p < 0.0001$.

χ^2 for grades significantly different ($\alpha = 0.05$) if designated by different letters (c to f).

Literature Cited

Banda, H.J. and R.J. Paxton. 1991. Pollination of greenhouse tomatoes by bees. Sixth International Symposium on Pollination. Acta Horticulturae, 228: 194-198.

Buchmann, S.L. 1983. Buzz pollination in Angiosperms. *In*: Jones, C.E. and R.J. Little (Eds.). Handbook of Experimental Pollination Biology. Van Nostrand-Rheinhold, Inc., New York, pp. 73-113.

Buchmann, S.L. 1986. Vibratile pollination in *Solanum* and *Lycopersicon*: a look at pollen chemistry. pp. 237-252. *In*: D'Arcy, W.G. (Ed.). Solanaceae Systematics and Biology. Columbia University Press, New York and London.

Plowright, R.C. and T.M. Laverty. 1987. Bumble bees and crop pollination in Ontario. Proceedings of the Entomological Society of Ontario, 118: 155-160.

Ravestijn, W. van and J. van der Sande. 1991. Use of bumble bees for the pollination of glasshouse tomatoes. Sixth International Symposium on Pollination. Acta Horticulturae, 228: 204-212.

Straver, W.A. and R.C. Plowright. 1991. Pollination of greenhouse tomatoes by bumblebees. Greenhouse Canada, 11(2): 10-12.

(Received 16 August 1991; Accepted 16 December 1991)

FACTORS AFFECTING THE EFFICACY OF *BACILLUS THURINGIENSIS* VAR SAN DIEGO AGAINST LARVAE OF THE COLORADO POTATO BEETLE

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Abstract *Proc. ent. Soc. Ont.* 122:21-25

The effects of age of larvae, interval between application and exposure of larvae, and fungicides on the activity of *Bacillus thuringiensis* var *san diego* against larvae of the Colorado potato beetle were tested under greenhouse conditions. Mortalities of larvae 7 days after exposure were 80% for second instars, 50% for third instars, and 13% for fourth instars, indicating the greater sensitivity of neonates to the bacterium. Activity of *Bacillus thuringiensis* var *san diego* on treated foliage held under greenhouse conditions for 1 and 2 weeks was 37% and 74%, respectively, less than that of recently-treated foliage. The addition of the fungicides chlorthalanil or mancozeb to *Bacillus thuringiensis* var *san diego* did not significantly alter the efficacy of the bacterial insecticide against larvae of the Colorado potato beetle. Mortality of larvae exposed to mancozeb only was higher than the mortality for the untreated check, suggesting that this fungicide might provide some activity against larvae of the Colorado potato beetle.

Introduction

The Colorado potato beetle, *Leptinotarsa decemlineata* (Say)(Coleoptera: Chrysomelidae), is a pest of potatoes, *Solanum tuberosum* L., practically wherever potatoes are grown in North America, including Prince Edward Island (P.E.I.). Studies on P.E.I. have shown that this pest can reduce yields of potatoes by 29% for cv 'Russet Burbank' (Stewart and Thompson 1988) and by 20% for cv 'Superior' (Stewart 1989). Concerns for human health and the environment have motivated growers to look for alternatives to chemical insecticides. *Bacillus thuringiensis* var *san diego*, an isolate of *Bacillus thuringiensis* which is active against some coleopteran pests (Hermstadt *et al.* 1986), has proved effective against the Colorado potato beetle in field trials in the United States (Ferro and Gelernter 1989; Zehnder and Gelernter 1989) and in Canada (Jaques and Laing 1989; Stewart and Dornan 1990). Second-instar larvae are more sensitive to *Bacillus thuringiensis* var *san diego* than third-instar larvae (Zehnder and Gelernter 1989). The sensitivity of fourth-instar larvae to this insecticide has not been tested.

One disadvantage of bacterial insecticides is their inability to withstand adverse environmental conditions such as ultraviolet light, heat, and desiccation (Dunkle and Shasha 1988). Unprotected *Bacillus thuringiensis* Berliner, a bacterial insecticide for control of lepidopterous larvae, lost all activity against European corn borer larvae after 4 days exposure to continuous sunlight (Dunkle and Shasha 1989). The rate of loss under more natural conditions would be lower. An increase in the period between application of *Bacillus thuringiensis* var *san diego* and the exposure to larvae of the Colorado potato beetle is expected to result in a loss of activity.

On P.E.I., more applications of *Bacillus thuringiensis* var *san diego* were needed to control populations of the Colorado potato beetle compared to a synthetic pyrethroid (Stewart and Thompson 1989). If growers on P.E.I. could mix *Bacillus thuringiensis* var *san diego* with fungicides such as chlorthalanil or mancozeb for control of early blight (*Alternaria solani*) and late blight (*Phytophthora infestans*), then they could grow potatoes with fewer trips through the fields, thus reducing soil compaction and application costs. However, the effect of mixing *Bacillus thuringiensis* var *san diego* with these fungicides is not known.

The objectives of the study were to determine the effect of age of larvae, the interval between application and exposure to larvae, and tank-mixes of two fungicides on the activity of *Bacillus thuringiensis* var *san diego* against the Colorado potato beetle.

Methods

Seed pieces of potato (cv 'Kennebec') were planted in a greenhouse from December 1987 until March 1988. The greenhouse was kept at 20°C during the day and 15°C at night. Fluorescent lights on a 14-hour light, 10-hour dark cycle were used to supplement natural lighting. A formulation of *Bacillus thuringiensis* var *san diego* (M-ONE®, Mycogen Corp.), containing 2.8 x 10^4 Colorado Potato Beetle International Units (CPBIU)/mg, was applied to potato plants about 25 cm in height at a rate of 269 billion (B) CPBIU/ha using a belt-driven spray cabinet that delivered a spray volume equivalent to 740 L/ha at a pressure of 276 KPa. After treatment, leaflets were placed in Petri dishes containing three larvae that were less than one week, one to two weeks, or two to three weeks old. These ages approximated second-, third-, and fourth-instar larvae, respectively, at 20°C day and 15°C night (data not published). A total of 45 larvae per age group (3 replicates of 15) were used. In addition, 45 larvae per age group were placed in petri dishes containing foliage treated with water only to assess non-treatment mortality. Larval mortality was assessed after 7 days.

In a second experiment, plants grown in the greenhouse were sprayed with a formulation of *Bacillus thuringiensis* var *san diego* at a rate of 269 B CPBIU/ha to determine if the interval between the application of the bacterial insecticide and ingestion by larvae of the Colorado potato beetle had any effect on the activity of the toxin. On the day of treatment, and after one week and two weeks of growth in the greenhouse, leaves selected at random were placed on Petri dishes each containing moistened filter paper and 3 larvae that were less than one week old. Three larvae per dish were fed foliage treated with water only to assess non-treatment mortality. Larval mortality was observed for a 7-day rearing period. Forty-five larvae per treatment were tested.

The effect of fungicides on the activity of *Bacillus thuringiensis* var *san diego* was tested in a third experiment. Plants grown in the greenhouse were sprayed with *Bacillus thuringiensis* var *san diego* at 269 B CPBIU/ha alone and in a tank mixture with chlorthalanil (Bravo) at 1.2 kg a.i./ha or with mancozeb (Dithane M-45) at 1.8 kg a.i./ha or chlorthalanil or mancozeb alone. Three-day-old larvae were placed on plants sprayed with the above treatments and foliage treated with water only. Larval mortality was observed after 7 days. Fifty-five larvae (one replicate of 25 larvae and two replicates of 15 larvae) were used per treatment except for chlorthalanil and mancozeb where 25 larvae per treatment were used. In a similar experiment, leaves were randomly removed from the treated plants and placed in Petri dishes with moistened filter paper and 3 larvae of less than one week old. Larval mortality was observed for a 5-day period. Forty-five larvae per treatment were tested.

Larval mortality, expressed as a proportion (p), was transformed to arcsine$\sqrt{p}$ prior to analysis. Analyses of variance were conducted and means were compared using a Duncan's Multiple Range Test ($P = 0.05$) if the analysis of variance was significant at $P \leq 0.05$ (SAS Inst. 1988).

Results and discussion

Second-instar larvae were more susceptible to *Bacillus thuringiensis* var *san diego* than third-instar or fourth-instar larvae ($P = 0.0001$, df = 2) (Table I). Previous studies (Zehnder and Gelernter 1989) have shown that mortality of third-instar larvae 96 hours after exposure to *Bacillus thuringiensis* var *san diego* at 0.125 times the recommended field rate was about 43% lower than the mortality of second-instar larvae. In our study, mortality seven days after exposure to the field rate of *Bacillus thuringiensis* var *san diego* was 38% less for third-instar larvae and 83% less for fourth-instar larvae compared to second-instar larvae (Table I). Based on the results from both studies, *Bacillus thuringiensis* var *san diego* should be applied soon after eggs begin hatching for maximum efficacy.

TABLE I. Effect of age of Colorado potato beetle larvae on mortality caused by ingestion of *Bacillus thuringiensis* var *san diego* (*B. t. sd.*).

Age of Larvae	Larval Mortality (%) 7 Days After Exposure (X ± S.E.M.)[1]	
	Check	*B. t. sd.*
Second-instar	0[a]	80 ± 9[a]
Third-instar	10 ± 5[a]	50 ± 10[b]
Fourth-instar	0[a]	13 ± 7[c]

[1] Numbers in a column followed by the same letter are not statistically different ($P < 0.05$, Duncan's Multiple Range Test). Means were transformed to arcsine$\sqrt{proportion}$ prior to analysis. Untransformed means are presented.

The interval between the application of *Bacillus thuringiensis* var *san diego* and ingestion by young larvae affected mortality. Compared with mortality on recently-treated foliage, mortality of larvae given foliage that was sprayed and kept under greenhouse conditions for one and two weeks was 37% and 74%, respectively, less (Table II). In field studies, *Bacillus thuringiensis* var *san diego* was applied more frequently than deltamethrin, a synthetic pyrethroid, to keep a population of Colorado potato beetle below an action threshold (Stewart and Thompson 1989), possibly because the bacterial insecticide was more sensitive to environmental conditions, such as ultraviolet radiation, than the synthetic pyrethroid. Applications of *Bacillus thuringiensis* var *san diego* should be timed to coincide with the presence of early instar-larvae on the crop (Ferro and Gelernter 1989; Zehnder and Gelernter 1989). Based on the data from this study, maximum effectiveness is achieved when young larvae are exposed to the bacterial insecticide immediately

after application. Hence, growers should wait until egg masses hatch before applying this bacterial insecticide rather than applying the product in anticipation of egg hatch.

TABLE II. Activity of *Bacillus thuringiensis* var *san diego* against larvae of the Colorado potato beetle.

Time Since Treatment	Mortality (%) 7 Days After Exposure (X ± S.E.M.)[1]
Untreated Check	3 ± 3^{a}
Fresh	90 ± 5^{d}
1 Week	57 ± 9^{c}
2 Weeks	33 ± 11^{b}

[1] Numbers in a column followed by the same letter are not statistically different ($P < 0.05$, Duncan's Multiple Range Test). Means were transformed to arcsine$\sqrt{proportion}$ prior to analysis. Untransformed means are presented.

The addition of fungicides to the spray mixture neither increased nor decreased the mortality of Colorado potato beetle larvae (Table III). As expected, chlorthalanil alone had no activity against the Colorado potato beetle. Mortality of larvae exposed to mancozeb was greater than that of the untreated check, suggesting that this fungicide may have some activity against larvae of the Colorado potato beetle. Whether the bacterial insecticide has any effect on the ability of these fungicides to control early and late blight is not known.

TABLE III. Effect of tank-mixes of fungicides on the activity of *Bacillus thuringiensis* var *san diego* (*B. t. sd.*) on mortality of Colorado potato beetle.

Treatment	% Mortality (X ± S.E.M.)[1]	
	Whole Plant - 7 Days	Leaflets - 5 Days
Check	8 ± 5^{a}	0^{a}
B. t. sd.	67 ± 8^{c}	100^{c}
Chlorthalanil	20 ± 9^{ab}	0^{a}
B. t. sd. + Chlorthalanil	63 ± 10^{c}	100^{c}
Mancozeb	32 ± 14^{b}	40 ± 19^{b}
B. t. sd. + Mancozeb	78 ± 8^{c}	87 ± 8^{c}

[1] Numbers in a column followed by the same letter are not statistically different ($P < 0.05$, Duncan's Multiple Range Test). Means were transformed to arcsine$\sqrt{proportion}$ prior to analysis. Untransformed means are presented.

Based on the results of these experiments, *Bacillus thuringiensis* var *san diego* must be applied against young larvae to be effective. Applying the product before larvae are present will result in a loss of activity. A tank mixture of chlorthalanil or mancozeb with *Bacillus thuringiensis* var *san diego* will not result in a loss of activity and may reduce the number of trips required to achieve pest control in a potato field thus reducing soil compaction and the cost of applying pesticides.

Acknowledgement

The statistical advice of J.B. Sanderson is gratefully acknowledged. Thanks are extended to Dow-Elanco, SDS Biotech Corp., and Ciba-Geigy for the donation of *Bacillus thuringiensis* var *san diego*, chlorthalanil, and mancozeb, respectively, for the purposes of research. This is Contribution No. 747, Agriculture Canada, Charlottetown, Prince Edward Island.

References

Dunkle, R.L. and B.S. Shasha. 1988. Starch-encapsulated *Bacillus thuringiensis*: A potential new method for increasing environmental stability of entomopathogens. Environmental Entomology, 17: 120-126.

Dunkle, R.L. and B.S. Shasha. 1989. Response of starch-encapsulated *Bacillus thuringiensis* containing ultraviolet screens to sunlight. Environmental Entomology, 18: 1035-1041.

Ferro, D.N. and W.D. Gelernter. 1989. Toxicity of a new strain of *Bacillus thuringiensis* to Colorado potato beetle (Coleoptera: Chrysomelidae). Journal of Economic Entomology, 82: 750-755.

Herrnstadt, C., G.C. Soares, E.R. Wilcox, and D.L. Edwards. 1986. A new strain of *Bacillus thuringiensis* with activity against coleopteran insects. Biotechnology, 4: 305-308.

Jaques, R.P. and D.R. Laing. 1989. Effectiveness of microbial and chemical insecticides in control of the Colorado potato beetle (Coleoptera: Chrysomelidae) on potatoes and tomatoes. Canadian Entomologist, 121: 1123-1131.

SAS Institute. 1988. SAS/STAT Users Guide, Release 6.03 Edition, SAS Institute, Cary, N.C., 1028 pp.

Stewart, J.G. 1989. Action thresholds for the control of Colorado potato beetle. Research Summary, Charlottetown Research Station, 1989, p. 68.

Stewart, J.G. and A.P. Dornan. 1990. Comparison of three management schemes for Colorado potato beetle on early-season potatoes in Prince Edward Island. Phytoprotection, 71: 121-127.

Stewart, J.G. and L.S. Thompson. 1988. Control of insect pests on potatoes. Pesticide Research Report, 1988. p. 96.

Stewart, J.G. and L.S. Thompson. 1989. Residual activity of new insecticides for control of Colorado potato beetle. Research Summary, Charlottetown Research Station, 1989. p. 67.

Zehnder, G.W. and W.D. Gelernter. 1989. Activity of the M-ONE formulation of a new strain of *Bacillus thuringiensis* against the Colorado potato beetle (Coleoptera: Chrysomelidae): Relationship between susceptibility and insect life stage. Journal of Economic Entomology, 82: 756-761.

(Received 20 June 1991; accepted 4 December 1991)

EVALUATION OF A TECHNIQUE FOR MONITORING PREDATION OF WESTERN CORN ROOTWORM EGGS, *DIABROTICA VIRGIFERA VIRGIFERA* (COLEOPTERA: CHRYSOMELIDAE)

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Abstract *Proc. ent. Soc. Ont.* 122:27-33

This paper reports on monitoring predation of corn rootworm eggs in corn fields using packets of 100 eggs buried in mesh bags during the fall, winter, and spring. Predation was measured as a reduction in the number of recovered eggs, and an increase in the number of ruptured empty chorions. Recovery of control eggs kept in the laboratory was >99% in the fall, but declined to an average 94% in the winter, and to 90% in the spring. Recovery of eggs from field packets was unaffected by depth of burial, or by enclosure in coarse, medium, or fine mesh. Ruptured empty chorions occurred in laboratory control packets and in fine-mesh control packets in the field and thus were nct a valid measure of predation. Either egg predation is not a significant factor worth monitoring for pest management purposes, or the method was inadequate.

Introduction

The western corn rootworm (WCR), *Diabrotica virgifera virgifera* LeConte, is an important pest of field corn. It is a univoltine species that overwinters as eggs in the soil of corn fields. Field scouts count adult beetles on corn plants in August. On the basis of these estimates, rootworm populations are predicted for the following year. However, beetle numbers are poorly correlated with subsequent damage (Tollefson 1986).

Predation of the eggs may account for this poor correlation because eggs are present in the soil for about ten months. Chaing (1970) suggested that predation by mites accounted for 19.7% control of rootworms under natural field conditions, and 63% control following application of manure. Predation by carabids (Tyler and Ellis 1979; Kirk 1982) and ants (Ballard and Mayo 1979; Kirk 1981) may also be important.

Estimates of the ovipositing beetle population would be more useful in pest management programs if a convenient method were found to estimate subsequent predation of the eggs. The objective of this research was to determine whether or not buried packets of rootworm eggs could be used to monitor egg predation for pest management purposes.

Materials and Methods

Production and Storage of Eggs

Eggs were obtained from field-collected beetles using procedures described by Branson *et al.* (1975). In addition to artificial dry diet (Guss and Krysan 1973), however, we provided the adults with immature ears of corn and sliced squash. Adults oviposited into a coating of 80-mesh soil on pieces of clay pot. This media was placed in plastic containers, which were 11.5 cm in diameter and 8 cm deep. They were covered with fluted tin foil that rested on top of plastic lids which contained 1-cm^2 holes for entry of beetles. Eggs were collected every second day by washing the oviposition medium over a 60-mesh U.S. standard sieve. Organic debris was separated from the eggs and they were transferred to Petri dishes containing unsterilized 80-mesh soil for storage. The water content was adjusted so the soil was moist (Branson *et al.* 1975). Petri dishes were sealed with Parafilm®, and held at 20 $\pm$ 3°C for two weeks (Branson *et al.* 1975). The eggs were stored in desiccators held at 100% relative humidity (RH) in darkness in cold chambers at 7.5°C until needed (Chaing 1974).

Preparation for Burial of Eggs in the Field

Fine-, medium-, and coarse-mesh packets were modified from those constructed by Macdonald (1988). Fine-mesh packets were square (25 cm^2), constructed of nylon material (about 900 holes/cm^2), and sealed using staples. They excluded all predators except for the most minute organisms. Medium-mesh packets had a fine-mesh under-side and a fibreglass screen material (42 holes/cm^2) on the upper-side. These were modified to form coarse-mesh packets by cutting four (1 cm^2) holes in the upper-side. Both the medium- and coarse-mesh packets allowed a greater number and diversity of predators access to the eggs. All packets allowed free water movement, prevented egg loss, and permitted rapid recovery of eggs.

Soil was obtained from the field and oven-dried to destroy any naturally occurring eggs and predators. WCR eggs used in all studies came from the same batch of eggs obtained in the laboratory. They were separated from the storage medium by washing into a 60-mesh sieve, and were transferred in groups of 100 to about 10-g samples of oven-dried field soil which were moistened and placed in the packets.

Control packets of eggs that were placed in the field were made of a double layer of fine-mesh material. Laboratory control packets were kept in sealed Petri dishes in desiccators (100% RH) in a cold chamber (7.5°C) for the same duration of time as those eggs held in the field.

Fibreglass screen cylinders (17 cm long by 9 cm in diameter) were constructed with a total of 69 (1 cm^2) holes provided throughout the mesh (42 holes/cm^2). They contained the packets in the field, allowed the entry of predators, provided efficient egg packet retrieval in the spring, and did not hinder natural water movement in the system.

Field Plots

Two fields were used that had been planted to corn for 10 (field 1) and 2 (field 2) consecutive years. They were located near Guelph and Rockwood, Ontario, respectively. Both fields were less than 12 ha in size, had loam-textured soils, and were not ploughed.

Each fibreglass cylinder had a total of four, 100-egg packets (one of a particular mesh size, and one control) placed side by side at both the 5 and 15 cm depths. Cylinders containing the three types of mesh packets were replicated three times for a total of nine cylinders per test. The nine cylinders were buried randomly between the rows in a level area of the two fields during each of three observational periods: fall 1987 (26 August - 13 November 1987), winter 1988 (6

December 1987 - 21 April 1988), and spring 1988 (21 April - 28 May 1988) (total of 54 cylinders). They were no closer than 18 m from the field edge and arranged 18 m apart in a square pattern.

Separation of Organisms from Soil in Cylinders

Soil organisms were recovered from soil in cylinders that contained packets of eggs buried in the fields to determine if any potential predators were present. Soil from four cylinders buried in field 1 (winter study), and six cylinders from field 2 (spring study), respectively, were placed separately into Burlese-Tullgren funnels and left for three days. The organisms collected were identified and enumerated.

Processing of Egg Samples and Data Analysis

The egg-bearing soil from each packet was washed through 40- and 60-mesh sieves, and the eggs recovered with the aid of a dissecting microscope. The empty chorions were easily distinguished from the whole eggs whether mouldy, shrivelled, or apparently viable. The empty chorions, which often floated on the water in the recovery plates, were further classified as being empty or ruptured. Empty eggs were recovered as flattened, transparent, and apparently undamaged chorions. Cause of death was unknown but was possibly due to poor quality chorions, or handling. The holes in the ruptured chorions suggested predation or parasitism. Egg loss due to hatching was not possible because they were placed in the soil after the temperature fell below the minimum threshold for development (11°C), and were removed before soil temperature rose above this level.

Mean percent recovery and percentage of ruptured chorions were calculated from the number of eggs buried. The analysis of variance (ANOVA) procedure (SAS Institute 1982) was used on data transformed using the arcsine transformation (Goulden 1952).

Results and Discussion

Recovery of Eggs from Fields

Recovery of control eggs kept in the laboratory was >99% in the fall but declined to an average 94% in the winter, and to 90% in the spring (Table I). This decline over time results from the disintegration of nonviable or damaged eggs to unrecognizable material. The relatively high (10%) decline in recoverable eggs in the controls probably resulted from our procedure of recovering eggs from colonies and cleaning them within 2 days of oviposition. Freshly oviposited eggs are more sensitive to injury. Recovery of eggs from control packets buried in the field also declined to about 90% by spring, but the decline occurred faster under field conditions than in the laboratory (i.e. recovery was only 84-97% in the fall as compared to >99% in the laboratory controls).

Mesh size did not affect the number of eggs recovered from packets buried in the field during either the fall, winter or spring (F = 0.47 - 1.76; df = 3, 17; P = 0.710 - 0.192). Similarly, recovery was unaffected by depth of burial (F = 0.00 - 1.61; df = 1, 17; P = 0.98 - 0.22) (Table I).

TABLE I. Comparison of mean percent recovery in fall, winter, and spring of WCR eggs buried in mesh packets of 3 sizes at 2 depths near Guelph, Ontario.

Mesh Size	Depth[2] (cm)	Recovery[1] (% ± SE) Fall 1987 Field 1	Fall 1987 Field 2	Winter 1988 Field 1	Spring 1988 Field 1	Spring 1988 Field 2
Fine	5	95.7 ± 2.2	94.7 ± 1.0	89.7 ± 8.9	98.7 ± 1.3	95.0 ± 0.6
	Control, Field	94.7 ± 1.9	95.3 ± 1.9	94.7 ± 1.9	95.7 ± 1.2	91.0 ± 4.5
	15	96.3 ± 2.7	96.0 ± 0.6	93.0 ± 4.1	96.7 ± 1.2	90.3 ± 6.2
	Control, Field	96.0 ± 1.2	96.0 ± 1.5	95.3 ± 2.6	94.3 ± 3.7	90.0 ± 0.6
	Control, Lab	99.7 ± 0.3	99.7 ± 0.3	97.7 ± 2.3		
Medium	5	89.3 ± 8.2	92.7 ± 1.2	95.7 ± 1.8	97.0 ± 2.5	94.7 ± 1.5
	Control, Field	95.0 ± 1.5	95.3 ± 0.3	95.3 ± 1.2	94.0 ± 6.0	96.0 ± 2.3
	15	94.0 ± 1.0	92.0 ± 0.0	94.0 ± 1.5	95.3 ± 2.2	82.3 ± 10.4
	Control, Field	93.7 ± 0.9	93.0 ± 1.2	96.3 ± 0.9	95.0 ± 0.6	93.0 ± 3.5
	Control, Lab	100.0 ± 0.0	96.7 ± 3.3	92.0 ± 3.5		
Coarse	5	97.3 ± 2.7	74.0 ± 22.6	90.3 ± 6.2	94.0 ± 1.9	79.3 ± 5.5
	Control, Field	97.0 ± 0.6	94.3 ± 1.9	95.0 ± 1.5	93.7 ± 3.4	78.3 ± 1.7
	15	91.0 ± 1.5	76.3 ± 18.3	94.3 ± 1.2	94.7 ± 1.7	82.0 ± 4.7
	Control, Field	96.0 ± 1.5	97.0 ± 0.6	95.7 ± 1.3	92.0 ± 3.6	80.7 ± 7.1
	Control, Lab	100.0 ± 0.0	99.3 ± 0.7	91.3 ± 3.5	91.3 ± 2.4	90.0 ± 7.0

[1] Each value obtained from 3 replications of 100 eggs each.

[2] Control, field = eggs buried at 5 or 15 cm in a double layer of fine mesh material to exclude predators; control, lab = eggs held in the laboratory at 7.5°C for the same length of time as eggs in the field.

Ruptured Chorions

A small percentage of control eggs had ruptured chorions even though they were held in the laboratory in sterilized soil (Fig. 1). This loss amounted to less than 1% of the eggs in the fall and about 2% in the winter. It probably resulted from handling eggs during their removal from the oviposition media and in preparing egg packets for storage.

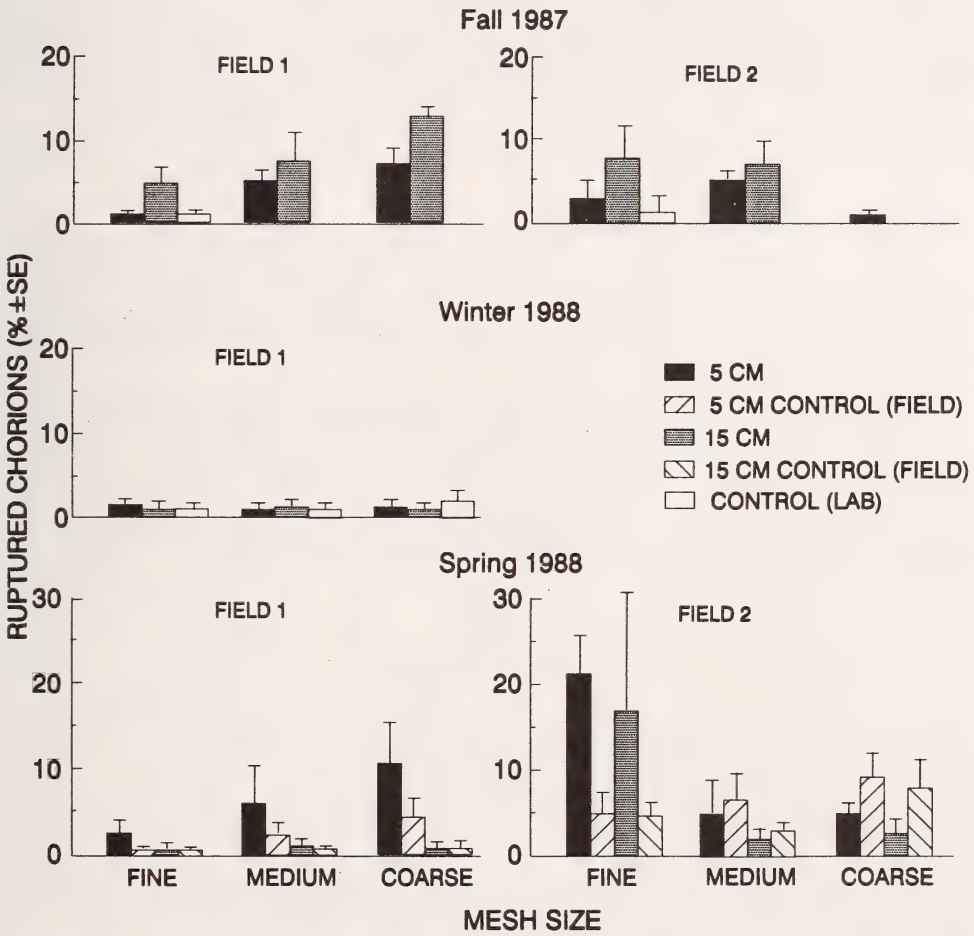

FIGURE 1. Seasonal mean percentage of WCR eggs with ruptured chorions in fine, medium, and coarse-mesh packets buried at two depths in corn fields. Control (field) = control eggs buried in the field in double, fine-mesh packets; Control (lab) = eggs stored at 7.5°C in the laboratory for the same duration of time.

The incidence of ruptured chorions in field 1 ranged from 1 to 13% in the fall (Fig. 1). Coarse packets contained 10% ruptured chorions compared with 3% in fine packets ($F = 6.7$; df = 2,12; $P = 0.011$). Eggs recovered from 15 cm also had a greater incidence of ruptured chorions than those from 5 cm ($F = 5.07$; df = 1,12; $P = 0.044$) (Fig. 1). Less than 2% of chorions were ruptured in any of the winter treatments, and treatments were not different from the laboratory controls (Fig. 1). Results in the spring were similar to those in the fall. However, more variability and a greater incidence of ruptured chorions in the field checks resulted in no significant differences due to mesh size or depth.

More eggs were damaged during the fall in field 2 in the fine and medium packets (both about 6%), compared with those in the coarse packets (<1%) ($F = 7.50$; df = 2,12; $P = 0.008$). Damage was not affected by the depth of burial ($F = 0.38$; df = 1,12; $P = 0.551$). Only in the fine-screened packets were damaged chorions more numerous than in the field controls.

Although the higher incidence of damaged chorions in coarse packets from field 1 could be attributed to greater predation, the data from field 2 do not support this conclusion.

Organisms Found in Samples of Soil from Cylinders

The most numerous organisms observed in both fields were mites. However, identifications by E.E. Lindquist (Biosystematics Research Institute, Ottawa) determined that the only predaceous mites were *Hypoaspsis (Gaeolaelaps) aculeifer* (Canestrini) (Family: Laelapidae). Generally laelapid mites prey on small arthropods and nematodes in the soil, and Mihm (1972) found that they fed on *Diabrotica* eggs in the laboratory.

Species of ground beetles, hister beetles, rove beetles, dermestid beetles, centipedes and a spider were recovered along with the egg packets. We assumed that predation had occurred in some packets which contained a predator and fewer eggs. However, other replicates of the same treatment were unaffected. If predation is relatively unimportant, as suggested by these experiments, but also a chance event that affects a few samples, then the expected result would be a few treatment means with high standard errors. Such high standard errors are evident in Table I.

Conclusions

We had hypothesized that different rates of parasitism would occur in different fields or seasons, and in packets of different mesh size or at different depths. We further hypothesized that these differences would be revealed in a lower percentage of recovered eggs or in a higher incidence of empty ruptured chorions. We conclude that parasitism was generally unimportant in the fields where we conducted our study, or that it could not be monitored by the methods we used. The percentage of damaged eggs in our controls was high and this percentage could be reduced by leaving eggs undisturbed for several weeks after oviposition. However, if predation affects relatively few samples then the resulting higher standard errors would make predation in the packets difficult to demonstrate statistically.

Acknowledgment

This research was supported in part by a grant to C.R. Ellis from the Ontario Pesticides Advisory Committee, and in part by the Ontario Ministry of Agriculture and Food.

References

Ballard, J.B. and Z.B. Mayo. 1979. Predatory potential of selected ant species on eggs of western corn rootworm. Environmental Entomology, 8: 575-576.

Branson, T.F., P.L. Guss, J.L. Krysan, and G.R. Sutter. 1975. Corn rootworms: Laboratory rearing and manipulation. Agricultural Research Service, United States Department of Agriculture, 18 pp.

Chaing, H.C. 1970. Effects of manure applications and mite predation on corn rootworm populations in Minnesota. Journal of Economic Entomology, 63: 934-936.

Chaing, H.C. 1974. Temperature effects on hatching of eggs of the western corn rootworm, *Diabrotica virgifera*: factual and theoretical interpretations. Entomologia Experimentalis et Applicata, 17: 149-156.

Goulden, C.H. 1952. Methods of statistical analysis. Second edition. Wiley Publ. in Statistics. New York, 467 pp.

Guss, P.L. and J.L. Krysan. 1973. Handling techniques for *Diabrotica virgifera virgifera*: adult maintenance; egg collection and egg storage. Northern Grain Insects Laboratories, Brookings, S. Dakota, 17 pp.

Kirk, V.M. 1981. Corn rootworm: population reduction associated with the ant, *Lasius neoniger*. Environmental Entomology, 10: 966-967.

Kirk, V.M. 1982. Carabids: minimal role in pest management of corn rootworms. Environmental Entomology, 11: 5-8.

Macdonald, P.J. 1988. Mortality of overwintering eggs and longevity and movement of first instars of corn rootworm (Coleoptera: Chrysomelidae). M.Sc. Thesis. University of Guelph.

Mihm, J.A. 1972. Ecological observations on predatory mites in relation to northern and western corn rootworms. M.Sc. Thesis. University of Minnesota, 75 pp.

SAS Institute. 1982. SAS user's guide: statistics. SAS Institute, Cary, North Carolina, 921 pp.

Tollefson, J.J. 1986. Field sampling of adult populations, pp. 123-146. *In*: J.L. Krysan and T.A. Miller (eds.), Methods for the study of pest *Diabrotica*. Springer-Verlag, New York.

Tyler, B.M.J. and C.R. Ellis. 1979. Ground beetles in three tillage plots in Ontario and observations on their importance as predators of the northern corn rootworm, *Diabrotica longicornis* (Coleoptera: Chrysomelidae). Proceedings of the Entomological Society of Ontario, 110: 65-73.

(Received 11 October 1990; accepted 28 May 1991)

HONEY BEES (*APIS MELLIFERA*: HYMENOPTERA: APIDAE) AND FONOFOS ON SWEET CORN (*ZEA MAYS*: POACEAE)

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Abstract *Proc. ent. Soc. Ont.* 122:35-40

Three formulations of fonofos (two granular (10-G, 20-G) and microencapsulated with a sticker) were applied at field recommended rates of 1.0 kg AI/ha to sweet corn *Zea mays* L. in which colonies of honey bees *Apis mellifera* L. had been placed. The honey bees, whether caged with treated corn or with free access to the fields and their surroundings, did not show any mortality which could be ascribed to fonofos. Bee mortality in the control field was not significantly different from that on treated fields and peaks of mortality occurred more or less synchronously for all honey bees on all fields studied. The mortality observed was probably the result of aerial application of other insecticides, notably carbofuran, in the area. Fonofos residues in dead honey bees and in pollen from hives were low. Mortality in experimental honey bee colonies did not correspond with levels of fonofos residue. Fonofos, even in the microencapsulated formulation with sticker, did not appear to be a hazard to honey bee colonies located near sweet corn fields.

Applications of insecticide to sweet corn, *Zea mays* L. protect the crop from corn ear worm, *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae) and European corn borer, *Ostrinia nubilalis* (Hübner) (Lepidoptera: Pyralidae). Some of the insecticides (e.g. carbofuran) that are used are highly toxic to honey bees (*Apis mellifera* L. (Hymenoptera: Apidae)) (Atkins 1981) which may forage for pollen directly from tasselling corn plants in the morning (Hanney and Harvey 1982; Mason and Tracewski 1982; Nowakowski and Morse 1982) or for nectar or pollen, or both from vegetation around corn fields. Serious losses of honey bees occurred in areas where sweet corn is grown in Ontario, especially in 1987 (personal communication with local beekeepers), and carbofuran was probably the insecticide involved.

Fonofos (O-ethyl S-phenyl ethylphosphonodithioate), or Dyfonate® (Chipman Chemical Inc., Stoney Creek, Ontario) is used mostly for the control of soil-inhabiting pest insects (Stauffer Chemical 1985a, b, 1986), but granular formulations are used to control European corn borer in parts of the United States of America (Stauffer Chemical 1985a, b). Fonofos is listed as moderately toxic to honey bees (LD_{50} = 8.68 µg/honey bee; probit slope = 48.7 µg/honey bee) in laboratory tests (Atkins 1981). I know of no field studies on the effects of fonofos on foraging honey bees. However, the hazard ratio ((use rate g AI/ha)/LD_{50}) is 115, which indicates the need for cage or field trials (see Felton *et al.* 1986).

My study was done to investigate the hazard to honey bees foraging in and around fields of sweet corn treated with fonofos in two granular formulations (10-G and 20-G) and microencapsulated with sticker. Microencapsulated insecticides are highly hazardous to honey bees that inadvertently collect the microcapsules (Barker *et al.* 1979; Ross and Harvey 1981; McLaren *et al.* 1987). The addition of stickers to pesticides makes them less accessible, and so less hazardous to honey bees (Hanny and Harvey 1982; Kevan *et al.* 1984; Mayer *et al.* 1987).

Materials and Methods

Four fields, separated by at least 2 km, of sweet corn, were chosen in the area around Strathroy, Ontario. The fields were of similar size and shape (4 ha and more or less square) with plants of the same age and variety ('Flavourvee'). Six strong colonies of honey bees (two supers, including the brood chamber) and two five-frame nucleus colonies of honey bees were placed in each field. All colonies in each type were equalized as far as possible for populations by adjusting the amount of brood and number of worker bees in each hive to Grade A orchard standard (Burgett *et al.* 1984; Kevan, 1988) on 29 July, 1987 before they were placed on the fields. All hives were placed in the fields on 12 August, 1987. The fonofos was applied five days (17 August) later to 2 ha of each of the three treated fields; it was applied directly over and around the hives of honey bees which were closed for the duration of application to protect bees from direct contamination during application of the fonofos. The nucleus hives were then enclosed in screen tents (ca. 3 x 3 x 2.5 m high) with screen roofs (see Kevan *et al.* 1984) to restrict them to sweet corn immediately after the fonofos had been applied. The control field was set up similarly, but no fonofos was applied.

The granular formulations consisted of fonofos contained in particles of montmorillonite clay carrier which provided uniformity of size. The uniformity reduced wear on metering equipment and allowed for quick calibration and application. Because the granular formulation resists leaching, it provides broad-spectrum and prolonged control of many important soil insects that attack crops (Stauffer Chemical 1986). When used in "over the top" applications on corn, the granules lodge in the leaf axils where they are effective in controlling European corn borer (Stauffer Chemical 1985a, b).

The microencapsulated formulation is an aqueous suspension with the active ingredient, fonofos, contained in microcapsules. When these microcapsules come into contact with soil or leaf moisture, the fonofos is released slowly, increasing residual activity, reducing toxicity, and providing physical and chemical stability in the environment. It has been used in the United Kingdom for control of cereal and crucifer pests (Stauffer Chemical undated).

Each field was used for only one formulation. The granular formulations were applied with a high-clearance tractor equipped with modified Gandy side-dress applicators which applied a 15 cm band over four rows of corn. The microencapsulated formulation was applied from the same tractor, but equipped with a 14 m boom sprayer working at 210 kPa of pressure giving a dosage of 325 L/ha. All formulations were applied at the field recommended dosage of 1.0 kg AI/ha to the sweet corn immediately before the emergence of the tassels.

Three strong, full-sized colonies (see above), each in two ten-frame boxes and one, five-frame nucleus colony per treatment were equipped with O.A.C. pollen traps (Smith 1963) and the same number with Todd dead bee traps (Atkins *et al.* 1970; Atkins 1975) to collect pollen and dead bees, respectively. The dead honey bees were counted and later tested for insecticide residues. Corn plants in screen tents were sprayed with water every second day. The intention was to simulate rain and to wash the insecticide (except in the control) into the axils of the leaves where the honey bees could forage for accumulated water.

Honey bees and pollen were sampled every two days until 1 September to give 13 samples per treatment. Throughout the experiment the hives were inspected at least twice each week to check for marked changes in the populations of honey bees and colony well-being (ie. normal levels of activity, brood rearing, and lack of disease and dead bees).

Samples of dead bees and pollen were taken to the Provincial Pesticide Residue Testing Laboratory, Agricultural Laboratory Service Branch of the Ontario Ministry of Agriculture and

Food, Guelph, Ontario. H. Braun and B. Ripley made the analyses for insecticide residues according to the methods of Frank *et al.* (1987). Samples of dead bees from consecutive collections were combined for analysis when few dead bees were available. P. Sibley, Department of Environmental Biology, University of Guelph, used a staining technique for examining honey bee collected pollen for the presence of microcapsules (Sibley 1989).

Statistical analysis was by Analysis of Variance for mortalities (number of dead bees/hive/day) in the different treatments.

Results

The accumulation of dead honey bees from the dead bee traps from all full-sized colonies on each of the fields were combined. The counts show similar mortality for all treatments, never exceeding 175 dead bees/hive/day throughout the experiment (Fig. 1). There was a marginally statistically significant difference in numbers of dead bees in the samples between the treatments ($\chi^2_r = 9.03$; $0.05 > p > 0.02$ Friedman two-way ANOVA by ranks (Siegel 1956)), but the relative rankings (10-G < control < microencapsulated < 20-G) nor residues in dead bees are consistent with fonofos poisoning. The results from the nucleus colonies in the screen tents are much the same with maximum mortality of 53 dead honey bees/hive/day, with most days providing no dead bees. Two peaks in honey bee deaths (one early and one late; Fig. 1) occurred in all fields, including the control which had the highest peak of all. The early peak corresponded with application of fonofos to the corn (on day 5) in both the full-sized hives (Fig. 1) and in the nucleus hives, but the deaths on the untreated field strongly suggest a common cause operating on all fields. Only the nucleus hive in the screen tent on the control field had no mortality immediately following the day of treatment. No marked changes in colony strength or well-being were noted throughout the duration of the experiment.

Analyses for residues of insecticides in dead honey bees showed no signs of fonofos in those from the control field. The samples from the other fields showed no relationship between levels of fonofos detected and numbers of dead honey bees. The highest levels of fonofos occurred when mortality was low with no later increase in the next few days. High levels of mortality were recorded with low to non-detectable levels of fonofos (Fig. 1).

Analyses of pollen taken from the pollen traps showed low levels of fonofos. Five samples of pollen from the control field had no detectable fonofos. From the field treated with 10-G the mean (± S.D.) level of fonofos residue in pollen was 0.085 ± 0.118 mg/kg (range from 0.007 to 0.36 mg/kg; n = 9 samples); for the field treated with 20G the values are 0.54 ± 1.04 mg/kg (0.023 to 2.1 mg/kg; n = 4); and for the field treated with the microencapsulated formulation the values are 0.031 ± 0.021 mg/kg (0.016 to 0.046; n = 2). Although staining for microcapsules in samples of pollen from the last mentioned treatment gave positive results, too few were detected to meaningfully quantify.

Discussion and Conclusions

Fonofos in the formulation, application rates and methods used in this study appear to pose little or no hazard to honey bees foraging in or around fields of sweet corn. Attempts, by using screen tents, to force honey bees to forage on corn treated with fonofos failed to cause any significant mortality, even when plants were sprayed with water to wash the chemical into the axils

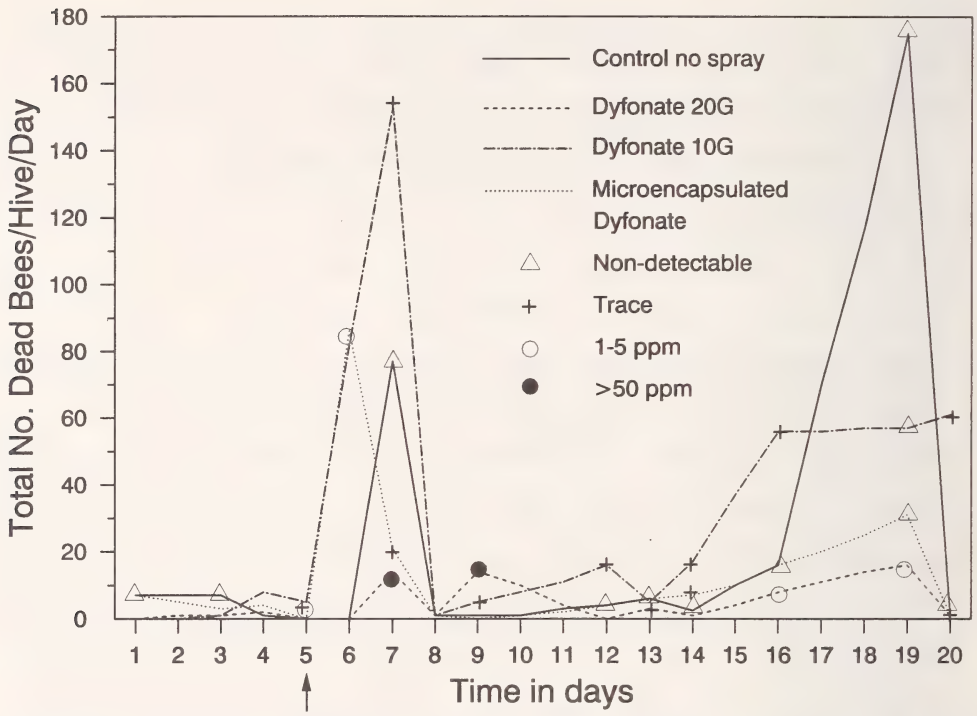

FIGURE 1. The number of dead bees recovered by regular sampling from Todd dead bee traps on hives of honey bees placed on fields of sweet corn treated with three formulations of fonofos (Dyfonate® 10-G, 20-G and microencapsulated with sticker) in summer, 1987, near Strathroy, Ontario as indicated by lines. The control field was not treated. Symbols indicate the levels of fonofos residues found in those samples of dead bees (consecutive samples combined if fewer than 25 dead bees available and symbols repeated for each day represented in the sample).

of the leaves where the bees could drink the contaminated water. The expected hazard posed by the microencapsulated formulation (see Barker *et al.* 1979; Ross and Harvey 1981; McLaren *et al.* 1987), which the honey bees may gather, was not realized. The sticker in that formulation probably reduces the extent to which honey bees can gather the microcapsules (Ross and Harvey 1982; Mayer *et al.* 1987) although, in my study, the bees did obtain some as evidenced by the presence of residues in dead bees and pollen and of microcapsules in pollen taken from the hive.

The peaks in mortality in honey bees on all experimental and control fields are more or less co-incidental (days 6 and 7, and 16 to 20). The mortality in the control field, together with the high mortality (550 honey bees) on day 19 in the nucleus hive in the screen tent (which had been knocked down by pranksters allowing the bees to escape) on the field treated with 10-G strongly indicate a cause other than fonofos. Carbofuran, which is highly toxic to honey bees (Atkins 1981) and the likely toxin, was being used in the general area at the time, but I was unable to discover exactly when and where. That fonofos was not the cause of mortality is further indicated by the low levels of the chemical in the dead honey bees associated with high levels of mortality.

The analyses for fonofos residues showed that a little material was present in dead honey bees, but the amounts are mostly well below those expected to cause mortality. Only one sample (the combining of the few dead honey bees from days 7, 8, and 9 of the experiment) from the field treated with 20G showed high levels (55 mg/kg), but that was not associated with large numbers of dead honey bees (see Fig. 1). That level is above the LD_{90} for honey bees (Atkins 1981) so the low level of mortality and high level of residue cannot be explained, except by post-experimental accidental contamination of the samples of dead bees.

The failure of the experiment to cause mortality in the caged honey bees which had no choice but to forage on corn treated with fonofos, or not forage, strengthens the conclusion that fonofos in granular or microencapsulated (with sticker) formulations is less hazardous to honey bee colonies near fields of sweet corn than other insecticides in use.

Acknowledgements

This work was supported in part under Program 30 of the Ontario Ministry of Agriculture and Food contract with the University of Guelph and by Stauffer Chemical Ltd., London, Ontario and Chipman Chemical Ltd., Stoney Creek, Ontario. I am especially grateful to F. Plante and S. Warren for their support of this research. P. Kelly, D. Lang, G. Maugham, J. McAllister, and A. Willsie provided technical assistance for and during the experiments. Special thanks are extended to H. Braun and B. Ripley of the Provincial Pesticide Residue Testing Laboratory, Agricultural Laboratory Services Branch of the Ontario Ministry of Agriculture and Food, Guelph, Ontario, for residue analyses of dead honey bees and pollen. B. Rathwell helped extensively with analysis of the results and in preparation of the manuscript, and to her I am also grateful. R. Brown, Ecology Section, ICI Agrichemicals, England, kindly reviewed this paper and made useful suggestions.

References

Atkins, E.L. 1975. Injury to honey bees by poisoning. pp. 663-696. *In*: The Hive and the Honey Bee. Dadant and Sons (Editors), Dadant and Sons, Hamilton, Illinois.

Atkins, E.L. 1981. *In*: Pesticide-Pollinator Interactions. National Research Council of Canada Publication No. 18471, Ottawa, 190 pp.

Atkins, E.L., F.E. Todd and L.D. Anderson. 1970. Honey bee field research aided by Todd dead bee hive entrance trap. California Agriculture, 20(10): 12-13.

Barker, R.J., Y. Lehner and M.R. Kunzmann. 1979. Pesticides and honey bees: The danger of microencapsulated formulations. Zeitschrift für naturforschung, 34C: 155-156.

Burgett, D.M., G.C. Fisher, D.F. Mayer and C.A. Johansen. 1984. Evaluating honey bee colonies for pollination: A guide for growers and beekeepers. Pacific Northwest Extension Publication, Oregon, Idaho, Washington PNW 25.

Felton, J.C., P.A. Oomen and J.H. Stevenson. 1986. Toxicity and hazard of pesticides to honey bees: Harmonization of test methods. Bee World, 67: 114-124.

Frank, R., H.E. Braun and B.D. Ripley. 1987. Residues of insecticides, fungicides and herbicides in fruit produced in Ontario, Canada, 1980 - 1984. Bulletin of Environmental Contamination and Toxicology, 39: 272-279.

Hanny, B. and J. Harvey. 1982. Sevin sprayable versus Sevin XLR applied to field corn (*Zea mays* L.) at Pine Bluffs, Wyoming -- Effects on honey bees (*Apis mellifera* L.). American Bee Journal, 122: 506-508.

Kevan, P.G. 1988. Pollination: Crops and Bees. Ontario Ministry of Agriculture and Food Publication 72, 13 pp.

Kevan, P.G., G.W. Otis, R.H. Coffin, M.H. Whitford and L.A. Elder. 1984. Hazards of carbaryl formulations to caged honey bees (*Apis mellifera*) foraging on flowering canola (*Brassica napus*) in Ontario. Proceedings of the Entomological Society of Ontario, 115: 49-54.

Mason, C.E. and K.T. Tracewski. 1982. Diurnal foraging activity for corn pollen by honey bees. Environmental Entomology, 11: 187-188.

Mayer, D.F., C.A. Johansen, J.D. Lunden and L. Rathbone. 1987. Bee hazard of insecticides combined with chemical stickers. American Bee Journal, 127: 493-495.

McLaren, D.A., B.P. Oldroyd and R.D. Goodman. 1987. Comparative toxicity of microencapsulated methyl parathion and emulsifiable concentrate methyl parathion to honey bees (*Apis mellifera* L.). American Bee Journal, 127: 718-720.

Nowakowski, J. and R. Morse. 1982. The behaviour of honey bees in sweet corn fields in New York state. American Bee Journal, 122: 13-16.

Ross, B. and J. Harvey. 1981. Penncap-M® versus Penncap-M® plus sticker applied to sunflower (*Helianthus annuus*) at Pine Bluffs, Wyoming -- Effects on honey bees (*Apis mellifera* L.). American Bee Journal, 121: 510-511 and 516.

Sibley, P.K. 1989. Impact of permethrin (emulsifiable concentrate) on the macroinvertebrate community of a headwater stream and of microencapsulated permethrin under laboratory conditions. M.Sc. dissertation. University of Guelph, Guelph, Ontario, Canada, 160 pp.

Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill Book Co., New York, Toronto, London, xvii + 312 pp.

Smith, M.V. 1963. The O.A.C. pollen trap. Canadian Bee Journal, 74(4): 4-5 and 8.

Stauffer Chemical Co. 1985a. Dyfonate 10-G. Publication A-10336/85, Stauffer Chemical Co., Westport, CT, U.S.A.

Stauffer Chemical Co. 1985b. Dyfonate 20-G. Publication A-10337/85, Stauffer Chemical Co., Westport, CT, U.S.A.

Stauffer Chemical Co. 1986. Dyfonate 10-G. Publication 207-413 09/86, Stauffer Chemical Co., London, Ontario, Canada.

Stauffer Chemical Co. undated. Technical Information: Dyfonate MS -- Experimental insecticide formulation plus product label. Stauffer Chemical Co., Richmond, California, U.S.A., and Bedford, United Kingdom.

(Received 1 February 1991; accepted 19 June 1991)

DISTRIBUTION IN SOUTHERN ONTARIO OF *BATHYPLECTES ANURUS* (HYMENOPTERA: ICHNEUMONIDAE), A LARVAL PARASITOID OF THE ALFALFA WEEVIL

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Abstract *Proc. ent. Soc. Ont.* 122:41-45

Bathyplectes anurus (Thomson), a European endoparasite of the alfalfa weevil, *Hypera postica* (Gyllenhal), has displaced *B. curculionis* (Thomson) in parts of southern Ontario. A detailed survey in 1990 showed that it has spread to 22 counties and was the dominant larval parasitoid in samples from the Bay of Quinte area and southern tier of counties bordering the eastern half of Lake Erie. The incidence of attack ranged from 0.1 to 15%, averaging 4.6%. Dispersal in Ontario has been the result of recolonization and natural spread from the United States.

Introduction

The alfalfa weevil, *Hypera postica* (Gyllenhal), continues to concern dairy farmers across southern Ontario. Since the late 1970s, numbers of the pest have fluctuated within narrow limits and generally at subeconomic levels, but there are periodic eruptions that exceed the damage threshold (Harcourt and Guppy 1991). Population trends are largely determined by *Zoophthora phytonomi* (Arthur), a fungal pathogen that causes mortality of the pest during recurring epizootics (Harcourt *et al.* 1977, 1984). However, the disease is inhibited by lack of rainfall (Harcourt *et al.* 1990) and weevil populations tend to build up rapidly when there is a succession of dry springs (Harcourt and Guppy 1991).

The potential for weevil outbreaks in southern Ontario is decreased by activity of an impressive guild of introduced natural enemies (Harcourt 1989). One of these, *Bathyplectes anurus* (Thomson), has recently displaced *B. curculionis* (Thomson) as the main larval parasitoid in the Bay of Quinte area (Harcourt 1990). However, *B. anurus* has poor powers of dispersal and has been notoriously slow to spread in eastern North America (Dysart and Day 1976).

In Ontario, a successful introduction of *B. anurus* was made in Prince Edward County in 1970 (Williamson 1971). Although it was recovered in the following year (Dysart and Day 1976), this parasitoid was not found outside the release area until 1981 when trace numbers were discovered at a study site in Hastings County, about 80 km to the north. In 1983, the density of *B. anurus* at this site increased sharply and that of *B. curculionis* decreased to a low level. Through 1986, the incidence of attack by *B. anurus* averaged 13%. Then, in 1987, the rate of attack increased

to 19%, and to 27 and 33% in the next 2 years (Harcourt 1990). The levels attained in 1988 and 1989 were associated with a lower incidence of fungal disease in populations of the host, suggesting that the parasitoid may exert a stabilizing influence in years when the disease is enzootic.

In southern Ontario, *B. anurus* overwinters in a cocoon in the alfalfa litter. The adult emerges in late May and deposits its eggs in the second- and third-instar weevils. The parasite larva feeds internally, killing the host after it spins its cocoon; the parasite then forms its own cocoon within that of the host. There is one generation a year, and adult activity overlaps that of the first generation of *B. curculionis*, which has a partial second brood. The objective of this study was to determine the current distribution of *B. anurus* in southern Ontario, and to assess its numerical status in relation to *B. curculionis*.

Materials and Methods

During the spring of 1990, sweepnet samples of third- and fourth-instar alfalfa weevils were taken from infested fields of alfalfa in each county of southern Ontario. To minimize the effects of fungal disease on sample collections, the samples were timed to avoid the onset of epizootics, which generally begin at 261 degree-days (DD) (base 9°C) after 1 April (Harcourt *et al.* 1990). Accordingly, samples in all areas were taken between 225 and 265 DD. Sampling was initiated in southwestern Ontario on 5 June and was completed progressively later throughout the province. The larvae were collected with a standard 38-cm sweepnet, and 200-500 pendulum sweeps were made at each of 79 locations in 41 counties. Generally, 2 sites were sampled per county (Fig. 1).

To reduce the effect of losses from handling and disease, not less than 100 larvae were collected per site. The larvae were reared in the laboratory to cocoon spin-up on fresh sprigs of alfalfa foliage. Within 4-5 days, ca. three-quarters of them pupated or gave rise to *Bathyplectes* spp. cocoons. The remainder died as larvae and displayed symptoms characteristic of *Z. phytonomi* disease (Harcourt *et al.* 1990). The parasitoid pupae were identified on the basis of cocoon characteristics (Brunson and Coles 1968).

Results and Discussion

Populations of the weevil were comparatively low in eastern Ontario, high in western Ontario, and moderate elsewhere. Approximately 9,000 larvae were collected and reared to cocoon formation. *B. anurus* was observed to have spread throughout much of southern Ontario (Fig. 1). It was found in 22 of the 41 counties and at 33 of the 79 sites (Table I); the incidence of parasitism ranged from 0.1 to 15.0% ($\bar{x}$ = 4.6%). *B. curculionis* was found in 36 counties and at 63 sites; the incidence of parasitism ranged from 0.1 to 18.3% ($\bar{x}$ = 5.5%).

The pattern of *B. anurus* occurrence is consistent with its previously reported distribution in Ontario and adjacent areas of the United States. It is apparent that the parasitoid has extended its range from Prince Edward and Hastings Counties to encompass the entire Bay of Quinte area and has spread eastward into several adjoining counties. The sampling data also indicate that the parasitoid has spread into the Niagara frontier from western New York where it has been known for several years (Holmes 1983). The prevalence of parasitism in southwestern Ontario is probably the result of an extensive release program in Michigan carried out by the USDA APHIS Project of Biological Control (Bryan *et al.* 1991).

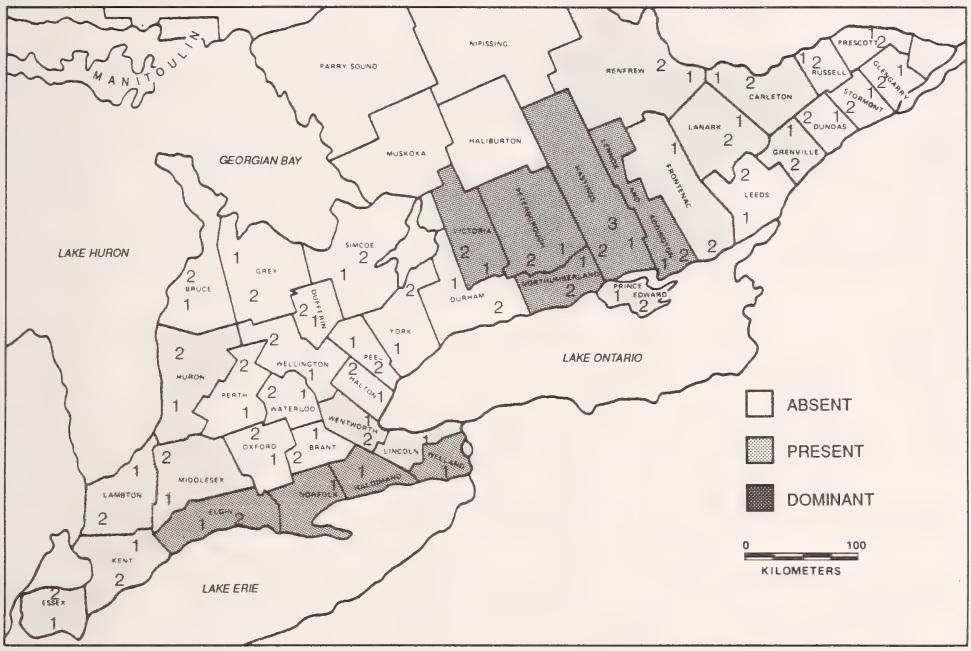

FIGURE 1. Locations sampled for *Bathyplectes anurus* in southern Ontario, and status of the parasitoid relative to *B. curculionis* in counties where it occurred. Generally, two sites (1 and 2) were sampled per county.

The results of this survey indicate that *B. anurus* has become the dominant larval parasitoid in the mainland Quinte area and in the southern tier of counties bordering the eastern half of Lake Erie. The incidence of host mortality in these areas was somewhat lower than expected based on earlier reports. However, the previous data (e.g. 1988 and 1989) were collected in years when the fungus was enzootic, or nearly so (Harcourt 1990). By contrast, *Z. phytonomi* was epizootic throughout central and western Ontario in 1990.

The data also reveal that *B. anurus* has not yet reached the Georgian Highlands and is not present in several counties in the Ottawa and St. Lawrence River Valleys. A program to recolonize *B. anurus* in these areas should be undertaken.

Acknowledgments

The technical assistance of Brian Beattie, Ted Margetts and John Walker is gratefully acknowledged. We also thank J.C. Guppy and J.S. Kelleher for their critical reviews of the manuscript. This article is contribution no. 1309 from the Plant Research Centre.

TABLE I. Parasitism of the alfalfa weevil in southern Ontario by larval parasitoids, 1990.

		% Parasitism				% Parasitism	
County	Site	*B. anurus*	*B. curculionis*	County	Site	*B. anurus*	*B. curculionis*
Brant	1	0.0	1.5	Lincoln	1	0.1	4.2
	2	0.0	5.2				
Bruce	1	0.0	6.1	Middlesex	1	2.5	3.3
	2	0.0	4.0		2	1.7	2.5
Carleton	1	0.0	14.7	Norfolk	1	2.1	0.1
	2	4.2	4.2				
Dufferin	1	0.0	14.9	North-	1	6.6	5.6
	2	0.0	14.3	umberland	2	2.5	0.0
Dundas	1	0.0	0.0	Oxford	1	0.0	1.5
	2	0.0	0.0		2	0.0	14.2
Durham	1	0.0	4.3	Peel	1	0.0	2.0
	2	0.0	1.6		2	0.0	0.0
Elgin	1	7.9	3.3	Perth	1	0.0	5.8
	2	4.7	3.3		2	0.0	10.0
Essex	1	6.4	10.6	Peter-	1	15.0	10.0
	2	0.0	7.3	borough	2	7.4	3.7
Frontenac	1	1.3	2.5	Prescott	1	0.0	0.0
	2	1.4	2.7		2	0.0	0.0
Grey	1	0.0	10.3	Prince	1	0.0	2.9
	2	0.0	1.1	Edward	2	0.7	7.8
Glengarry	1	0.0	0.0	Renfrew	1	4.0	4.0
	2	0.0	0.0		2	4.5	9.1
Grenville	1	3.2	3.2	Russell	1	0.0	0.0
	2	0.0	0.0		2	0.0	0.0
Haldimand	1	2.1	0.1	Simcoe	1	0.0	6.1
	2				2	0.0	1.4
Halton	1	0.0	3.2	Stormont	1	0.0	0.0
	2	0.0	3.1		2	0.0	0.0
Hastings	1	6.2	2.0	Victoria	1	4.0	1.3
	2	7.7	1.3		2	9.1	6.1
	3	13.0	1.0				
Huron	1	0.1	5.8	Waterloo	1	0.0	2.5
	2	0.0	6.7		2	0.0	5.8
Kent	1	0.1	3.3	Wellando	1	8.3	2.5
	2	0.0	0.0				
Lambton	1	12.1	9.1	Welling-	1	0.0	3.3
	2	5.6	18.3	ton	2	0.0	0.0
Lanark	1	0.0	12.7	Went-	1	0.0	1.7
	2	1.4	9.7	worth	2	0.1	5.8
Leeds	1	0.0	4.1	York	1	0.0	13.3
	2	0.0	3.3		2	0.0	7.9
Lennox &	1	4.0	2.7				
Addington	2	1.0	0.0				

References

Bryan, M.D., R.J. Dysart, and T.L. Burger. 1991. Releases of introduced parasites of the alfalfa weevil in the United States. United States Department of Agriculture Miscellaneous Publication.

Brunson, M.H., and W. Coles. 1968. The introduction, release, and recovery of parasites of the alfalfa weevil in eastern United States. United States Department of Agriculture Production Research Report 101, 12 pp.

Dysart, R.J., and W.H. Day. 1976. Release and recovery of introduced parasites of the alfalfa weevil in eastern North America. United States Department of Agriculture Production Research Report 167, 61 pp.

Harcourt, D.G. 1989. Biological control in southern Ontario populations of the alfalfa weevil: An update. Proceedings 26th Northeast Regional Field Crops Insect Conference, pp. 65-72, State College, Pa.

Harcourt, D.G. 1990. Displacement of *Bathyplectes curculionis* (Thoms.) (Hymenoptera: Ichneumonidae) by *B. anurus* (Thoms.) in eastern Ontario populations of the alfalfa weevil, *Hypera postica* (Gyll.) (Coleoptera: Curculionidae). Canadian Entomologist, 122: 641-645.

Harcourt, D.G., and J.C. Guppy. 1991. Numerical analysis of an outbreak of the alfalfa weevil (Coleoptera: Curculionidae) in eastern Ontario. Environmental Entomology, 20: 217-223.

Harcourt, D.G., J.C. Guppy, and M.R. Binns. 1977. The analysis of intrageneration change in eastern Ontario populations of the alfalfa weevil, *Hypera postica* (Coleoptera: Curculionidae). Canadian Entomologist, 109: 1521-1534.

Harcourt, D.G., J.C. Guppy, and M.R. Binns. 1984. Analysis of numerical change in subeconomic populations of the alfalfa weevil, *Hypera postica* (Coleoptera: Curculionidae), in eastern Ontario. Environmental Entomology, 13: 1627-1633.

Harcourt, D.G., J.C. Guppy, and D. Tyrrell. 1990. Phenology of the fungal pathogen *Zoophthora phytonomi* (Arthur) in southern Ontario populations of the alfalfa weevil, *Hypera postica* (Coleoptera: Curculionidae). Environmental Entomology, 19: 612-617.

Holmes, M.C. 1983. Current status of APHIS-cooperator alfalfa weevil biological control project. Proceedings 20th Northeast Regional Alfalfa Insects Conference, pp. 34-56, Newark, De.

Williamson, G.D. 1971. Insect liberations in Canada. 1970. Parasites and predators. Canadian Agriculture Liberation Bulletin 34, 16 pp.

(Received 9 January 1991; accepted 20 March 1991)

INABILITY OF WESTERN FLOWER THRIPS, *FRANKLINIELLA OCCIDENTALIS* (PERGANDE) (THYSANOPTERA: THRIPIDAE), TO OVERWINTER IN SOUTHERN ONTARIO

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Abstract *Proc. ent. Soc. Ont.* 122:47-49

Neither laboratory-reared nor field-collected populations of western flower thrips, *Frankliniella occidentalis* (Pergande), were able to overwinter on garden chrysanthemums at 2 locations in southern Ontario in 1989-90 or 1990-91. The latest collection of live adults of western flower thrips on caged plants was on January 9, 1991. There was no evidence of overwintering thrips in the spring of 1990 in tomato fields near Harrow which were heavily infested with an introduced Georgian population of western flower thrips in 1989.

Introduction

The western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), was first recorded in an Ontario greenhouse in 1983, and is now a major pest of greenhouse crops and the primary vector of Tomato Spotted Wilt Virus (TSWV) (Broadbent *et al.* 1987). The collection of western flower thrips from tomato and pepper in Southwestern Ontario in June, 1989 was the first record of this species in a field crop in Ontario (Pitblado *et al.* 1990). It is believed that these thrips were brought into Ontario on TSWV-infected tomato and pepper seedlings imported from Georgia. Adults of *F. occidentalis* overwinter in the orchards of the Okanagan Valley, B.C. (Madsen and Procter 1982), and in alfalfa in Alberta (Anonymous 1988). On January 22, 1988, a live western flower thrips adult was found outside on garden chrysanthemum, 4 m from a greenhouse in St. Catharines, Ontario. Our objective was to investigate if the local greenhouse strain of western flower thrips was able to overwinter outside on chrysanthemum in Ontario.

Materials and Methods

In August 1989 and 1990, plots containing 25, 8-week-old garden chrysanthemums (cv. Sunday Morning) were planted in a 5 x 5 grid (45 cm between centres) at Agriculture Canada's Jordan Station farm and also at the Harrow Research Station farm. Each year, at both sites, a minimum of 12 plants were covered by pyramidal emergence cages (1 m^2-based) covered with

September of 1989 and 1990, 100-200 live thrips of all life stages were taken from a laboratory culture of western flower thrips maintained on flowering chrysanthemums and introduced into the cages. At Harrow, western flower thrips, collected from field infestations on tomatoes and peppers imported from Georgia, were caged on 12 more chrysanthemum plants.

From October to June 1989-90 and 1990-91, cages were inspected monthly for thrips. On each sampling date, 10 flower heads were removed from caged plants, placed in plastic bags, and examined in the laboratory, by tapping them on white paper. In addition, intact plants in the field cages were tapped 10 times onto white paper. All thrips found on the paper were aspirated into collecting vials and identified in the laboratory. Yellow sticky boards (20 x 10 cm) were placed in the cages in April of each year and monitored biweekly for thrips until July 1.

Results

At Jordan Station in 1989-90, 5 live adult western flower thrips were recovered in October and none thereafter up to the end of monitoring on July 1, 1990. In 1990-91, 4 live adults were recovered in December, 7 live individuals were found in January, and none thereafter up to July 1, 1991. At Harrow, in 1989-90, 2 dead adult western flower thrips were recovered in January, 2 dead individuals were found in February, and 1 dead adult was found in March. In 1990-91, 2 dead adults were recovered in January, 1 dead adult was found in February, and none thereafter up to July 1, 1991. The latest collection of live adults of western flower thrips was on January 9, 1991 at Jordan Station; however, five second instar nymphs were found alive in flower heads on February 11, 1991. These nymphs were placed in clip cages on chrysanthemum (Allen and Broadbent 1986) in the laboratory, but all were dead within 24 h. Since they did not develop to adulthood we were unable to identify individuals to species. At Harrow, live nymphs of unknown species were found in early January of both years, but these did not complete development to adults in the laboratory.

The sticky boards did not trap any western flower thrips between April and July of 1990 or 1991 at Jordan Station or Harrow. On March 15, 1991 a live adult eastern flower thrips, *F. tritici* (Fitch), was tapped out of a flower, and on June 5, 1990 an adult onion thrips, *Thrips tabaci* Lindeman, was detected on a yellow board at Jordan.

Discussion

Our results suggest that neither the laboratory-reared nor the field-collected populations of *F. occidentalis* were able to overwinter in Southwestern Ontario. There was no evidence of overwintering thrips in the spring of 1990 in tomato fields in Southwestern Ontario which were heavily infested with Georgian strain western flower thrips in the summer of 1989. In Nova Scotia, *F. occidentalis* was unable to overwinter in cages placed outdoors in 1990-91 (pers. comm., J.P. LeBlanc, Truro, N.S.).

It has been shown that the supercooling and overwintering ability within insect species can vary in populations from different geographical areas (Somme 1982). In western Canada, a strain of *F. occidentalis* overwinters outdoors. In California, Bryan and Smith (1956) noted three colour forms of *F. occidentalis* (light, medium, dark), with the dark form being the most cold-tolerant. Within greenhouses in Ontario, we have found a predominance of the light form. This form survived -3°C for up to 10 days in a cold tolerance test in the laboratory (Broadbent, unpublished

data). It is probable that a biotype will eventually be selected for or introduced that can survive Ontario winter conditions. Such a population of western flower thrips could be sustained on many common weed hosts in Ontario (Stobbs *et al.* 1991) and therefore pose an ongoing threat to greenhouse as well as field crops.

ACKNOWLEDGEMENTS

The authors thank Carla Carlson and H. Eric Maw for technical assistance.

REFERENCES

Allen, W.R. and A.B. Broadbent. 1986. Transmission of tomato spotted wilt virus in Ontario greenhouses by *Frankliniella occidentalis*. Canadian Journal of Plant Pathology, 8: 33-38.

Anonymous. 1988. Insects and mites on alfalfa in Alberta. Agriculture Canada Research Branch Technical Bulletin 1988-3E.

Broadbent, A.B., W.R. Allen and R.G. Foottit. 1987. The association of *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) with greenhouse crops and the tomato spotted wilt virus in Ontario. Canadian Entomologist, 119: 501-503.

Bryan, D.E. and R.F. Smith. 1956. The *Frankliniella occidentalis* (Pergande) complex in California. University of California, Publications in Entomology, 10: 359-410.

Madsen, H.F. and P.J. Procter. 1982. Insects and mites of tree fruits in British Columbia. Ministry of Agriculture and Food Publication, 82-6: 48.

Pitblado, R.E., W.R. Allen, J.A. Matteoni, R. Garton, J.L. Shipp and D.W.A. Hunt. 1990. Introduction of the tomato spotted wilt virus and western flower thrips complex into field vegetables in Ontario, Canada. Plant Disease, 74: 81.

Somme, L. 1982. Supercooling and winter survival in terrestrial arthropods. Comparative Biochemistry and Physiology, 73: 519-543.

Stobbs, L.W., A.B. Broadbent, W.R. Allen and A.L. Stirling. 1991. Transmission of tomato spotted wilt virus by the western flower thrips to weeds and native plants found in southern Ontario. Plant Disease, 76: 23-29.

(Received 5 December 1991; accepted 12 January 1992)

ACQUISITION AND TRANSMISSION OF *PSEUDOMONAS CICHORII* BY *LIRIOMYZA TRIFOLII* (DIPTERA: AGROMYZIDAE)

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Abstract. *Proc. ent. Soc. Ont.* 121:79-84

Adults of the serpentine leafminer, *Liriomyza trifolii* (Burgess) were able to acquire and transmit *Pseudomonas cichorii* (Swingle) Stapp. both *in vitro* from cultures of the bacteria, and *in situ* from infected to non-infected chrysanthemums. Forty-three percent of adult leafminers exposed to *P. cichorii* in culture jars acquired the bacterium. More infected leafminers were detected by homogenizing (43.0%) as compared to rinsing (15.0%), suggesting ingestion of bacteria by leafminers. The use of the wetting agents Tween 20® and bacitracin enhanced the recovery of *P. cichorii* from homogenized adults of *L. trifolii*.

A mean of 7.9 bacterial leafspots per plant was observed after a 48 h exposure of healthy chrysanthemums to 10 adult leafminers which had been confined on infected chrysanthemums for 24 h. Less than 5% of leafminers observed under a scanning electron microscope had detectable bacterial particles on the cuticle that were in the size range expected for *P. cichorii*. Larval leafminers acquired *P. cichorii* and transmitted bacteria as did adults when confined to culture jars. When *P. cichorii* was introduced to chrysanthemums after oviposition by leafminers, there was a 41.7% reduction in subsequent emergence of prepupae.

The editor apologizes for the omission of this paper from the Table of Contents of the Proceedings of the Entomological Society, Volume 121, 1990. The abstract is reprinted here to allow readers to refer to pages 79-84 of Volume 121 for the full text.

NOTES ON THE BIOLOGY AND CONTROL OF THE BLACK ARMY CUTWORM, *ACTEBIA FENNICA* (LEPIDOPTERA: NOCTUIDAE), IN BLACK SPRUCE PLANTATIONS

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Abstract *Proc. ent. Soc. Ont.* 122:53-63

The biology and control of the black army cutworm, *Actebia fennica* (Tausch.), in Newfoundland were examined in several studies. The adult flight period lasted from July to October and peaked in August. Black spruce seedlings were severely defoliated but non-coniferous plants were preferred and eaten first in an infested plantation. The incidence of parasitism was as high as 60% but failed to prevent severe defoliation in 1988 in black spruce plantations infested in 1987-88. Larval numbers were low in these plantations in 1989. Parasites included *Gonia* sp. (Diptera: Tachinidae); and *Campoletis* sp., *Enicospilus* sp., *Ichneumon creperus* (Cresson) and *Arenetra rufipes* Cresson (Hymenoptera: Ichneumonidae). Ground applications of permethrin (Ambush®) effectively reduced larval numbers and protected black spruce seedlings from defoliation. Recovery of untreated black spruce seedlings severely defoliated in 1988 was excellent in 1989 and 1990. Spraying black spruce seedlings with an aqueous suspension of a cold-tolerant nematode species, *Steinernema feltiae* LIC, effectively prevented defoliation and killed a high percentage of black army cutworm larvae in a laboratory trial.

Introduction

The black army cutworm (BAC), *Actebia fennica* (Tausch.), has long been known as a pest of blueberry, *Vaccinium angustifolium* Ait., (Phipps 1927; Maxwell 1950; Wood and Neilson 1956), vegetable and forage crops (Gibson 1915; Bierne 1971). More recently the BAC has become a forestry pest damaging conifer seedlings planted in areas burned by wildfire or as a prescribed silvicultural activity intended to reduce competition from weeds (Humble *et al.* 1989). Damage to conifer seedlings was first observed in British Columbia in 1973 (Ross and Ilnytzky 1977), and BAC outbreaks have since been reported from the Yukon (Wood and Van Sickle 1983) and Ontario (Kondo and Moody 1986). Infestations of black spruce, *Picea mariana* (Mill.) B.S.P., seedlings in managed plantations have occurred in Newfoundland since 1983 (Clarke and Carew 1984, 1988, 1989).

The biology and population dynamics of the BAC in Newfoundland are not well known and outbreaks cannot be predicted. When damaging populations do occur on black spruce, the only insecticide registered for use is permethrin, a synthetic pyrethroid, but for environmental reasons it cannot be aerially applied. Research is required to predict changes in BAC populations, determine susceptibility of plantations to attack, identify natural mortality factors, assess long-term damage and recovery from infestations, and provide alternative control measures.

This paper summarizes studies begun in 1988 to examine the adult flight period, food preferences of larvae, and incidence of parasitism; evaluate operational ground applications of permethrin and make preliminary evaluations of a cold-tolerant, local species of entomogenous nematode, as a control measure in Newfoundland.

Methods

Field sites:

Field sites were plantations located in western Newfoundland and on well drained and exposed land that had been recently clearcut, prescribed-burned or burned by a wildfire, and planted with black spruce. Drought did not occur and the BAC was the only defoliating species present during the growing seasons observed. The location and history of the plantations used for field studies are as follows:

1. Journois Brook (48° 21'N, 58° 29'W). The plantation, prescribed-burned in 1985 and planted in the springs of 1986 and 1987, had a light (4-6 larvae/m^2) infestation of the BAC in 1987 which caused slight (<10%) defoliation. Treatment with fenitrothion in 1987 was ineffective.
2. St. Fintan's (48° 10'N, 58° 46'W). The plantation, prescribed-burned in 1985 and planted in the fall of 1986, was infested with BAC larvae in 1987 when severe (>50%) defoliation occurred. Treatments with fenitrothion in 1987 were ineffective.
3. Heatherton (48° 18'N, 58° 40'W). The plantation, prescribed-burned in 1988 and planted in the fall of 1988, had no previous history of BAC infestation.
4. Pynn's Brook (49° 01'N, 57° 29'W). The plantation was burned by a wildfire and planted in the summer of 1989. BAC were not observed before 1990.

Adult flight period:

Multi-Pher® traps (Bio-Controle Services, Ste. Foy, Que.) baited with BAC pheromone (Struble *et al.* 1989, supplied by Raylo Chemicals Ltd., Edmonton, Alta.) were used to monitor the adult flight period at the Journois Brook and St. Fintan's plantations in 1988 and 1989 and the plantation at Heatherton in 1989. The pheromone dispenser consisted of a red rubber septum impregnated with 1000 µg of a heptane dilution of (Z)-7-dodecenyl acetate and (Z)-11-tetradecenyl acetate in a ratio of 1:20. A loading of 1000 µg of this attractant blend per septum gives a consistent catch for a minimum of 90 days (Gray *et al.* 1991). The numbers of traps used per year were 10 at Journois Brook, 5 at St. Fintan's and 2 at Heatherton. Traps were placed 1 m above the ground on tripods about 100 m apart in a line and checked for male moths from July to October every week in 1988 and every two weeks in 1989. New lures were used each year but not replaced during seasonal monitoring.

Food preferences of larvae:

Fifteen 50 m^2 circular plots in an infested unsprayed area of the Journois Brook plantation were used in 1988 to identify food preferences of larvae. Plots were examined on 30 May when larvae were in their 5th instar and on 16 June when larvae were beginning to pupate. The percentage of foliage eaten on the 5 most common non-coniferous plant species and the black spruce seedlings present in each plot was estimated. The abundance of non-coniferous plant species in each plot was ranked from 1 (most abundant) to 5 (least abundant). Values of 5, 4, 3, 2, and 1 were assigned to ranks 1, 2, 3, 4, and 5, respectively.

Parasitism levels:

BAC larvae were collected weekly from the Journois Brook and St. Fintan's plantations from 29 May to 16 June 1988 and reared to obtain emerging parasites. Larvae were reared at 21±5°C

on birch foliage in 30 ml diet cups lined with moistened peat moss; pupae were reared similarly but birch foliage was not provided. Larvae and pupae also were collected for rearing from black spruce plantations at St. Fintan's, Heatherton and Pynn's Brook in June 1990. Larval numbers in 1989 were too low to determine parasitism levels.

Evaluation of an operational application of permethrin:

Ambush 500EC® was applied at the Journois Brook plantation on 19 May 1988 at a rate of 140 ml in 45 L water per ha with a MB200SK Automatic Mistblower equipped with an AU5000-2 Micronair air blaster and mounted on a Tree Farmer C5D Porter. The majority of larvae were in their third or fourth instars at the time of application. Six 1 m^2 quadrats randomly chosen within each of five 50 m^2 circular plots in both the treated area and in an untreated area were used for the counting of larvae just prior to treatment and after treatment on 28 May. Larvae present on vegetation and in soil, raked with a small cultivator to a depth of 10 cm, were counted. The circular plots were a minimum of 50 m apart. The untreated area was similar to and about 300 m from the treated area. Population reduction due to treatment was calculated using Abbott's (1925) formula as described by Fleming and Retnakaran (1985).

One hundred seedlings along a 100 m transect across each of the treated and untreated areas were used to assess damage and recovery from BAC. The seedlings were planted in the spring of 1987 as 2+1 stock. The heights of the treated and untreated groups averaged (±SE) 34±1 cm and were not significantly different ($P<0.05$, Student's t-test). Seedlings were examined on 5 July 1988 to determine the percentage of leader buds destroyed and percentage of 1988 buds attacked per seedling, estimate total defoliation (to the nearest 5%) per seedling, and measure seedling height and leader growth. The leader growth and height of the seedlings were measured on 16 August 1989 and 14 August 1990 to estimate annual vertical growth. Means were compared by Student's t-test; the maximum probability of a type-I error was set at 0.05.

Evaluation of *Steinernema feltiae* LIC as a control agent.

Steinernema feltiae LIC isolated from soil samples in Newfoundland (J. Finney-Crawley, Memorial University, St. John's, Nfld., unpublished data) was propagated on greater wax moth, *Galleria mellonella* (L.) larvae following the method of Dutky *et al.* (1964) to provide enough material for efficacy testing. Two-year old black spruce seedlings were planted in pairs in peat moss in each of eight 41 x 28 x 15 cm plastic tubs. Six tubs were sprayed for 5 seconds with an aqueous stock suspension of *S. feltiae*; the other two tubs were untreated and used as checks. Calibrations (n=10) indicated that in 5 seconds 83 ml were applied and contained 15 000 live nematodes. Ten fourth- or fifth-instar field-collected BAC larvae then were added to each tub and reared for 9 days at 20-25°C at the Forestry Canada field laboratory at Pasadena, Nfld. Tubs were placed in deep cardboard boxes to prevent larvae from escaping. The number of larvae in the tubs was counted 5 and 9 days after treatment and dead larvae were examined for the presence of *Steinernema*. Defoliation of the seedlings was assessed 9 days after treatment.

Results

Adult flight period:

Male moths were caught from 11 July to 7 October 1988 and from 18 July to 12 October 1989 indicating that the BAC has a lengthy flight period (Fig. 1) in Newfoundland. Peak catch was in mid- to late August. Larval densities were less than 1/m^2 at Journois Brook and St. Fintan's in 1989 and at all locations in 1990 (Forestry Canada, Forest Insect and Disease Survey, unpublished data).

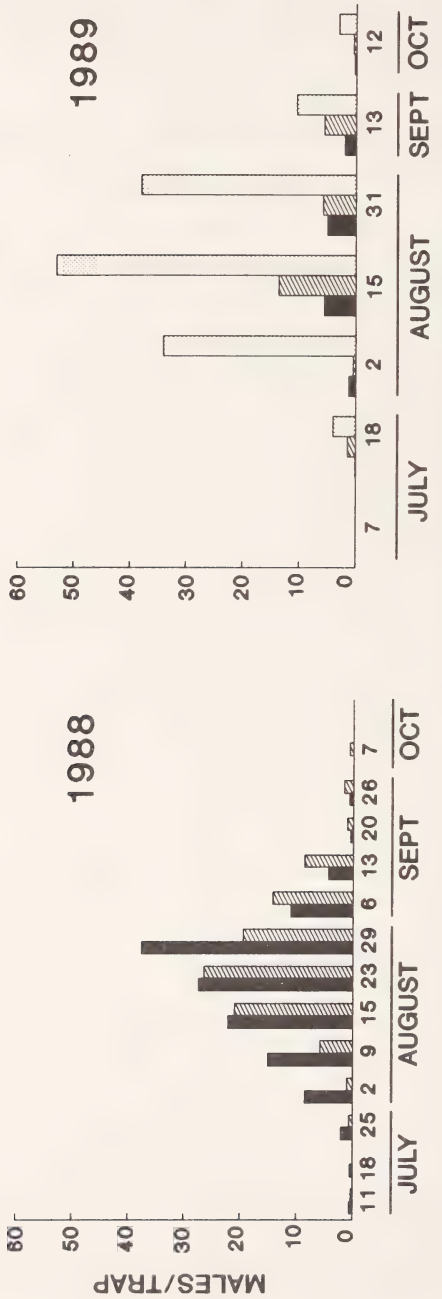

FIGURE 1. Seasonal catches of male black army cutworm moths in pheromone traps placed in black spruce plantations in western Newfoundland, 1988-89. Solid bars = Journois Brook, striped bars = St. Fintan's, dotted bars = Heatherton.

Food preferences of larvae:

Fireweed (*Epilobium angustifolium* L.), elderberry (*Sambucus canadensis* L.), raspberry (*Rubus idaeus* L.) and birch (*Betula papyrifera* Marsh.) were the most common non-coniferous plants (Table I) and all were severely defoliated (Fig. 2). Other plants occasionally found in the plots also were severely defoliated and included red maple (*Acer rubrum* L.), pearly everlasting (*Anaphalis margaritacea* (L.) Benth. & Hook.), sorrel (*Rumex acetosella* L.), mountain ash (*Sorbus americana* Marsh.), and hairy cap moss (*Politricum commune* Hedw.). By 30 May, about 40% of the current-year foliage and 0 to 5% of the older foliage on the black spruce seedlings was eaten, less than half that eaten on the other plant species. By 16 June, the non-coniferous plants were defoliated by 90 to 100% and 90% of the current-year foliage and 63% of the older foliage on the black spruce seedlings was eaten (Fig. 2). A preference for a particular non-coniferous plant was not detected, but non-coniferous plants appeared to be preferred over the black spruce seedlings. The black spruce was severely defoliated after the non-coniferous cover was consumed.

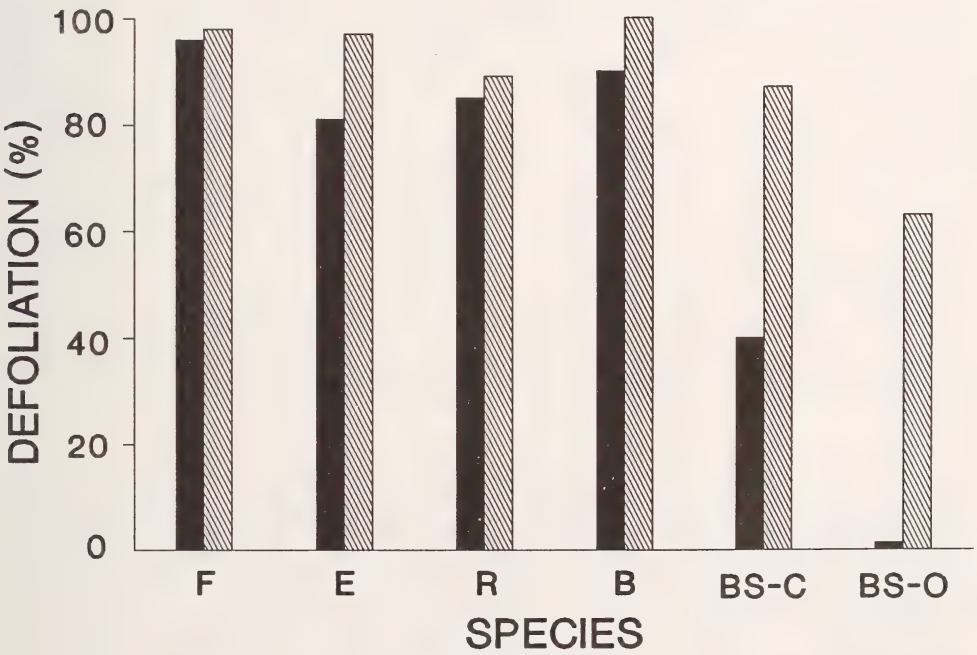

FIGURE 2. Percent of plants defoliated by black army cutworm larvae in a black spruce plantation at Journois Brook, Newfoundland in 1988. F = fireweed, E = elderberry, R = raspberry, B = white birch, BS = black spruce (C, current-year foliage, O, old foliage). Solid bars = 30 May, striped bars = 16 June.

Parasitism levels:

Approximately 45% of larvae collected from St. Fintan's and Journois Brook in 1988 were parasitized by either dipterous or hymenopterous species (Table II). The parasites died before reaching the adult stage and were not identified. Parasitism levels were under 15% in 1990 (Table II) and the following parasites were reared from collected larvae and pupae: *Tachinomyia panaetius* (Walker) (Diptera: Tachinidae, from larva); *Gonia* sp. (Diptera: Tachinidae, from pupa); *Campoletis* sp. (Hymenoptera: Ichneumonidae, from larva); *Enicospilus* sp., *Ichneumon creperus* (Cresson) and *Arenetra rufipes* Cresson (Hymenoptera: Ichneumonidae, from pupa).

TABLE I. Relative abundance of non-coniferous plant species in 50 m^2 circular plots in a black spruce plantation infested with black army cutworm at Journois Brook, Newfoundland in 1988. Absence from plot is indicated by a (-).

Species	30 May		16 June*	
	Mean value	Rank	Mean value	Rank
Fireweed	4.6	1	1.5	4
Raspberry	3.6	2	4.2	1
Birch	1.4	3	2.8	2
Red maple	1.1	4	-	-
Elderberry	0.7	5	2.3	3
Sorrel	0.5	6	-	-
Pearly everlasting	0.4	7	-	-
Mountain ash	-	-	0.3	5

* The relative abundance of plants in 5 of the 15 plots was not determined because the plants were completely defoliated and could not be identified.

Evaluation of an operational application of Ambush:

Larvae were essentially eliminated from the treated area within 9 days of the application of Ambush whereas larval numbers were still high enough to cause severe damage in the check plot (Table III). Movement of larvae was high in the untreated area and may explain the apparent increase in numbers in some of the plots.

The seedlings treated with Ambush received little bud damage (Table IV) and averaged (±SE) 14.4±0.8 cm of leader growth in 1988, the year of BAC attack. The untreated seedlings were extensively damaged and averaged only 1.7±0.7 cm in leader growth in 1988 but recovered well in 1989 when average leader growth was 15.9±0.7 cm, however, this was still significantly less than 21.9±0.9 cm, the average leader growth for the treated seedlings that year. There was no dieback but 63% of the leaders of the untreated seedlings were crooked in 1989. In 1990 the average leader growth was 26.7±0.8 cm for the untreated seedlings, significantly higher than 20.7±0.9 cm for the treated seedlings. The average seedling height in 1990 was 89.8±3.0 cm for the treated seedlings, significantly higher than 77.6±1.9 cm for the untreated seedlings. Seedlings were not damaged by BAC larvae or other insects in 1989 or 1990 in either the treated or untreated plots.

TABLE II. Incidence of parasitism of black army cutworm in black spruce plantations in western Newfoundland in 1988 and 1990. L=larvae, P=pupae.

Year and Location	Number/stage collected	Percentage parasitized by	
		Hymenoptera	Diptera
1988			
St. Fintan's			
29-V	224/L	5	25
1-VI	56/L	43	16
8-VI	202/L	42	16
Journois Brook			
29-V	208/L	31	4
1-VI	146/L	34	5
8-VI	210/L	49	0
15-VI	206/L	59	1
1990			
St. Fintan's			
25-VI	116/P	4	1
28-VI	111/P	4	0
Heatherton			
22-VI	71/L	6	10
	22/P	9	0
Pynn's Brook			
10-VI	83/L	1	0

Evaluation of *Steinernema feltiae* LIC as a control agent.

The average percentage (±SE) of larvae still alive in the treated tubs was 13.3±4.9 % after 5 days and 6.7±3.3 % after 9 days. Infective and reproducing stages of the nematode were present in all dead larvae. All larvae in the untreated tubs were still alive after 9 days. The treated seedlings were not defoliated whereas roughly 80% of the current-year growth on the untreated seedlings was eaten.

Discussion

The length of the flight period observed is similar to that of moths in the Maritimes (Gibson 1915) and British Columbia (Gray *et al.* 1991) but begins and ends later presumably because of late springs in Newfoundland. The peak flight period occurred in August and monitoring could be restricted to this month if budgets were restricted. Seasonal catches of male moths caught per trap in 1988 and 1989 were under 200 and were followed by low larval densities and no seedling

TABLE III. Effect of ground application of Ambush on larvae of the black army cutworm at Journois Brook, Newfoundland in 1988. Treated plots were matched with untreated plots that had similar pre-spray population counts.

Plot	Mean number of larvae/m^2 (±SE)		Reduction due to treatment (%)*
	Pre-spray	Post-spray	
1 Treated	44.0 ± 7.7	0.3 ± 0.2	99
Untreated	46.8 ± 4.0	24.6 ± 4.3	
2 Treated	48.7 ± 6.7	0.2 ± 0.2	99
Untreated	46.8 ± 4.0	24.6 ± 4.3	
3 Treated	0.5 ± 0.2	0	100
Untreated	0.3 ± 0.2	25.8 ± 2.5	
4 Treated	24.7 ± 4.1	0.2 ± 0.2	99
Untreated	30.7 ± 5.5	43.3 ± 11.7	
5 Treated	21.5 ± 4.7	0	100
Untreated	17.6 ± 6.7	34.2 ± 4.9	

* Calculated by Abbott's (1925) formula.

TABLE IV. Damage to Ambush-treated and untreated black spruce seedlings in a plantation at Journois Brook, Newfoundland infested with black army cutworm in 1988.

Treatment	% Leader buds destroyed	% Buds damaged/ seedling (±SE)	Average % defoliation/seedling (±SE)
Ambush	4	1.8 ± 1.0	1.2 ± 0.6
Untreated	91	85.8 ± 2.3	48.7 ± 3.2

damage in 1989 and 1990. These observations agree with Gray *et al.* (1991) who, using the same trap, lure and pheromone concentration, considered seasonal catches under 350 moths/trap low and indicative of no risk to conifer seedlings the following spring. Annual trapping of BAC moths in newly burned areas with estimates of larval densities and seedling damage the following spring is recommended to establish correlations of predictive value. Such activity has been carried out since 1988 in Newfoundland by Forestry Canada's Forest Insect and Disease Survey. Some predictive value also might be gained by studies correlating densities and fecundities of female moths with pheromone trap catches.

Numerous authors (eg., Pulliainen 1963; Ross and Ilnytzky 1977; Hodgkinson 1986) have reported that BAC larvae feed on a wide variety of non-coniferous plants. However, the question as to whether or not larvae prefer non-coniferous to coniferous plants has not been adequately addressed. The present results indicate that black spruce seedlings are susceptible to BAC attack, but non-coniferous plants are preferred and eaten first (Fig. 2). Therefore, the decision of when to plant conifer seedlings should be partly influenced by the amount of non-coniferous vegetation present. Delaying planting until after the larval feeding period would be advisable when BAC populations are high.

Parasitism levels were as high as 60% in 1988 and may have partly accounted for the low population levels in 1989. Care should therefore be taken to encourage the persistence of the complex of parasites observed by using target-specific insecticides or, if this is not possible, by leaving certain areas unsprayed to serve as reservoirs for parasites, particularly those which have alternate hosts. The tachinids reared are likely generalists; records in Arnaud (1978) indicate that they have several hosts in the families Lymantriidae, Lasiocampidae, and Noctuidae. Perhaps one or more of the parasites identified from Newfoundland may be of value in the biocontrol of BAC in other areas of Canada. *Tachinomyia panaetius* (Walker), *Gonia* sp., *Campoletis* sp., *Enicospilus* sp. and *Arenetra rufipes* are not on existing lists of BAC parasites in British Columbia (Ross and Ilnytzky 1977; Humble *et al.* 1989). Ambush® effectively reduced larval numbers and protected conifer seedlings from defoliation in the year of BAC attack. Although defoliation of the untreated seedlings was severe they recovered well in the first year after attack and leader growth in the following year actually surpassed that of the treated seedlings. These observations agree with those of Langstrom and Hellqvist (1989) who found that young Norway spruce, *Picea abies* (L.) Karst., seedlings responded to severe defoliation with relatively small growth losses of short duration. The greater leader growth in the untreated seedlings in 1990 is difficult to explain. Young balsam fir, *Abies balsamea* (L.) Mill., trees have rapid root growth following defoliation (Redmond 1959); perhaps partial defoliation contributed to increased root development for the untreated seedlings.

My results suggest that operational control programs may not be warranted if the loss of only one year's growth is not a major concern. However, factors such as site quality, rainfall, the age and condition of the seedlings at the time of infestation, degree of non-coniferous cover and monetary value of the plantation need to be considered in planning or rejecting the use of controls. In the present study, drought and other insect infestations were not a factor and the seedlings were able to grow for one year prior to severe BAC attack. Newly planted seedlings may have been more susceptible. Transient effects of damage by the BAC also have been noted for other crops. Gibson (1915) reported good recovery of peas and clover following attack in May in Ottawa, Ontario.

High mortality of larvae within 5 days and the lack of defoliation on black spruce seedlings treated with a suspension of the nematode, *S. feltiae* LIC, indicate a potential alternative to chemical control. Assuming effectiveness in field trials, nematodes may be useful in treating BAC populations in environmentally sensitive areas either from the ground or the air. Morris *et al.* (1990) recently found that *S. feltiae* LIC could kill the Bertha armyworm, *Mamestra configurata* Wlk., an agricultural pest. The present results suggest that nematodes may be of value in forestry as well.

Acknowledgements

I thank D.S. Durling, T. Mitchell, A. Jacobs, and D. Eason for excellent technical assistance and the Newfoundland Department of Forestry and Agriculture for providing details of the operational application of Ambush. J. Finney-Crawley provided nematode cultures and determined the presence of nematodes in dead larvae from the bioassays. Parasites were identified by J.R. Barron, H.E. Bisdee and J. Poirier. Helpful reviews of the manuscript were made by J.N. McNeil, R.F. Shepherd, L.M. Humble and W.W. Bowers.

The exclusion of certain manufactured products does not necessarily imply disapproval, nor does the mention of other products necessarily imply endorsement by Forestry Canada.

References

Abbott, W.S. 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology, 18: 265-267.

Arnaud, P.H. 1978. A host-parasite catalogue of North American Tachinidae (Diptera). United States Department of Agriculture, Miscellaneous Publication 1319. 860 p.

Bierne, B.P. 1971. Pest insects of annual crop plants in Canada. Memoirs of the Entomological Society of Canada, 78: 2.

Clarke, L.J. and G.C. Carew. 1984. Forest insect and disease conditions in Newfoundland and Labrador in 1983. Canadian Forestry Service Information Report N-X-223. 28 p.

Clarke, L.J. and G.C. Carew. 1988. Forest insect and disease conditions in Newfoundland and Labrador in 1987. Canadian Forestry Service Information Report N-X-265. 37 p.

Clarke, L.J. and G.C. Carew. 1989. Forest insect and disease conditions in Newfoundland and Labrador in 1988. Forestry Canada Information Report N-X-268. 38 p.

Dutky, S.R., J.V. Thompson and G.E. Cantwell. 1964. A technique for mass propagation of the DD-136 nematode. Journal of Insect Pathology, 6: 417-422.

Fleming, R. and A. Retnakaran. 1985. Evaluating single treatment data using Abbott's formula with reference to insecticides. Journal of Economic Entomology, 78: 1179-1181.

Gibson, A. 1915. Cutworms and their control. Canadian Department of Agriculture Bulletin, 10: 27-28.

Gray, T.G., R.F. Shepherd, D.L. Struble, J.B. Byers, and T.F. Maher. 1991. Selection of pheromone trap and attractant dispenser load to monitor black army cutworm, *Actebia fennica*. Journal of Chemical Ecology, 17: 309-316.

Hodgkinson, R. 1986. A preliminary assessment of the initial impact of black army cutworm in the Prince George Forest Region. British Columbia Forest Service Internal Report. PM-PG-5. 31 p.

Humble, L.M., R.F. Shepherd, and T.F. Maher. 1989. Biology, outbreak characteristics and damage caused by the black army cutworm (Lepidoptera: Noctuidae). pp. 82-88. *In*: R.I. Alfaro and S.G. Glover (Eds.), Insects Affecting Reforestation: Biology and Damage - Proceedings of the International Union of Forest Research Organizations Working Group S2.07-03, July 3-9, 1988, Vancouver, B.C., Forestry Canada (Pacific and Yukon Region), Victoria, B.C.

Kondo, E.S. and B.H. Moody. 1986. Forest Insect and disease conditions in Canada in 1985. Forest Insect and Disease Survey, Canadian Forestry Service. Ottawa, Ontario. 128 p.

Langstrom, B. and C. Hellqvist. 1989. Effects of defoliation, decapitation, and partial girdling on root and shoot growth of pine and spruce seedlings. pp. 89-100. *In*: R.I. Alfaro and S.G. Glover (Eds.), Insects Affecting Reforestation: Biology and Damage - Proceedings of the International Union of Forest Research Organizations Working Group S2.07-03, July 3-9, 1988, Vancouver, B.C., Forestry Canada (Pacific and Yukon Region), Victoria, B.C.

Maxwell, C.W.B. 1950. Field observations on the black army cutworm, *Actebia fennica* (Tausch.) and its control on blueberries in New Brunswick. Scientific Agriculture, 30: 132-135.

Morris, O.N., V. Converse, and J. Harding. 1990. Virulence of entomopathogenic nematode-bacteria complexes for larvae of noctuids, a geometrid and a pyralid. Canadian Entomologist, 122: 309-319.

Phipps, C.R. 1927. The black army cutworm, a blueberry pest. Maine Agricultural Experiment Station Bulletin, 340: 201-216.

Pulliainen, E. 1963. On *Actebia fennica* Tausch. (Lepidoptera: Noctuidae), its biology and occurrence in Eastern Fennoscandia. Annales Entomologici Fennici, 29: 52-68.

Redmond, D.R. 1959. Mortality of rootlets in balsam fir defoliated by the spruce budworm. Forest Science, 5: 64-69.

Ross, D.A. and S. Ilnytzky. 1977. The black army cutworm in British Columbia. Canadian Forestry Service Information Report BC-X-154. 23 p.

Struble, D.L., J.R. Byers, R.F. Shepherd, and T.G. Gray. 1989. Identification of sex pheromone components of the black army cutworm, *Actebia fennica* (Tauscher) (Lepidoptera: Noctuidae), and a sex attractant blend for adult males. Canadian Entomologist, 121: 557-563.

Wood, C.S. and G.A. Van Sickle. 1983. Forest insect and disease conditions British Columbia & Yukon 1982. Canadian Forestry Service Information Report BC-X-239.

Wood, G.W., and W.T.A. Neilson. 1956. Notes on the black army cutworm, *Actebia fennica* (Tausch.) (Lepidoptera: Phalaenidae), a pest of low-bush blueberry in New Brunswick. Canadian Entomologist, 88: 93-96.

(Received 19 June 1991; accepted 5 November 1991)

ANALYSES OF THREE SAMPLING TECHNIQUES FOR LARVAE OF SPRING *AEDES* SPP. (DIPTERA: CULICIDAE)

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Abstract *Proc. ent. Soc. Ont.* 122:65-72

Of three larval samplers [invertebrate cone trap, bucket and cylinder samplers] the bucket sampler is recommended for sampling spring *Aedes* species. The invertebrate cone trap collected significantly ($P<0.05$) fewer larvae of *Aedes stimulans* (Walker); *Aedes euedes* Howard, Dyar and Knab; *Aedes provocans* (Walker); *Aedes excrucians* (Walker) and *Aedes fitchii* (Felt and Young) within the woodland and open field pools than the bucket and cylinder samplers. The invertebrate cone trap collected more larvae at higher temperature. The bucket and cylinder samplers performed equally in all categories of analysis. Ease of use, low cost and short time needed for sampling make the bucket sampler superior to the other two sampling devices.

Introduction

In Canada spring *Aedes* spp. mosquitoes are vectors of California group viruses (Artsob *et al.* 1982), and dog heartworm (Arnott and Edman 1978). In addition, these mosquitoes often adversely affect outdoor activity in Canada (Laird 1982), and the northern United States (Hocking 1960) and thus require suppression, preferably in the larval stage.

In a review of methods for sampling mosquito larvae, Service (1976) noted that the oldest and most used method is the pint dipper. Welch and James (1960) suggested that an area sampler, "the Belleville trap", would give better estimates of species' densities and composition. Later authors have devised simpler, more efficient area samplers (Roberts and Scanlon 1979; Wagner and Newson 1975).

Comparisons of larval numbers collected by area samplers and pint dippers have been made by Roberts and Scanlon (1979), Taylor (1979) and Downing (1977) with conflicting results. Enfield and Pritchard (1977) have outlined the time and temperature interaction between the area sampler and numbers of larvae collected.

This paper reports a comparison of three sampling devices for estimating larval numbers, species composition and age of larval spring *Aedes* spp. The practicality of the devices in terms of labour and expense were also considered.

Materials and Methods

The first sampling method, the bucket sampler, consisted of an 11-litre plastic pail filled with water by pushing it to the bottom of the pool and filling it with water. Preliminary studies had indicated that randomly selected pint dips collected too few larvae for meaningful comparisons to be made and that a greater water volume was required.

The second method consisted of an invertebrate cone trap (invertebrate cone trap), a modified minnow trap used to sample aquatic invertebrate populations (Helson and Surgeoner 1986). An invertebrate cone trap consisted of two inverted plastic cones (Nalgene, 100 mm funnel, spout removed) with 2 cm diameter holes at their apices, fastened to the end of a plastic cylinder, 26 cm long X 11 cm in diameter. The cylinder was made from two one-litre plastic containers (with bottoms removed) joined together.

The third sampler was a modified "Belleville" sampler, constructed from galvanized metal (Welch and James 1960). The outer cylinder was 75 cm in height X 25 cm in diameter with a bottom lip, 0.62 cm wide, for the inner cylinder to rest upon. The inner cylinder was 24.5 cm in diameter and had an inverted funnel (5 cm in length) welded 7.5 cm from the bottom.

Sampling devices were evaluated during the spring of 1980 and 1981 in three distinct spring *Aedes* spp. habitats within 8 km of Guelph, Ontario (43° 30' N, 80° 20' W). The first habitat consisted of a 4-5 hectare (depth 11-45 cm) pool with a leaf litter base within a deciduous wood (denoted woodland pool). The second pool (open field pool with a grass substrate) was in a farm field that had lain fallow for several years. The pool covered approximately 3 hectares and its depth fluctuated between 8 and 30 cm. The third pool, located in a cedar bog, covered approximately 0.25 hectares and ranged in depth from 7 to 50 cm. Its substrate consisted of bare loosely packed soil with small patches of leaf litter.

Two crossing transects (each 10 m in length) were established in each pool. Five sampling stations were placed at 2 m intervals along each transect. At each sampling station an invertebrate cone trap was tied loosely to a stake allowing it to float with the cone holes approximately 5 cm below the water surface. Only live organisms could enter the trap and few would have been able to escape. Ten traps were placed continuously in each pool and emptied on each sampling date. The contents of each trap were drained using a fine mesh aquarium net. The samples were transported to the laboratory in 0.5 litre containers and all larvae and pupae were removed for counting, instar determination and identification using Wood *et al.* (1979).

Bucket samples were taken at each station and handled in a similar manner to the invertebrate cone trap. Cylinders were placed in position at sampling stations for a minimum of 30 minutes at temperatures below 10° C and a minimum of 15 minutes at temperatures above 10° C. A large rubber stopper was placed in the funnel once the sampling time had elapsed. The contents were then handled in the same manner as the previous samples. During sampling, the invertebrate cone trap was emptied and the bucket and Belleville sampler used at each station, before moving on to the next station, to reduce disturbance to the rest of the transect.

Pools were sampled once every three days starting from initial egg hatch until the disappearance of pupae. Temperature of the water was recorded at each station during the sampling period. Analysis of variance (ANOVA), Duncan's Multiple Range Test for differences between means (DMRT), linear regression and multilinear regression were used through the Statistical Analysis System computer package at the University of Guelph to test for differences between sampling devices (SAS 1982).

Results

A) Woodland Pool

Larvae of *Aedes stimulans* (Walker), *Ae. provocans* (Walker), *Ae. euedes* Howard, Dyar and Knab, *Ae. excrucians* (Walker), *Ae. cinereus* Meigen and *Culiseta morsitans* (Theobald) were collected in this pool by all samplers.

Using DMRT there was no significant difference ($P>0.05$) between the bucket and cylinder samplers in per cent capture of *Ae. stimulans* and *Ae. euedes* (i.e. sampler versus species). DMRT indicated that both the bucket and cylinder samplers collected higher percentages of *Ae. stimulans* and *Ae. euedes* than the invertebrate cone trap (Table I). ANOVA and DMRT showed no significant difference ($P>0.05$) between samplers in the percentage of *Ae. provocans* and *Ae. excrucians* larvae collected (Table I).

TABLE I. Mean number of larvae and percent of total collected by sampler, Guelph, Ontario, 1980-1981.

Species	Woodland Pool Samplers			Open Field Pool Samplers			Cedar Bog Samplers		
	I[1]	B[2]	C[3]	I	B	C	I	B	C
Aedes stimulans									
Mean No. of Larvae	64	119	112	4	29	12	96	81	78
% of Total[4]	21.7	40.3	38.0	8.8	64.4	26.8	37.6	31.7	30.7
Aedes provocans									
Mean No. of Larvae	3	4	4	3	14	8	61	53	49
% of Total	27.2	36.4	36.4	12.0	56.0	32.0	37.4	32.5	30.1
Aedes euedes									
Mean No. of Larvae	29	57	48	7	19	14	2	3	3
% of Total	21.6	42.5	35.9	17.5	47.5	35.0	25.0	37.5	37.5
Aedes excrucians									
Mean No. of Larvae	3	4	4	9	27	26	110	114	84
% of Total	27.2	36.4	36.4	14.5	43.5	42.0	35.7	37.0	27.3
Aedes fitchii									
Mean No. of Larvae	-	-	-	15	31	25	5	4	3
% of Total	-	-	-	21.5	43.6	35.3	41.6	33.3	25.1
Aedes canadensis									
Mean No. of Larvae	-	-	-	-	-	-	26	19	19
% of Total	-	-	-	-	-	-	40.6	29.7	29.7

1 Invertebrate cone trap
2 Bucket sampler
3 Cylinder sampler
4 % of total *A. stimulans* caught

There was no significant difference (P>0.05) between the three samplers in the age of *Ae. stimulans*, *Ae. euedes*, *Ae. provocans* and *Ae. excrucians* larvae collected at each sampling date (i.e. age versus sampler). Larvae of other species were too few for analysis.

Larval numbers of each species (y axis) were plotted against date (x axis) or temperature (x axis) by sampler type using linear regression. The resulting combinations were expressed as two opposite conditions. A negative slope of the regression line of larval numbers against increasing time and temperature was the condition to be expected in a spring *Aedes* pool (Condition 1) because, as the pool warms, the larval population gradually diminishes as it develops to maturity (i.e. pupation) and as mortality occurs (Haufe 1957; Chodorowski 1969; Lakhani and Service 1974; Pritchard and Scholefield 1983). The opposite condition (Condition 2) was a positive slope of the regression line of larval numbers against increasing time or temperature which would indicate a continuously increasing larval population within a pool. A spring *Aedes* larval sampling device should reflect Condition 1 to give a true measurement of the age of a larval population and its approximate size. A device that conforms to Condition 2 gives an incorrect interpretation of mosquito development within a pool unless subsequent egg hatch occurs (an unusual event for spring *Aedes* spp.). Such a device probably reflects changes of temperature. In the woodland pool, the invertebrate cone trap exhibited Condition 2 for all the species collected (Table II). Trapping by invertebrate cone trap appeared temperature dependent, capturing more larvae as the pool temperature increased. This phenomenon occurred because first and second instar larvae are relatively inactive at lower water temperatures and remain near the bottom. Only as the pool warms do they become active and move into the invertebrate cone trap at the water's surface. Conversely, the bucket and cylinder samplers showed decreasing capture rates as time and temperature increased, reflecting larval mortality and pupation.

TABLE II. Comparison of the slope of the regression lines of mosquito larval numbers against time and temperature for the woodland pool, Guelph, Ontario, 1980-81.

Species	Sampler					
	ICT		Bucket		Cylinder	
	1980	1981	1980	1981	1980	1981
Ae. stimulans						
Slope of time line	1.54*	0.82*	-1.64	-2.26	-0.71	-1.51
Slope of temperature line	3.63*	0.95*	-2.68	-6.14	-0.37	-18.10
Ae. provocans						
Slope of time line	-0.05	0.18*	-0.06	-0.01	-0.06	-0.01
Slope of temperature line	-0.10	0.20*	-0.45	-0.01	-0.14	-0.11
Ae. euedes						
Slope of time line	0.05*	0.07*	-0.13	-0.39	-0.10	-0.60
Slope of temperature line	1.53*	3.00*	-0.51	-1.53	-0.01	-3.79
Ae. excrucians						
Slope of time line	0.02*	-0.07	-0.09	-0.10	-0.21	-0.20
Slope of temperature line	0.30*	-0.20	-0.16	-0.90	-0.01	-0.70

* Positive slope of the regression lines indicates increasing larval numbers with time or temperature.

B) Open Field Pool

Larvae of the previously mentioned six species and those of *Aedes fitchii* (Felt and Young) were collected from the open field pool by all sampling methods.

Analysis of the percentage capture of larval *Ae. stimulans* and *Ae. provocans* in the open field pool indicated that there was a significant difference ($P<0.05$) between all three sampler types. DMRT showed that the bucket sampler collected significantly ($P<0.05$) more larvae than the cylinder sampler which in turn collected significantly ($P<0.05$) more larvae than the invertebrate cone trap (Table I). The invertebrate cone trap collected significantly lower percentages ($P<0.05$) of larvae of *Ae. euedes*, *Ae. excrucians* and *Ae. fitchii* than did the bucket and cylinder samplers which performed equally (Table I).

No sampler type was biased towards larval instar (i.e. age versus species) in capture of *Ae. stimulans*, *Ae. provocans* and *Ae. euedes*. The invertebrate cone trap collected significantly younger ($P<0.05$) larvae of *Ae. excrucians* and *Ae. fitchii* than did the bucket and cylinder samplers in the open field pool. In comparing sampling devices in relation to time and temperature and larval collections the invertebrate cone trap exhibited a trend of increased capture for increasing time or temperature for all species except *Ae. excrucians* (Table III). The bucket and cylinder samplers showed a negative correlation in the slopes of the lines between all species, except for *Ae. fitchii* in which larval numbers increased with time and temperature.

TABLE III. Comparison of the slope of the regression lines of mosquito larval numbers against time and temperature for the open field pool, Guelph, Ontario, 1980-81.

Species	Sampler					
	ICT		Bucket		Cylinder	
	1980	1981	1980	1981	1980	1981
Ae. stimulans						
Slope of time line	-0.22	0.03*	-0.92	-0.44	-1.01	-0.37
Slope of temperature line	0.18*	0.14*	-1.32	-0.70	-1.45	-0.13
Ae. provocans						
Slope of time line	0.01*	-0.01	-0.02	-0.10	-0.10	-0.31
Slope of temperature line	-0.01	-0.18	-0.10	-0.80	-0.10	-0.76
Ae. euedes						
Slope of time line	-0.43	0.01*	-0.63	-0.11	-0.57	-0.18
Slope of temperature line	-0.30	0.02*	-0.59	-0.12	-0.76	-0.20
Ae. excrucians						
Slope of time line	-0.53	-0.03	-1.64	-0.15	-1.50	-0.27
Slope of temperature line	-0.05	-0.32	-1.92	-0.60	-2.67	-0.63
Ae. fitchii						
Slope of time line	0.28*	-0.63	0.44*	-0.09	0.10*	-1.01
Slope of temperature line	2.07*	-1.72	1.94*	-0.04	0.92*	2.80*

* Positive slope of the regression lines indicates increasing larval numbers with time or temperature.

C) Cedar Bog

In addition to the seven species previously described, *Aedes canadensis* (Theobald) was collected.

Analysis of samplers within the cedar bog indicated no significant difference (P>0.05) in per cent species composition or age of larvae (Table I).

The invertebrate cone trap sampler showed a tendency to be temperature dependent in relation to numbers of larvae collected for all species, whereas the bucket sampler was temperature dependent for only *Ae. fitchii* and *Ae. canadensis* (Table IV).

TABLE IV. Comparison of the slope of the regression lines of mosquito larval numbers against time and temperature for the cedar bog pool, Guelph, Ontario, 1980-81.

Species	Sampler					
	ICT		Bucket		Cylinder	
	1980	1981	1980	1981	1980	1981
Ae. stimulans						
Slope of time line	-0.14	-16.6	-0.10	-0.18	-0.29	-5.16
Slope of temperature line	6.90*	-55.30	-0.39	-21.60	-0.20	-12.20
Ae. provocans						
Slope of time line	-0.16	-7.60	-0.03	-4.50	-0.01	-2.20
Slope of temperature line	0.22*	-19.20	-0.31	-10.30	-0.14	-3.80
Ae. euedes						
Slope of time line	0.47*	0.09*	-0.02	-0.01	-0.04	-0.02
Slope of temperature line	0.32*	-7.41	-0.50	-2.28	-0.19	-0.10
Ae. excrucians						
Slope of time line	-0.19	-17.0	-0.85	-12.10	-0.88	-12.10
Slope of temperature line	1.64*	-0.02	-1.97	-37.90	-3.21	-28.10
Ae. fitchii						
Slope of time line	-1.29	0.02*	0.13*	-0.43	-0.08	-0.02
Slope of temperature line	-3.02	0.01*	0.33*	-1.17	-0.10	-0.04
Ae. canadensis						
Slope of time line	0.55*	-0.01	0.18*	0.12*	0.11*	-0.05
Slope of temperature line	-1.50	-3.10	1.56*	8.28*	8.28*	7.01*

* Positive slope of the regression lines indicates increasing larval numbers with time or temperature.

Discussion

For all sites, the invertebrate cone trap collected significantly (P<0.05) fewer larvae of *Ae. stimulans*, *Ae. euedes*, *Ae. provocans*, *Ae. excrucians* and *Ae. fitchii* than did the bucket and cylinder samplers. In the open field pool the invertebrate cone trap collected significantly younger (P<0.05) larvae of *Ae. excrucians* and *Ae. fitchii* than did the bucket and cylinder samplers. The bucket and cylinder samplers performed similarly in the categories of analysis (i.e. percentage

species composition, instar of larvae and numbers of larvae in relation to temperature and time). The inverse relationship of larval numbers versus time and temperature was believed to indicate the natural situation within a spring *Aedes* spp. pool.

The invertebrate cone trap was a passive device, left in the pool and emptied at convenience. Despite ease of use, its temperature dependency prevented it from being an effective sampling device to indicate population trends of spring *Aedes* larvae.

As the bucket and cylinder samplers performed equally, the ease of use, cost of the sampler and time needed to sample became the criteria to determine the preferred device. The cylinder sampler had to be left in position for up to 30 minutes at low water temperatures to allow for collection of relatively inactive early instar larvae, i.e. for ten samples, five hours were required to sample a pool. A bucket sample could be taken in less than a minute regardless of temperature. The cylinder sampler proved to be cumbersome when compared to the easily maneuvered bucket. The bucket sample was inexpensive (i.e. three to five dollars) compared to the cylinder which was specially constructed (i.e. fifty to one hundred dollars depending on materials used in construction). The bucket sampler is therefore recommended as the best of the three sampling devices for collecting larvae of spring *Aedes* spp., if densities per unit area are not required.

Acknowledgements

The authors thank Dr. Blair Helson and Dr. Harold Newson for their advice and suggestions. Technical assistance was provided by Misses Lesley Slight, Rhonda Gilhen and Daphne Witson and Mr. Hans Biberhoffer. This project was supported by a grant from the Ontario Pesticides Advisory Committee through the Ontario Ministry of the Environment.

References

Arnott, J.J. and J.D. Edman. 1978. Mosquito vectors of dog heartworm, *Dirofilaria immitis* in Western Massachusetts. Mosquito News, 38: 222-230.

Artsob, H.L., L. Spence, G. Surgeoner, B. Helson, J. Thorsen, L. Grant and C. Th'ng. 1982. Snowshoe hare virus activity in Southern Ontario. Canada Journal Public Health, 73: 345-349.

Chodorowski, A. 1969. The desiccation of ephemeral pools and the rate of development of *Aedes communis* larvae. Polskie Archiwum Hydrobiologii, 16: 7-91.

Downing, J.D. 1977. A comparison of the distribution of *Aedes canadensis* larvae within woodland pools using the cylindrical sampler and the standard pint dipper. Mosquito News, 37: 362-366.

Enfield, M.A, and G. Pritchard. 1977. Methods for sampling immature stages of *Aedes* sp. (Diptera: Culicidae) in temporary ponds. Canadian Entomologist, 109: 1435-1444.

Haufe, W.O. 1957. Physical environment and behavior of immature stages of *Aedes communis* (Deg.) (Diptera: Culicidae) in subarctic Canada. Canadian Entomologist, 89: 129-139.

Helson, B.V. and G.A. Surgeoner. 1986. Efficacy of Cypermethrin for the control of mosquito larvae and pupae and impact on non-target organisms, including fish. Mosquito News, 2: 269-275.

Hocking, B. 1960. Northern biting flies. Annual Review of Entomology, 5: 135-152.

Lakhani, K.H. and M.W. Service. 1974. Estimated mortalities of immature stages of *Aedes cantans* (Mg.) (Diptera: Culicidae) in a natural habitat. Bulletin Entomological Research, 64: 265-276.

Laird, M. 1982. Biting flies in Canada: Health effects and economic consequences. N.R.C.C. No. 19248 Associate Committee on Science for Environmental Quality, 157 pp.

Pritchard, G. and P.J. Scholefield. 1983. Survival of *Aedes* larvae in constant area ponds in Southern Alberta (Diptera: Culicidae). Canadian Entomologist, 115: 183-188.

Roberts, D.R. and J.E. Scanlon. 1979. Field studies on the population biology of immature stages of six woodland mosquito species in the Houston, Texas area. Mosquito News, 39: 26-34.

SAS Institute Inc. 1982. SAS User Guide: Statistics, 1982 Edition. SAS Institute Inc., Cary, NC, 584 pp.

Service, M.W. 1976. Mosquito ecology - Field sampling methods. J. Wiley and Sons, N.Y. and Toronto, 583 pp.

Taylor, N.J. 1979. A rapid efficient area sampler for estimating absolute abundance of floodwater mosquito larvae. Environmental Entomology, 8: 1004-1006.

Wagner, V.E. and H.D. Newson. 1975. Field investigations on *Aedes fitchii* mosquito populations in woodland pool ecosystems. Mosquito News, 35: 518-522.

Welch, H.E. and H.G. James. 1960. The Belleville trap for quantitative samples of mosquito larvae. Mosquito News, 20: 23-26.

Wood, D.M., A.T. Dang and R.A. Ellis. 1979. The Insects and Arachnids of Canada. 6. The Mosquitoes of Canada (Diptera: Culicidae). Agriculture Canada Publication 1686, 390 pp.

(Received 25 March 1991; accepted 27 September 1991)

AN INTRODUCTION TO THE BOREAL FOREST IN ONTARIO[1]

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Abstract *Proc. ent. Soc. Ont.* 122:73-86

Boreal forest covers approximately 80% of the total forested lands in Canada and comprises 73% of Ontario's commercially productive forest area. In Ontario, biological activity in the boreal zone is constrained by cold temperatures and a short growing season. Upland mineral soils are generally fragmental, acidic and poor in available nutrients; decomposition rates are slow, and active incorporation of humic material into mineral soil is minimal. Organic soils cover extensive areas where the water table is persistently high; much of the boreal region in Ontario consists of forested peatlands. The boreal forest is characterized by a predominance of coniferous tree species, although broadleaved trees form a significant canopy component in southern portions of the region. Although plant species diversity is relatively low, ecosystem structure ranges from simple to complex.

Introduction

The boreal forest or "taiga" forms a broad, circumpolar band in the northern hemisphere, immediately to the south of the arctic tundra. It comprises approximately 25% of the world's closed-canopy forests (Janz 1990). About 75% of the worldwide boreal region is found in the Soviet Union, with slightly more than 20% occurring in North America. Boreal forest covers approximately 4.5 million km^2 of Canada, occupying 61% of the total Canadian land area and about 80% of the total forested lands (Bickerstaff *et al.* 1981).

Within Canada, the boreal forest extends as a broad, continuous, east-west belt that covers portions of all provinces and territories except New Brunswick, Prince Edward Island and Nova Scotia. It can be subdivided into three broad subregions (Rowe 1972; Bickerstaff *et al.* 1981):

a) the **Continuous Boreal Forest**, a subregion of closed-canopy, conifer-dominated forest occupying the central band of the east-west boreal belt.
b) the **Forest-Grassland Transition** subregion, occurring in the interior of the continent between the prairie grasslands in the south and the continuous boreal forest. Within this subregion, the forest is characterized compositionally by the predominance of broadleaved tree species, especially trembling aspen (*Populus tremuloides* Michx.), and physiognomically by a gradation from open parkland to intermittent clumps of trees within the true prairie.

[1] Paper No. 1 of the Entomological Society of Ontario's symposium on boreal entomology held at the Annual General Meeting 1990 in Sault Ste. Marie, Ontario.

c) the **Forest-Barrens Transition** subregion, occupying the northern edge of the boreal region, which is transitional to the treeless arctic tundra. This subregion reflects a northward physiognomic gradient from open, lichen woodland to discontinuous patches of stunted trees as the continental treeline is reached.

In Ontario, the boreal forest region contains elements of both the Continuous Boreal Forest and the Forest-Barrens Transition (Fig. 1). This paper will emphasize the features of the Continuous Boreal Forest, which comprises the majority of Ontario's boreal region and constitutes the boreal environment of highest importance to most human activities. For example, 73% of Ontario's commercially productive forest area is boreal, contributing to a forest products industry that employed more than 70,000 people and produced greater the $9 billion worth of goods in 1985 (Smyth and Campbell 1987).

FIGURE 1. Forest regions of Ontario (after Rowe 1972).

Climate

The climate associated with the world's boreal forests is characterized by short, moderately warm, moist summers and long, extremely cold, dry winters (Bonan and Shugart 1989). Regional climatic conditions may be modified by continental and maritime influences. Across Eurasia and most of North America, the boundaries of the boreal belt seem best defined by temperature (Janz 1990) -- the northern and southern limits of the boreal forest approximately coincide, respectively, with the July 13°C and 18°C isotherms (Ritchie and Hare 1971; Larsen 1980). These boundaries also represent, in general, the average summer and winter frontal positions of the arctic air mass (Bryson 1966).

Typically, most of the total annual precipitation in the boreal region falls during the summer months. Snow cover can be light, especially in continental areas (where temperature extremes are greatest). The resultant combination of cold temperatures and a thin, insulating snow cover can create conditions of severe moisture and thermal stress for perennial vegetation and overwintering fauna. Even during the growing season, cold soil temperatures, often associated with the presence of permafrost in northern portions of the boreal zone, can result in high soil moisture content and inhibited root metabolism.

In Ontario's boreal forest, a short growing season compresses biological activity into a 2-4 month period. For 5-6 months of the year, the mean daily temperature is below 0°C and the net radiation balance is negative (Anonymous 1982). Annual mean daily temperature is near or below 0°C, with a pronounced seasonal variation between temperature extremes (approximately 70°C to 80°C). Mean annual precipitation ranges from less than 60 cm near the Manitoba border to slightly greater than 85 cm in the lee of Lake Superior (Anonymous 1982). The northern portion of Ontario's boreal region (approximated by the Forest-Barrens Transition subregion) lies within the zone of discontinuous permafrost.

Landscape and Soils

When considering the landscape and soil features that characterize the boreal zone, it helps to recall that, with very few areas of exception worldwide, the entire boreal region has been repeatedly glaciated during the last million years. The last major glaciation, known in North America as the Wisconsinan, began to recede approximately 20,000 years ago. Due to climatic fluctuations during the period of recession, which resulted in various re-advances and stationary positions, much of the current boreal region of Ontario was still covered by ice as recently as 7,000 to 9,000 years ago. It has only been 5,000 to 7,000 years since post-glacial water levels receded across large areas of northeastern and northwestern Ontario (Dyke and Prest 1987).

Contemporary northern Ontario landscapes display the results of this intense glacial activity. They are typically irregular and undulating, and are dominated by countless water bodies and wetlands that reflect the interrupted nature of most drainage networks (Fig. 2). In much of Ontario, the Continuous Boreal Forest is underlain mainly by the Precambrian Shield, which was intensively scoured by glaciation. In these areas, topography can be very rugged and broken, with upland soil cover dominated by shallow, fragmental, coarse-textured tills (Fig. 3).

Because of the relatively short history of pedogenic activity, mineral soils in the boreal region are often juvenile in their characteristics. Podzolization is the dominant pedogenic process on upland, boreal soils (Fig. 4) and most are classified as either brunisols or podzols (Larsen 1980). In general terms, these soils are acidic and poor in available nutrients, especially nitrogen.

FIGURE 2. Aerial view of the Continuous Boreal Forest on the Precambrian Shield in northern Ontario.

FIGURE 3. Upland soils on the Precambrian Shield consist primarily of coarse-textured, highly fragmental till. Shallow soil deposits (i.e. <1 m deep) overlying bedrock are common.

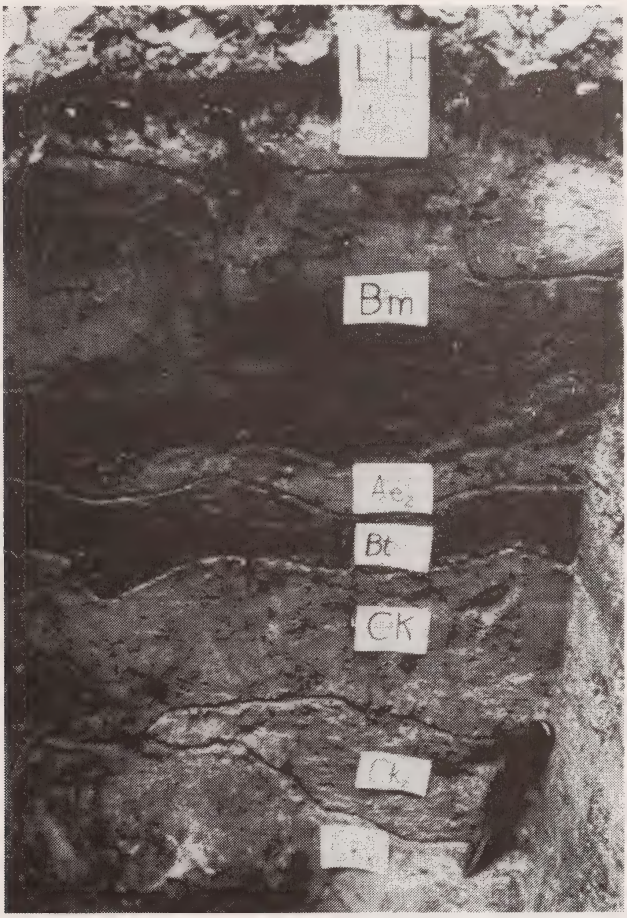

FIGURE 4. With moderate amounts of precipitation and generally coarse-textured parent materials, podzolization is the predominant soil-forming process in Ontario's upland boreal soils. Most of these soils are considered juvenile, with poorly developed characteristics.

Luvisols occur frequently in fine-textured mineral deposits, often on low-lying site positions; these soils can be very productive.

Decomposition rates are slow in boreal ecosystems, mainly due to limiting temperature and moisture conditions (although litter composition and soil chemistry are also important factors). Upland soil humus forms are typically mors, with much of the decomposition activity contributed by fungi and little direct incorporation of humic material into the mineral strata. Within boreal forest ecosystems, a large proportion (up to 60%) of the total carbon and nitrogen is contained in the litter and humus layers (Barbour *et al.* 1980). Consequently, feeder roots of woody vegetation are concentrated at the top of the soil profile. Mycorrhizal associations, which facilitate nutrient

uptake in relatively unproductive soils, are characteristic of many vascular plant species in the boreal forest.

An abundance of surface water in ponds, lakes and wetlands reflects the restricted drainage and high water tables that are common in low-lying areas of the boreal region. Boreal wetlands tend to become colonized by *Sphagnum* mosses and/or graminoid species, typically leading to the development of swamps, bogs and fens (Jeglum *et al.* 1974). On these sites, accumulation of partially decomposed peat leads to the development of organic soils (Fig. 5). Bog and fen vegetation communities are characterized by distinctive and highly specialized species, such as pitcher plant (*Sarracenia purpurea* L.), sundew (*Drosera* spp.), bog laurel (*Kalmia polifolia* Wang.) and cotton grass (*Eriophorum* spp.), which are adapted to acidic, nutrient-poor, water-logged substrates.

FIGURE 5. On sites with persistently high water tables, partially decomposed organic materials accumulate as peat deposits. In northern Ontario, peat deposits rarely exceed 3-5 m in depth and typically consist of *Sphagnum* mosses, sedges and woody debris. The range pole is marked in 10 cm bands.

Vegetation

In comparison with forest regions at lower latitudes, plant species diversity in the boreal forest is low, and productivity moderate. Total annual productivity of tree species in the Continuous Boreal Forest of Ontario averages about 1.6 m^3/ha (Bickerstaff *et al.* 1981), compared with about 1.8 m^3/ha in the Great Lakes-St. Lawrence forest region and 2.7 m^3/ha in the southern Deciduous

forest region. In terms of net annual primary productivity, the boreal forest average of around 800 g/m^2 is comparable with savanna and open woodland, about 2/3 that of deciduous temperate forest and about 1/3 that of tropical rain forest (Whittaker 1975).

At a gross level, perhaps the most distinctive feature of the boreal forest is its mosaic pattern, with the scale of patches ranging from tens of metres to tens of kilometres (Fig. 6). To a large extent, especially at higher latitudes, site-related factors influence the expression of vegetation conditions. Spatial variability and ecosystem dynamics within the boreal forest are also strongly influenced by the history of local disturbance. Catastrophic disturbance, by fire, insect infestation or windthrow, is an integral part of the natural ecology of the boreal forest (Fig. 7). The reproductive strategies, life spans, successional dynamics and nutrient cycling capabilities of major boreal plant species (and boreal ecosystems in general) are well adapted to post-fire renewal. Even-aged, post-fire vegetation communities constitute a characteristic element of the boreal forest (Fig. 8).

FIGURE 6. The boreal landscape is characterized by a mosaic of vegetation communities, reflecting the influence of soil/site conditions as well as disturbance history.

The vegetation stereotype of the boreal region is one of extensive coniferous (especially spruce- (*Picea* spp.) and fir- (*Abies* spp.) dominated) forests (Whittaker 1975; Barbour *et al.* 1980). In Ontario, this image is increasingly accurate northward along a north-south transect in the boreal zone. In the southernmost portions of the Continuous Boreal Forest, however, mixed stands containing a significant proportion of broadleaved tree species cover large areas of the landscape (Fig. 9). More than one-third of the Vegetation Types recognized in northeastern Ontario's Clay

FIGURE 7. Wildfire is an important natural process in boreal forest ecology. The life histories of many boreal plant species are adapted to respond to fire disturbances.

Belt Forest Ecosystem Classification (FEC) are mixedwoods, indicating the compositional diversity of boreal forest stands (Jones *et al.* 1983). In the Northwestern Ontario Forest Ecosystem Classification (NWO FEC), more than half of the Vegetation Types contain a broadleaved component (Sims *et al.* 1989). The main coniferous tree species in northern Ontario include jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*Picea glauca* (Moench) Voss), balsam fir (*Abies balsamea* (L.) Mill.) and tamarack (*Larix laricina* (Du Roi) K. Koch). Broadleaved tree species include balsam poplar (*Populus balsamifera* L.), trembling aspen and white birch (*Betula papyrifera* Marsh.).

Compared with the deciduous forests of southern Ontario and the mixed forests of the Great Lakes-St. Lawrence region, stand structure in the boreal forest can be relatively simple. For example, in dense stands of small, even-aged, narrow-crowned conifers (characteristically black spruce), stand structure often consists of two strata -- the tree canopy and a continuous carpet of thick moss or lichen ground cover -- with virtually no herb or shrub layers (Fig. 10). The forest-floor layer (mosses, lichens and non-decomposed organic matter) is a critical structural component of the boreal forest, influencing energy flow, nutrient cycling and moisture status (Bonan and Shugart 1989). Complex stand structure is encountered in stands where diffuse crowns (e.g., trembling aspen) or canopy openings (e.g., senescent stands) reduce the moss cover and permit the development of a secondary spruce/fir canopy and/or a dense tall-shrub stratum.

FIGURE 8. Even-aged conifer stands of post-fire origin constitute a classic image of the boreal forest. These stands display relatively low species and structural diversities.

In the boreal forest of Ontario, species composition and structure are most variable in the understory. In mixedwood or hardwood stands, herb- and shrub-rich understories develop where diffuse canopies permit the transmission of light to the forest floor. In Ontario, broadleaved species such as green alder (*Alnus crispa* (Ait.) Pursh), beaked hazel (*Corylus cornuta* Marsh.), mountain maple (*Acer spicatum* Lam.), bush honeysuckle (*Diervilla lonicera* Mill.) and large-leaved aster (*Aster macrophyllus* L.) often dominate these communities. In dense, upland pine/spruce/fir stands, the understory commonly consists of a thick carpet of feathermoss (e.g., *Pleurozium schreberi* (Brid.) Mitt.) with sparse herb and shrub cover. Herbaceous species such as bunchberry (*Cornus canadensis* L.) and Canada mayflower (*Maianthemum canadense* Desf.)

FIGURE 9. Mixedwood stands, consisting of hardwood and conifer species and often comprising several age classes, constitute a large proportion of the southernmost, upland boreal forest.

tend to occur in association with ericaceous shrub species such as blueberry (*Vaccinium* spp.) (Fig. 11), Labrador tea (*Ledum groenlandicum* Oeder) (Fig. 12) and snowberry (*Gaultheria hispidula* (L.) Muhl.). Balsam fir is often persistent in the shrub layer of these densely shaded stands.

Throughout northern Ontario, a large proportion of the land area is covered by poorly drained wetlands. Much of the Continuous Boreal Forest consists of forested peatlands and the vast majority of the Forest-Barrens Transition zone comprises wetland ecosystems. In Ontario, numerous wetland site types can be identified based on vegetation physiognomy and dominance (Jeglum *et al* 1974). These include a range of forested wetland types (e.g., swamps, treed fens and treed bogs); vegetation communities in which herb, graminoid and/or shrub species are predominant (e.g., wet meadows, open fens and open bogs); and semi-aquatic ecosystems, such as marshes. In forested wetland communities of the Ontario boreal region, the most abundant tree species are black spruce (Fig. 13) and tamarack; eastern white cedar (*Thuja occidentalis* L.) occurs occasionally.

FIGURE 10. An open understory, dominated by a continuous carpet of feathermoss (e.g. *Pleurozium schreberi* (Brid.) Mitt.), is a common feature of even-aged, upland black spruce and jack pine stands.

Summary

Vegetation patterns throughout the boreal forest, as well as structure and function within individual boreal ecosystems, reflect a complex of environmental and biotic factors found at high latitudes. Climate, soil moisture, nutrient availability, forest floor cover and catastrophic disturbances such as wildfire and insect outbreaks all contribute to the dynamics of the boreal forest. Interactions among unique combinations of these factors result in the mosaic pattern of vegetation conditions which is the boreal forest.

FIGURE 11. Species of the family Ericaceae are well represented in the boreal flora. Blueberries (*Vaccinium myrtilloides* Michx. and *V. angustifolium* Ait.) are common in all but the most nutrient-rich habitats.

FIGURE 12. *Ledum groenlandicum* Oeder occurs commonly on acidic, nutrient-poor sites with periodic water table fluctuations.

FIGURE 13. Wetland forest types cover large areas of the boreal zone. In Ontario, wetland forest cover is particularly prevalent in the Clay Belt region of NE Ontario and in the Hudson Bay Lowland. Black spruce and tamarack are the dominant tree species of boreal wetlands.

Acknowledgements

I wish to thank P.A. Addison, V.G. Nealis, R.A. Sims and P. Uhlig for critical reviews of this manuscript. Rob Lowe prepared Figure 1. Photographs were provided from the Northwestern Ontario Forest Ecosystem Classification collection.

References

Anonymous. 1982. Canadian Climate Normals (1951 - 1980). Volume 2 & 3. Environment Canada, Atmospheric Environment Service, Ottawa, Ontario, 908 pp.

Barbour, M.G., J.H. Burk and W.D. Pitts. 1980. Terrestrial Plant Ecology. Benjamin/Cummings Publishing Company, Incorporated, Menlo Park, California, 604 pp.

Bickerstaff, A., W.L. Wallace and F. Evert. 1981. Growth of Forests in Canada, Part 2: A Quantitative Description of the Land Base and the Mean Annual Increment. Environment Canada, Canadian Forestry Service, Petawawa, Ontario. Information Report PI--X-1, 136 pp.

Bonan, G.B. and H.H. Shugart. 1989. Environmental factors and ecological processes in boreal forests. Annual Review of Ecology and Systematics, 20: 1-28.

Bryson, R.A. 1966. Airmasses, streamlines, and the boreal forest. Geographic Bulletin, 8: 228-269.

Dyke, A.S. and V.K. Prest. 1987. Paleogeography of Northern North America, 18,000 - 5,000 years ago. Geological Survey of Canada, Ottawa, Ontario. Map 1703A, scale 1:12,500,000.

Janz, K. 1990. The present state of boreal forests. Transcript of paper presented at International Symposium on Boreal Forests, Arkhangelsk, USSR. July 1990, 23 pp.

Jeglum, J.K., A.N. Boissonneau and V.F. Haavisto. 1974. Toward a Wetland Classification for Ontario. Environment Canada, Canadian Forest Service, Sault Ste. Marie, Ontario. Information Report O-X-215, 54 pp. + appendices.

Jones, R.K., G. Pierpoint, G.M. Wickware, J.K. Jeglum, R.W. Arnup and J.M. Bowles. 1983. Field Guide to Forest Ecosystem Classification for the Clay Belt, Site Region 3E. Ontario Ministry of Natural Resources, Toronto, Ontario, 161 pp.

Larsen, J.A. 1980. The Boreal Ecosystem. Academic Press, New York, N.Y., 500 pp.

Ritchie, J.C. and F.K. Hare. 1971. Late-Quaternary vegetation and climate near the arctic treeline of northwestern North America. Quaternary Research, 1: 331-342.

Rowe, J.S. 1972. Forest Regions of Canada. Department of the Environment, Canadian Forestry Service, Ottawa, Ontario. Publication No. 1300, 172 pp.

Sims, R.A., W.D. Towill, K.A. Baldwin and G.M. Wickware. 1989. Field Guide to the Forest Ecosystem Classification for Northwestern Ontario. Ontario Ministry of Natural Resources, Toronto, Ontario, 191 pp.

Smyth, J.H. and K.L. Campbell. 1987. Selected Forestry Statistics, Ontario: 1987. Environment Canada, Canadian Forestry Service, Sault Ste. Marie, Ontario. Information Report O-X-387, 106 pp + appendices.

Whittaker, R.H. 1975. Communities and Ecosystems, 2nd edition. Macmillan Publishing Co., Inc., New York, N.Y., 385 pp.

(Received 4 November 1991; accepted 28 January 1992)

CONE BEETLES IN THE BOREAL FOREST: AT THE CUTTING EDGE (COLEOPTERA: SCOLYTIDAE: *CONOPHTHORUS* SPP.)[1]

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Abstract *Proc. ent. Soc. Ont.* 122:87-100

In the south central area of the Boreal Forest Region, the red pine cone beetle, *Conophthorus resinosae* Hopkins (Coleoptera: Scolytidae), feeds on the cones of red pine. Within this area, the shoots of jack pine are attacked by what has been recognized as *C. banksianae* McPherson. Taxonomic evidence from karyotype, allozyme, and cuticular hydrocarbon characters, and from re-examination of the characters in the original diagnosis, clearly support the synonymy of *C. banksianae* with *C. resinosae*. Jack pine shoot attacks by *C. resinosae*, first discovered about 40 years ago, are likely an emergency response by the cone beetles as a result of forest cutting and reforestation practices that remove small stands of red pine and replace them with jack pine. However, *C. resinosae* does not appear to be fully adapted to jack pine shoots, which may explain the confined distribution of jack pine shoot attacks and the widespread decline of beetle populations after a few years.

Introduction

Throughout most of the south central area of the Boreal Forest Region, where it meets the northern edge of the Great Lakes-St. Lawrence Forest Region (Rowe 1972), the red pine cone beetle, *Conophthorus resinosae* Hopkins (Coleoptera: Scolytidae) feeds on the cones of red pine, *Pinus resinosa* Ait. Red pine, however, is a relatively rare tree within this section of the boreal forest and is usually found in isolated mixedwood stands or with jack pine, *P. banksiana* Lamb., on warm dry sites (Horton and Bedell 1960). Beginning in the early 1950s, shoot attacks by cone beetles in young jack pine stands were first noticed near Nipigon, Ontario (Thomas and Lindquist 1956). Herdy and Thomas (1961) described the life history and shoot attack behaviour of *Conophthorus* on jack pine, a species morphologically indistinguishable from the red pine cone beetle. McPherson *et al.* (1970a,b) concluded that differences in the adult size and behaviour of the twig-infesting species merited its recognition as *C. banksianae* McPherson. Persistent doubts about the validity of *C. banksianae* (Wood 1982), coupled with the failure to find morphological taxonomic characters (Thomas 1957, 1967, 1971; Herdy 1963; Wood 1982), led Wood (1989) to place *C. banksianae* in synonymy with *C. resinosae*. However, species-specific differences in the

[1] Paper No. 2 of the Entomological Society of Ontario's symposium on boreal entomology held at the Annual General Meeting 1990 in Sault Ste. Marie, Ontario.

shoot attack behaviour between the two putative species appear to occur (Mattson 1989) - once again clouding their taxonomic status.

In this paper, I will argue that the species known as *C. banksianae* is nothing more, at present, than an ecophenotypic variant of *C. resinosae*, a variant that likely has risen in prominence because of forest cutting and forest regeneration practices in the boreal forest. To advance this case, I will present data on the geographical distribution of jack pine shoot attacks, review recent additional studies of taxonomic characters of *Conophthorus*, discuss the shoot attack behaviour of *Conophthorus* under resource-rich and resource-poor conditions, and implicate the role of human activities in changing the feeding habits of *Conophthorus*. To maintain clarity in discussion, I will retain the two species names: *C. resinosae* referring to populations that feed in red pine cones, and *C. banksianae* referring to populations that feed in jack pine shoots, until the taxonomic evidence is presented that *C. banksianae* should be a synonym of *C. resinosae*.

Distribution of *C. resinosae*, *C. banksianae*, and their Hosts

The geographic distributions of *C. resinosae* and *C. banksianae* are shown in Figures 1 and 2, respectively. Locality data to produce these maps were obtained from: 1) published records (Bright 1976; Wood 1982), 2) published reports and unpublished data from the Forest Insect and Disease Survey, Forestry Canada and, 3) labels of specimens held in insect collections of museums and institutions in North America. To facilitate future studies of this group, a list of locality records from museum specimens is given in the Appendix. The geographic distributions of red and jack pine, obtained from Little (1971), are shown in Figures 3 and 4, respectively.

The distribution of *C. resinosae* suggests that it is found throughout the range of red pine. In contrast, the geographic distribution of *C. banksianae* indicates that it is confined to isolated and localized parts of northern Michigan, and has been verified in a few locations elsewhere in the Lake States, and to localized parts of the provinces of Ontario and Quebec. Two striking features of the distribution of *C. banksianae* are: 1) this species is totally absent from the vast tracts of jack pine west of Ontario, and 2) it is essentially confined to the northern distribution of red pine. The confined distribution of *C. banksianae* can suggest at least three things: 1) *C. banksianae* may be present west of Ontario, but has simply been overlooked, 2) the distribution of *C. banksianae* is coincident with the botanical and ecological features of jack pine in the northern range of red pine, or 3) *C. banksianae* is really *C. resinosae* that has adapted to jack pine in this region.

The first possibility, that *C. banksianae* occurs west of Ontario appears remote because 30-35 years of forest insect surveys have never recorded *C. banksianae* in jack pine in the Prairie provinces (Forest Insect and Disease Survey, Forestry Canada, unpublished data; B. Moody, pers. comm., Forestry Canada, Ottawa, Ontario). Considering the second possibility, the distribution of *C. banksianae* does not appear to follow the known genetic and phenotypic variability in jack pine (Schoenike 1976; Rudolf and Yeatman 1982). Jack pine populations have been divided into the Great Lakes and Western geographic regions (Critchfield 1985), and *C. banksianae* occurs in both of them. Much of the variation in jack pine occurs in the Great Lakes region (Schoenike 1976; Hyun 1979), where *C. banksianae* is found. In fact, Wright (1972) proposed that the populations of jack pine in the upper and the lower peninsulas of Michigan represent distinct races. Outside this region, jack pine is fairly uniform from eastern Alberta to Quebec, with increased variation in the Maritime provinces and in New England where the distribution is fragmented (Schoenike 1976).

The third possibility, that *C. banksianae* is a synonym of *C. resinosae* deserves further attention because McPherson *et al.* (1970a,b) erected *C. banksianae* on the basis of questionable data and a dubious interpretation of those data.

FIGURE 1. Geographic range of *Conophthorus resinosae* Hopkins in North America.

Taxonomic Evidence for *C. banksianae*

McPherson *et al.* (1970b) named the new species *C. banksianae* McPherson stating as diagnosis: "This species [*C. banksianae*] is nearly identical to *C. resinosae* Hopkins but differs in mean size, behaviour and preferred host". Differences in life history parameters were also observed.

Although most adults of *C. resinosae* are larger than *C. banksianae* (Herdy 1963; McPherson *et al.* 1970a; Wood 1982), "the overlap is sufficient to make measurements useless for distinguishing cone from tip beetles" (McPherson *et al.* 1970a). In addition, consideration should

FIGURE 2. Geographic range of *Conophthorus banksianae* McPherson in North America.

be given to the fact that *C. resinosae* can also breed in twigs and that the less favourable habitat and abnormal host (jack pine) could account for the size difference in what is recognized as *C. banksianae* (Wood 1982). McPherson *et al.* (1970a) found that the immature life stages of *C. banksianae* were present in the field for a much longer time than those of *C. resinosae*. It was also noted that *C. banksianae* was apparently bivoltine, whereas *C. resinosae* was not. However an extensive re-investigation of the life history of *C. banksianae* (de Groot and Borden 1991) has clearly demonstrated that *C. banksianae* is not bivoltine and that the duration of the life stages of both species is about the same.

McPherson *et al.* (1970a) also observed a host acceptance behaviour in *C. banksianae* differing from *C. resinosae*. They found that field populations of *C. banksianae* fed only on shoots of jack pine, red pine, scotch pine (*P. sylvestris* L.), or ponderosa pine (*P. ponderosa* (Laws.)), whereas *C. resinosae* was known to attack only the cones and shoots of red pine (Lyons

FIGURE 3. Botanical range of red pine, *Pinus resinosa* Ait., in North America, from Little (1971).

1956; McPherson *et al.* 1970a). In a series of field cage experiments, McPherson *et al.* (1970b) found that *C. banksianae* showed a preference for the shoots of jack pine, and did not attack red pine cones. On the other hand, *C. resinosae* showed a preference for red pine cones. However, these experiments should be regarded as inconclusive because: 1) the preference of *C. banksianae* for jack pine shoots may have been induced because they had fed on jack pine shoots just prior to testing, whereas *C. resinosae* had no such feeding experience (see Papaj and Prokopy 1989 for a review of insect feeding on host-choice 'decisions'), 2) the sample sizes used in the experiments were small (each host/structure and insect combination was tested in only 4 cages), thus reducing the possibility of rejecting a null hypothesis, and 3) host data for species diagnosis is made difficult because both species were able to attack jack pine shoots (in fact, *C. resinosae* attacked more shoots in the tests than did *C. banksianae*), and both species reproduced in jack pine shoots.

The search for taxonomic characters to confirm the validity of *C. banksianae* has provided negative results. Karyotype analysis (de Groot and Ennis 1990) failed to reveal any morphological or numerical differences in the chromosomes between *C. banksianae* and *C. resinosae*, but did establish large differences for the white pine cone beetle, *C. coniperda* (Schwarz). Similarly,

FIGURE 4. Botanical range of jack pine, *Pinus banksiana* Lamb., in North America, from Little (1971).

cuticular hydrocarbon analysis (Page *et al.* 1990), and isozyme analysis (de Groot *et al.* 1992) did not confirm recognition of *C. banksianae*, but did again reaffirm the validity of *C. coniperda*. Taxonomic characters on the male genitalia are absent for all three species (unpublished data). These studies all support the synonymy of *C. banksianae* with *C. resinosae* (Wood 1989).

Mattson (1989) observed that *C. banksianae* "handled" new shoots in a manner entirely different from *C. resinosae*, and suggested *C. banksianae* would maintain its unique shoot-handling

behaviour on other pine species as implied by McPherson (1968). However, it remains to be demonstrated that these differences are species unique, and not different responses of different populations of *C. resinosae* to host plant availability and suitability over time.

Shoot Attack Behaviour of *Conophthorus*

All species of cone beetles, except *C. terminalis* Flores and Bright, (Flores and Bright 1987), feed on the cones of pines (de Groot 1986) but cone production by pines is highly variable and large cone crops usually occur once every 3-10 years (Fowells 1965). To cope with cone crop failures, or cone scarcity, several species of cone beetles have extended quiescence (Mattson 1980), and some, like *C. resinosae*, have evolved a strategy to attack shoots.

Populations of *C. resinosae* invariably increase in number until limited by the number of cones (Mattson 1971, 1978, 1980). Large fluctuations in cone crop size from year to year can be dampened because *C. resinosae* may enhance cone production because of their destruction of immature cones of the previous year (Mattson 1978). Nevertheless, in some years, after extensive cone losses have occurred, females finish ovipositing in red pine shoots. Attacks on shoots following the depletion of cone resources have also been observed for *C. ponderosae* Hopkins (Struble 1947) and *C. coniperda* (Godwin and Odell 1965). Oviposition in red pine shoots by *C. resinosae* is negligible when cones are abundant (Mattson 1980). When *C. resinosae* attack shoots, few beetle progeny are produced, thus in the following year there are usually many more cones available than beetles (Mattson 1980). Oviposition in red pine shoots does not appear to contribute largely to the annual population growth of *C. resinosae*, but functions as a survival strategy to prevent extinction in poor cone crop years (Mattson 1980).

Cone beetles attack cones early in the spring when cones are small. In addition to offering advantages over other insect competitors (Mattson 1986), cone attacks early in the spring take advantage of the high nutritional content of red pine cones (Dickmann and Kozlowski 1969a). As the cones age, they become less suitable for food, not only because of a decreasing concentration of nutrients, but also because of an increase in cellulose, lignin and terpenes (Dickmann and Kozlowski 1969b; Mattson 1978). Consequently, beginning about early July, *C. resinosae* switch away from apparently 'available' cones to shoots because cones have become an unsuitable resource (Mattson 1989). When this occurs, its shoot-handling behaviour exactly parallels the behaviour of *C. banksianae* (Mattson 1989).

Mattson (1989) found that most *C. banksianae* entered shoots about 6 mm below the base of the bud, whereas *C. resinosae* entered randomly along the shoots, but seldom near the bud. Furthermore, there was a tendency for *C. resinosae* to attack new shoots near the shoot base earlier in the growing season and close to the top later. It is interesting to note that the shoot-handling behaviour of *C. resinosae* near the end of the oviposition period is similar to *C. banksianae* at the beginning of its oviposition period. Another difference was that *C. banksianae* extended their galleries into the bud of jack pine while *C. resinosae* did not extend galleries into red pine buds (Mattson 1989). To determine if these behaviours are species-specific, it would be essential to demonstrate that their behaviours are the same in each others' host. One striking difference between the two species that both Mattson (1989) and McPherson *et al.* (1970a) observed was that *C. banksianae* attack new shoots only after they complete elongation, whereas, *C. resinosae* attack new shoots in all stages of development.

In northern lower Michigan, there is a delay between feeding and the beginning of oviposition (McPherson *et al.* 1970a; Mattson 1989). Why *C. banksianae* apparently needs to wait until shoot

elongation has ceased remains a mystery (Mattson 1989). In the study of McPherson *et al.* (1970a), an abnormally cold spring (McPherson 1968) may have delayed the development of the beetles until shoot elongation was complete (de Groot and Borden 1991). Mattson (1989) offered three hypotheses why *C. banksianae* need to wait until shoot elongation is complete: 1) elongating pine shoots are too narrow to support the beetles, 2) buds are the only important food source and therefore the beetles must wait for bud development to conclude, and 3) host plant defences may prevent beetles from attacking shoots until they are fully elongated. These hypotheses, however, do not explain the shoot attack behaviour of *C. banksianae* elsewhere. Throughout northern Ontario (Herdy and Thomas 1961; de Groot and Borden 1991) and northeastern Quebec (personal observations), *C. banksianae* primarily attack the previous year's shoot. Thus, they have a resource that will support them, they do not require buds as a food source, and host plant defences are quickly overcome because they girdle the old growth before feeding distally from the entrance hole (de Groot and Borden 1991). In Ontario, shoot attacks in the new growth occasionally occur, but almost always before shoot elongation is complete (de Groot and Borden 1991). The variation in behaviour between *C. banksianae* in northern lower Michigan and elsewhere may be attributable to the differences in jack pine (see above; Wright 1972).

Considering the flexibility or 'plasticity' in behaviour of *C. resinosae* to adapt to shoots when cones are unavailable or unsuitable, the ability of *C. resinosae* to attack and reproduce in jack pine shoots (McPherson *et al.* 1970b) and to attack white pine cones and shoots (Tabashnik *et al.* 1985), the failure to detect taxonomic characters for *C. banksianae*, and finally, the variation in behaviour of *C. banksianae* that obscures some of the apparent differences between the two species (Mattson 1989), it would be more prudent to regard the populations of *Conophthorus* on jack pine as *C. resinosae* rather than cling to the notion that they are a distinct species. However, none of these arguments help explain why *C. resinosae* attack the shoots of jack pine. Why should it switch tree species and possibly risk greater mortality through predation, desiccation, etc., rather than switch to red pine shoots when red pine cones become scarce? I postulate that *C. resinosae* attacks jack pine shoots as a survival strategy, but in order for tree-host switching to occur, a large-scale reduction or removal of red pine trees in an area is required. Such reductions in the forest can occur naturally by fire, or by clear-cutting the forest and converting the stand to other species such as jack pine. After such a disturbance event, residual populations of *C. resinosae* are left at the cutting edge.

At the Cutting Edge

The geographic distribution of *C. banksianae* (Fig. 1), or more correctly, *C. resinosae* on jack pine, clearly shows that almost all of the attacks on jack pine occur at the northern fringe of red pine. Red pine in this area usually occurs in small and isolated stands, largely restricted to lake landscapes or rough topography (Haddow 1948; Horton and Bedell 1960; Van Wagner 1971; Butson *et al.* 1987; Bergeron and Brisson 1990). Horton and Bedell (1960) suggested that many marginal stands of red pine extending into the Boreal Forest Region are relict on warm sites with a favourable soil or fire regime. Haddow (1948) described red pine at the northern limit of its range in Ontario as a decadent and retreating species, and provides several historical accounts of red pine stands fast disappearing from the northern boundary because of cutting and subsequent fires. As a result of extensive logging and changes in fire frequency, large areas that were once occupied by red pine have converted to other species (Chapeskie *et al.* 1989). Following fires, red pine must re-establish by seeding from mature trees that have escaped fire (Horton and Bedell

1960; Van Wagner 1971). Red pine is well adapted to surface fires of light to moderate density, but in the boreal forest the fire regime is dominated by crown fires or high-intensity surface fires (Van Wagner 1971; Bergeron and Brisson 1990). The fire regime in the boreal forest favours black spruce, *Picea mariana* (Mill.) BSP, and jack pine.

Jack pine, the prodigal son of Ontario forestry (Galloway 1986), has clearly captured the hearts and reforestation minds of foresters (see Smith and Brown 1984). Utilization and reforestation of this species has increased dramatically since World War II (Moore 1984). The silvics of jack pine require a type of harvesting that creates an after-effect similar to fire; therefore, jack pine in the boreal forest is managed exclusively under the clear-cut system (Galloway 1986). Forest managers tend to plant jack pine after site preparation especially on better sites (Smith and Brown 1984), often as single species (monoculture) plantations.

Clear-cutting of the boreal forest, followed by planting of jack pine have probably led to an increase in the incidence of jack pine feeding by *C. resinosae*. Characteristically, *C. resinosae* is found in young trees, often in plantations (Herdy and Thomas 1961; McPherson *et al.* 1970a; Hall and Wilson 1974), and seldom on mature trees (personal observations). My personal observations in northern Ontario of monoculture jack pine plantations infested with *C. resinosae* indicate that almost all of these areas formerly had a small component of red pine. Typically, red pine, which would be a minor component of the forest, would not be replaced on its former site because it would not be available as nursery stock for the site region, and because the financial and technical capability for its natural replacement (e.g. tree seed method) in the boreal forest was lacking (Fred Pinto, pers. comm., Ontario Ministry of Natural Resources, North Bay). By and large, forest management decisions are made by the unit forester, and published evidence of small-scale conversions of red pine to jack in forest management plans, or elsewhere, would be incomplete or absent (Fred Pinto, pers. comm.). Cone beetles left at these cut-over sites face three response options or 'decisions': 1) migrate to find other red pines, 2) die, or 3) feed on the new hosts on the site. It may be adaptive for *C. resinosae* to 'choose' to attack jack pine shoots rather than to search unsuccessfully for red pine cones (a superior host) because total reproductive success is likely to be higher (see Roitberg 1990).

The red pine cone beetle may have used jack pine as a strategy to survive natural catastrophic disturbances in the forest before the arrival of commercial logging. No doubt, the awareness of jack pine shoot attack is a result of the substantial increase in forest insect and disease surveys conducted after World War II. However, at the same time an increase in the incidence of jack pine shoot attacks could have been caused by an increase in artificial forest regeneration. Jack pine silviculture tends to do two things differently than natural forest fires to favour populations of *C. resinosae* on jack pine: 1) the silviculture would not decimate cone beetle populations, whereas fires would likely destroy most of the population (less than 10% of the jack pine sites are prepared by prescribed burning (Galloway 1986)), and 2) the silviculture provides cone beetles with only one host (jack pine) to choose from, whereas fires in red pine-jack pine forests can leave unburned areas of red pine (Bergeron and Brisson 1990) and thus some refuge for cone beetles to feed on red pine cones.

Although *C. resinosae* uses jack pine shoots, this strategy appears to be maladaptive. Wood (1982) implies that jack pine could be an unfavourable host and thus produce smaller insects, which is a notable characteristic of *C. resinosae* on jack pine (Herdy and Thomas 1961; McPherson *et al.* 1970a). Jack pine shoots may also lead to a reduction in adult fecundity and survival, but this has not been examined. If *C. resinosae* is maladapted to use jack pine shoots over a long period, it may explain why jack pine has not been used throughout its range (Fig. 1).

Furthermore, it may explain why *C. resinosae* seldom persists in plantations for more than 4-5 years (personal observations).

Cone beetles in the Boreal Forest Region were at the wrong side of the cutting edge, because of the decline in self-sustaining red pine stands, and because it does not sustain itself on jack pine. The general decline of red pine in the Boreal Forest Region appears, however, to be an account of the past. An increased interest in forest biodiversity, and ecological and public concerns about 'climate change' and 'old-growth' white pine and red pine forests will, hopefully, result in the return of red pine to their sites - good news for the red pine cone beetle.

Acknowledgements

I thank William J. Mattson for many fruitful and thought-provoking discussions about the behaviour and taxonomy of *C. resinosae*/*C. banksianae*. I greatly appreciate the guidance and wisdom of my major professor, John H. Borden, during my Ph.D. studies, on which this paper is based. I am grateful to curators noted in the appendix for sending locality data, and the many individuals of the Forest Insect and Disease Survey, Forestry Canada, for allowing me to use their data on the distribution of *C. resinosae* and *C. banksianae*.

References

Arnett, R.H. and G.A. Samulenson. 1970. Directory of Coleoptera Collections of North America (Canada through Panama). Department of Entomology, Purdue University, Lafayette, Indiana, 122 pp.

Bergeron, Y. and J. Brisson. 1990. Fire regime in red pine stands at the northern limit of the species' range. Ecology, 7: 1352-1364.

Bright, D.E. 1976. The insects and arachnids of Canada. Part 2. The bark beetles of Canada and Alaska, Coleoptera: Scolytidae. Canada Department of Agriculture, Biosystematics Research Institute, Publication 1576, 241 pp.

Butson, R.G., P. Knowles and R.E. Farmer, Jr. 1987. Age and size structure of marginal disjunct populations of *Pinus resinosa*. Journal of Ecology, 75: 685-692.

Chapeskie, D.J., D.F. Galley, J.R. Mihell, N.W. Quinn and H.H. Struik. 1989. A silvicultural guide for the white pine and red pine working groups in Ontario. Ontario Ministry of Natural Resources, Science and Technology Series, Volume 6, 102 pp.

Critchfield, W.B. 1985. The late Quaternary history of lodgepole and jack pines. Canadian Journal of Forest Research, 15: 749-772.

de Groot, P. 1986. Cone and twig beetles (Coleoptera: Scolytidae) of the genus *Conophthorus*: an annotated bibliography. Canadian Forestry Service, Information Report FPM-X-76, 36 pp.

de Groot, P. and J.H. Borden. 1991. Life history of the jack pine tip beetle, *Conophthorus banksianae* McPherson (Coleoptera: Scolytidae): Implications for species status. Canadian Entomologist, 123: 211-217.

de Groot, P. and T.J. Ennis. 1990. Cytotaxonomy of *Conophthorus* (Coleoptera: Scolytidae) in eastern North America. Canadian Entomologist, 122: 1131-1135.

de Groot, P., G.T. Harvey and P.M. Roden. 1992. Genetic divergence among eastern North American cone beetles, *Conophthorus* (Coleoptera: Scolytidae). Canadian Entomologist, 124: 189-199.

Dickmann, D.I. and T.T. Kozlowski. 1969a. Seasonal changes in the macro- and micronutrient composition of ovulate strobili and seeds of *Pinus resinosa*. Canadian Journal of Botany, 47: 1547-1554.

Dickmann, D.I. and T.T. Kozlowski. 1969b. Seasonal variations in reserve and structural components of *Pinus resinosa* cones. American Journal of Botany, 56: 515-520.

Flores, J.L. and D.E. Bright. 1987. A new species of *Conophthorus* from Mexico: descriptions and biological notes (Coleoptera: Scolytidae). The Coleopterists Bulletin, 41: 181-184.

Fowells, H.A. 1965. Silvics of forest trees of the United States. United States Department of Agriculture, Agricultural Handbook No. 271, 762 pp.

Galloway, R. 1986. Jack Pine Working Group. Silvicultural Guide Series. Ontario Ministry of Natural Resources, 40 pp.

Godwin, P.A. and T.M. Odell. 1965. The life history of the white pine cone beetle, *Conophthorus coniperda*. Annals of the Entomological Society of America, 58: 213-219.

Haddow, W.R. 1948. Distribution and occurrence of white pine (*Pinus strobus* L.) and red pine (*Pinus resinosa* Ait.) at the northern limit of their range in Ontario. Journal of the Arnold Arboretum, 29: 217-226.

Hall, D.J. and L.F. Wilson. 1974. Within-generation mortality of the jack pine tip beetle, *Conophthorus banksianae* McPherson, in Michigan. Great Lakes Entomologist, 7: 89-93.

Heppner, J.B. and G. Lammas. 1982. Acronyms for world museum collections of insects, with an emphasis on Neotropical Lepidoptera. Bulletin of the Entomological Society of America, 28: 305-315.

Herdy, H. 1963. A comparative study of the external anatomy of *Conophthorus* Hopkins (Coleoptera: Scolytidae) with a taxonomic interpretation of species in Ontario. Interim Research Report, Forest Insect Laboratory, Canada Department of Forestry, 70 pp.

Herdy, H. and J.B. Thomas. 1961. The seasonal development of a species of *Conophthorus* Hopkins (Coleoptera: Scolytidae) in the shoots of jack pine, *Pinus banksiana* (Lamb.), in Ontario. Canadian Entomologist, 93: 936-940.

Horton, K.W. and G.H.D. Bedell. 1960. White and red pine. Ecology, Silviculture, and Management. Canada Department of Northern Affairs and National Resources, Forestry Branch, Bulletin 124, 185 pp.

Hyun, J.O. 1979. Geographic variation of jack pine (*Pinus banksiana* Lamb.). pp. 107-116. *In:* Proceedings of the Thirteenth Lake States Forestry Tree Improvement Conference. United States Department of Agriculture, Forest Service, General Technical Report, NC-50, 171 pp.

Little, E.L. 1971. Atlas of United States Trees. Volume 1. Conifers and Important Hardwoods. United States Department of Agriculture, Forest Service, Miscellaneous Publication Number 1146, 9 pp. + plates.

Lyons, L.A. 1956. Insects affecting seed production in red pine. Part I. *Conophthorus resinosae* Hopk. (Coleoptera: Scolytidae). Canadian Entomologist, 88: 599-608.

Mattson, W.J. 1971. Relationship between cone crop size and cone damage by insects in red pine seed production areas. Canadian Entomologist, 103: 617-621.

Mattson, W.J. 1978. The role of insects in the dynamics of cone production of red pine. Oecologia, 33: 327-349.

Mattson, W.J. 1980. Cone resources and the ecology of the red pine cone beetle, *Conophthorus resinosae* (Coleoptera: Scolytidae). Annals of the Entomological Society of America, 73: 390-396.

Mattson, W.J. 1986. Competition for food between two principal cone insects of red pine, *Pinus resinosa*. Environmental Entomology, 15: 88-92.

Mattson, W.J. 1989. Contributions to the biology of the jack pine tip beetle, *Conophthorus banksianae* (Coleoptera: Scolytidae), in Michigan. pp. 117-132. *In:* G.E. Miller (compiler) Proceedings of the 3rd cone and seed insects working party conference. Forestry Canada, Victoria, B.C., vii + 242 pp.

McPherson, J.E. 1968. Non-morphological separation of a *Conophthorus* population found on jack pine from *Conophthorus resinosae* Hopkins, with a description of a new species *Conophthorus banksianae* (Coleoptera: Scolytidae). Ph.D. Dissertation, Michigan State University, University Microfilms Incorporated, Ann Arbor, Michigan.

McPherson, J.E., L.F. Wilson and F.W. Stehr. 1970a. A comparison between *Conophthorus* shoot-infesting beetles and *Conophthorus resinosae* (Coleoptera: Scolytidae). I. Comparative life history studies in Michigan. Canadian Entomologist, 102: 1008-1015.

McPherson, J.E., F.W. Stehr and L.F. Wilson. 1970b. A comparison between *Conophthorus* shoot-infesting beetles and *Conophthorus resinosae* (Coleoptera: Scolytidae). II. Reciprocal host and resin toxicity tests; with a description of a new species. Canadian Entomologist, 102: 1016-1022.

Moore, W.S. 1984. Status and potential of jack pine in Ontario. pp. 1-13. *In:* C.R. Smith and G. Brown (co-chairmen) Jack Pine Symposium. Proceedings of the Canada-Ontario Joint Forestry Research Committee Symposium, Timmins, Ontario, Canadian Forestry Service, Department of the Environment, O-P-12, 195 pp.

Page, M., L.J. Nelson, M.I. Haverty and G.J. Blomquist. 1990. Cuticular hydrocarbons of eight species of North American cone beetles, *Conophthorus* Hopkins. Journal of Chemical Ecology, 16: 1173-1198.

Papaj, D.R. and R.J. Prokopy. 1989. Ecological and evolutionary aspects of learning in phytophagous insects. Annual Review of Entomology, 34: 315-350.

Roitberg, B.D. 1990. Variation in Behavior of Individual Parasitic Insects: Bane or Boon? pp. 25-39. *In:* M. Mackauer, L.E. Ehler, J. Roland (editors) Critical Issues in Biological Control. Intercept Ltd. Andover, Hants, United Kingdom, xvii + 330 pp.

Rowe, J.S. 1972. Forest regions of Canada. Department of the Environment, Publication, No. 1300, 172 pp.

Rudolf, T.D. and C.W. Yeatman. 1982. Genetics of jack pine. United States Department of Agriculture, Forest Service, Research Paper, WO-38, 64 pp.

Schoenike, R.E. 1976. Geographic variation in jack pine. University of Minnesota Agricultural Experiment Station, Technical Bulletin, 304, 49 pp.

Smith, C.R. and G. Brown (editors). 1984. Jack Pine Symposium. Proceedings of the Canada-Ontario Joint Forestry Research Committee Symposium, Timmins, Ontario, Canadian Forestry Service, Department of the Environment, O-P-12, 195 pp.

Struble, G.R. 1947. Twig damage in sugar pine caused by the cone beetle. Journal of Forestry, 45: 48-50.

Tabashnik, B.E., W.J. Mattson and J.R. Miller. 1985. Host acceptance behavior of the red pine cone beetle (*Conophthorus resinosae*). Entomologica Experimentalis et Applicata, 37: 3-7.

Thomas, J.B. 1957. The use of larval anatomy in the study of bark beetles (Coleoptera: Scolytidae). Canadian Entomologist, 89 (Supplement 5), 45 pp.

Thomas, J.B. 1967. A comparative study of gastric caeca in adult and larval stages of bark beetles (Coleoptera: Scolytidae). Proceedings of the Entomological Society of Ontario, 97: 71-83.

Thomas, J.B. 1971. The immature stages of Scolytidae: the genus *Conophthorus* (Coleoptera: Scolytidae). Canadian Entomologist, 103: 1021-1026.

Thomas, J.B. and O.H. Lindquist. 1956. Notes on bark beetles and associated insects feeding in pine shoots. Canada Department of Agriculture, Forest Biology Division, Bi-Monthly Progress Report, 12(4): 2.

Van Wagner, C.E. 1971. Fire and red pine. Proceedings of the Tall Timbers Fire Ecology Conference, 10: 221-224.

Wood, S.L. 1982. The bark and ambrosia beetles of North and Central America (Coleoptera: Scolytidae). A taxonomic monograph. Great Basin Naturalist, Memoir 6, 1359 pp.

Wood, S.L. 1989. Nomenclatural changes and new species of Scolytidae (Coleoptera), Part IV. Great Basin Naturalist, 49: 167-185.

Wright, J.W. 1972. Genetic variation in Michigan's native trees. Michigan Academy, 5: 61-69.

Appendix

Listed below are locality records for *C. banksianae* and *C. resinosae* from museum specimens and the museums where they are housed, with the names of curators in parentheses. Acronyms for the institutions were obtained from Heppner and Lamas (1982) and Arnett and Samulenson (1970). Specimens listed in Wood (1982) and verified by him are marked with an asterisk (*).

CNC	Canadian National Collection of Insects, Ottawa, Ontario. (Donald E. Bright).
FIDS-SSM	Forest Insect and Disease Survey, Sault Ste. Marie, Ontario. (Paul Syme).
FRLC	Forest Insect and Disease Survey, Fredericton, New Brunswick. (Edward Hurley).
MSUE	Michigan State University, East Lansing, Michigan. (Gregory A. Dahlem).
OSU	Ohio State University, Columbus, Ohio. (Charles A. Triplehorn).
PUL	Purdue University, West Lafayette, Indiana. (Arwin Provnsha).
SIUC	Southern Illinois University at Carbondale, Carbondale, Illinois. (John E. McPherson).
USNM	United States Museum of Natural History, Washington, D.C. (Donald M. Anderson).
UMAA	University of Michigan, Ann Arbor, Michigan. (Mark F. O'Brien).
UMSP	University of Minnesota, St Paul, Minnesota. (Philip J. Clausen).
UWM	University of Wisconsin-Madison, Madison, Wisconsin. (Steven Krauth).

***C. banksianae*. CANADA. Ontario**: Black Sturgeon Lake* (CNC), Chapleau (CNC, FIDS-SSM), Dryden (CNC, FIDS-SSM), Franz* (CNC), Gogama (CNC, FIDS-SSM), Hurkett (CNC), Oba* (CNC), Sault Ste. Marie* (FIDS-SSM). **UNITED STATES. Michigan**: Cadillac* (CNC, MSUE, USNM), Christensen Nursery*, Fife Lake* (CNC, MSUE, USNM), Grand Traverse Co* (CNC, MSUE, USNM), Kalkaska Co.* (CNC, MSUE, USNM), Wellston*, Wexford Co.* (MSUE, CNC, USNM). **Minnesota**: Cass Lake*, Ithasca Co.* **Wisconsin**: Three Lakes.*

***C. resinosae*. CANADA. Ontario**: Algoma Mills (CNC, FIDS-SSM), Burnt River* (CNC, FIDS-SSM), Camp Borden* (CNC), Carnarvon (CNC, FIDS-SSM), Carp*, Chalk River* (CNC, FIDS-SSM), Dorset* (CNC), Haley Station (CNC), Luden*, Manitoulin Island (CNC, FIDS-SSM), Midhurst (CNC), Midland* (CNC, FIDS-SSM), North Bay (CNC, FIDS-SSM), Parry Sound* (CNC), Sault Ste. Marie* (CNC, FIDS-SSM), Temagami* (CNC), Tobermory (FIDS-SSM). **Quebec**: Laniel*, St. Chrysostome (CNC), Kazubazua*. **New Brunswick**: Albert Co. (CNC, FRLC), Sunbury Co. (CNC), York Co. (CNC, FRLC). **Nova Scotia**: Kentville* (CNC, FRLC). **Prince Edward Island**: Murray Harbor, Kings Co. (CNC, FRLC). **UNITED STATES. Indiana**: Underwood, Clark Co. (PUL). **Michigan**: Cheboygan Co. (UMAA), Harrison (UMSP), Keweeno Co.* (USNM), Marquette (UMSP), Raco* (UWM), Rapid River (UMSP), Wexford Co. (UMSP). **Minnesota**: Brainerd (UMSP), Cass Lake* (USNM), Ithasco Co.* (USNM). **New Hampshire**: Effingham* (USNM). **New Jersey**: Greenwood Lake*. **New York**: East Hampton* (USNM), Farmingdale* (USNM). **North Carolina**: McDowell Co. (SIUC). **Pennsylvania**: Troy (OSU). **West Virginia**: Huttonsville* (USNM). **Wisconsin**: Chippewa Falls*, Dane Co. (UWM), Lincoln Co. (UWM), Oneida Co. (UWM), Three Lakes (UMSP), Lake du Flambeau (UMSP), Vilas Co. (UWM), Wood Co. (UWM).

(Received 6 August 1991; accepted 1 November 1991)

A SIMPLE METHOD FOR DISTINGUISHING BETWEEN FEMALE AND MALE FOUR-SPOTTED SAP BEETLES, *GLISCHROCHILUS QUADRISIGNATUS* SAY (COLEOPTERA: NITIDULIDAE)

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Proc. ent. Soc. Ont. 122:101-102

The sap or picnic beetle *Glischrochilus quadrisignatus* Say is an economically important pest of several fruits and vegetables in Ontario (Foott and Hybsky 1976) and is a serious threat to various crops in Québec (Rivard *et al.* 1982). It is a univoltine species in Ontario, overwintering as an adult in the top 2.5 cm of soil (Foott and Timmins 1977). Ears of field corn missed by harvesting machinery are the principle reproductive sites. Adult sap beetles are able to detect the presence of buried corn down to a depth of 15 cm. The larvae feed on fermenting corn and can develop only when there is a growth of fungal mycelia on the food source (Luckmann 1963). Adults infest both sweet and field corn, entering holes made by other insects or birds (Dougherty and Brett 1966). Several species of fungi have been found in close association with the larvae, pupae and adults of *G. quadrisignatus* and it has been inferred that this beetle serves as a vector for both *Fusarium* wilt in corn (Windels and Windels 1974) and *Gibberella* corn ear rot (Attwater and Busch 1983). The adult beetles also bore into ripe tomatoes, raspberries and other soft fruit, embedding themselves deep in the flesh. They have even been reported as an occasional primary pest in apple orchards in Ontario (Wilde 1970). Sap beetles are difficult to control because they attack fruit immediately before harvest when insecticides cannot be used.

Experiments were conducted to investigate the possibility of controlling sap beetle populations, in the field, using a trap baited with chemical attractants. A chemical that attracted only one sex would be of little use in field situations if baited traps were the only method of controlling the insect population. For this reason, a quick, easy method for distinguishing between females and males was developed. Four-spotted sap beetle specimens were obtained from the Montreal, Québec and London, Ontario areas.

This technique is based on differences in morphology between male and female mouthparts, and allows the separation of adult and late pupal stages using a low power dissecting microscope. Female sap beetles have two small teeth on their mandibles (Fig. 1A), but males have three (Fig. 1B). With experience this difference can be seen without the use of a microscope and proved to be a rapid and efficient technique. Dissections of the internal genitalia of 15 male and 15 female beetles confirmed that the number and shape of mandibular teeth were accurate determinants of sap beetle sex.

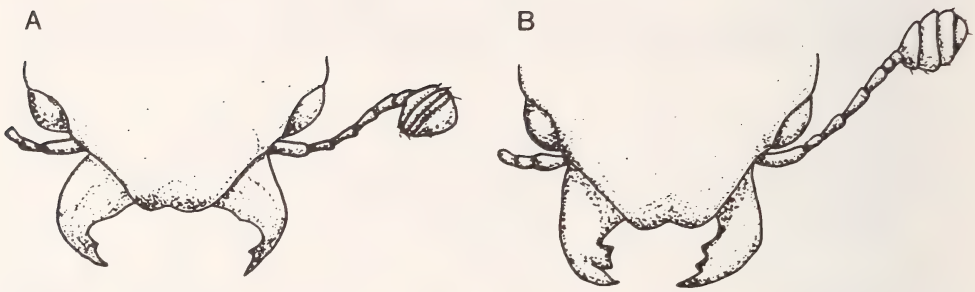

FIGURE 1. Part of the head showing the mandibles of (A) female (magnification x 18.5) and (B) male (magnification x 15) of the four-spotted sap beetle *Glischrochilus quadrisignatus* (dorsal view).

References

Attwater, W.A. and L.V. Busch. 1983. Role of the sap beetle *Glischrochilus quadrisignatus* in the epidemiology of gibberella corn ear rot. Canadian Journal of Plant Pathology, 5: 158-163.

Dougherty, D.M. and C.H. Brett. 1966. Nitidulidae associated with sweet corn in North Carolina and influences affecting their damages to this crop. North Carolina Agriculture Experimental Station Bulletin 171, 40 pp.

Foott, W.H. and H.E. Hybsky. 1976. Capture of *Glischrochilus quadrisignatus* (Coleoptera: Nitidulidae) in bait traps, 1970-1974. Canadian Entomologist, 108: 837-839.

Foott, W.H. and P.R. Timmins. 1977. Biology of *Glischrochilus quadrisignatus* (Coleoptera: Nitidulidae) in southwestern Ontario. Proceedings of the Entomological Society of Ontario, 108: 37-44.

Luckmann, W.H. 1963. Observations on the biology and control of *Glischrochilus quadrisignatus*. Journal of Economic Entomology, 56: 681-686.

Rivard, I., R.O. Paradis, G. Bélair and M. Mailloux. 1982. Les ravageurs des cultures fruitières du Québec en 1981. Société d'Entomologie du Québec, 37: 158-162.

Windels, C.E. and M.B. Windels. 1974. Nitidulid beetles as vectors for *Fusarium* species in corn. Annual Proceedings of the American Phytopathological Society, 1: 131.

Wilde, W.H.A. 1970. *Glischrochilus quadrisignatus*, the sap beetle, a pest of apple in Ontario. Canadian Entomologist, 102: 112.

(Received 22 October 1990, accepted 30 January 1991)

AN IMPROVED METHOD FOR PRODUCING SMALL, CONSISTENT SAMPLES OF HOSTS FOR PRESENTATION TO THE EGG PARASITOID, *TRICHOGRAMMA MINUTUM*

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Proc. ent. Soc. Ont. 122:103-104

While conducting research on the efficacy of the egg parasitoid, *Trichogramma minutum* Riley (Hymenoptera: Trichogrammatidae), we developed a method for presenting individual parasitoids with small but consistent numbers of eggs of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae), with no damage to and minimal wastage of host eggs. Previously, we prepared host eggs for parasitization by spreading non-toxic white glue on cardboard strips, sprinkling eggs on the glue, and allowing the glue to dry (Laing and Eden 1990). The cardboard strips were then cut to the area containing the desired number of eggs. This process was messy, time consuming, imprecise, and resulting in numbers of damaged host eggs at the cut edges of the cardboard pieces. In this note, we describe the fabrication of a new sampling strip which overcomes these problems.

We separated a 100 page, 3M, Post-it® message pad (76x127 mm) into 10 page sections (Fig. 1). For each section, we measured the width of the adhesive area, then we created the desired size of the sample surface by cutting off part of the adhesive area (e.g., for ca. 250 *E. kuehniella* eggs per strip, all but 4 mm of adhesive area would be cut off) (Fig. 1). We passed each 10 page set through an Olympia® 3104B paper shredder, which cuts them into packets of strips approximately 6 mm wide. In the absence of a shredder, this step can be done with scissors or a paper guillotine. Each set of 10 pages produces ca. 20 packets of sample strips, so a whole pad can yield ca. 2,000 sample strips. The pieces of adhesive surface remaining from the fabrication of the sample strips are large enough (ca. 10x127 mm surface) for presentation of host eggs used to maintain parasitoid populations in culture.

Eggs are quickly and easily affixed to a sample strip by passing the adhesive area through host eggs stored in a vial. Excess eggs are removed by tapping the strip against the side of the vial. The strip can be used immediately, as there is no waiting for the adhesive to dry. Individual strips are easily handled by the ca. 60 mm long non-adhesive section, and experimental details pertaining to the sample can be written in this area (Fig. 1).

Depending on the amount of adhesive area cut off during fabrication, a sample strip can hold 80-1100 eggs of *E. kuehniella*. A batch of strips is relatively consistent with respect to the number of host eggs they will hold (e.g., 174±18 eggs of *E. kuehniella* per strip [N=10]). Females of both *T. minutum* and *T. evanescens* Westwood readily parasitize host eggs attached to the strips, and adults of *Trichogramma* spp. can walk on the adhesive surface without sticking to it.

The strips have successfully been used with the eggs of *E. kuehniella* and *Sitotroga cerealella* (Olivier) [Lepidoptera: Gelechiidae] as well as with the larger eggs of *Manduca sexta* (Johannson) [Lepidoptera: Sphingidae] and *Lambdina fiscellaria* Guene [Lepidoptera: Geometridae]. The technique should be suitable for use with any material of small particle size when a small, consistent and undamaged sample is required for rearing or experimental work.

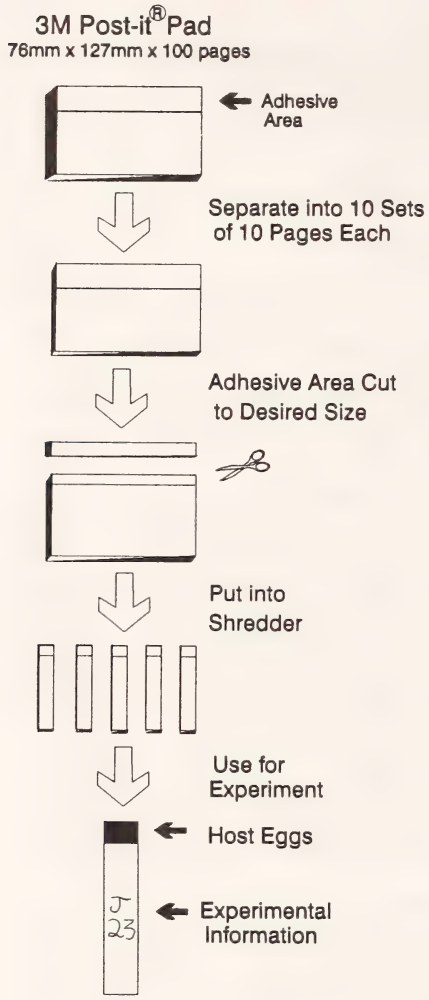

FIGURE 1. Manufacturing process for host-egg sampling strips.

Reference

Laing, J.E. and G.M. Eden. 1990. Mass-production of *Trichogramma minutum* Riley on factitious host eggs. pp. 10-24 *In*: S.M. Smith, J.R. Carrow and J.E. Laing (Eds.). Inundative release of the egg parasitoid, *Trichogramma minutum* (Hymenoptera: Trichogrammatidae), against forest insect pests such as the spruce budworm, *Choristoneura fumiferana* (Lepidoptera: Tortricidae): The Ontario project 1982-1986. Memoirs of the Entomological Society of Canada, No. 153, 87 pp.

(Received 8 October 1991, accepted 10 October 1991)

ANTHIDIUM MANICATUM (HYMENOPTERA: MEGACHILIDAE), AN INTERESTING NEW CANADIAN RECORD

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Proc. ent. Soc. Ont. 122:105-108

On July 5, 1990 I saw a pair of unusual bees, swiftly patrolling around a clump of woolly lamb's ears (*Stachys* sp.)[1] in the weed garden at the University of Guelph. I collected the bees and with the help of Dr. S. A. Marshall, we identified them as male and female specimens of the wool-carder bee, *Anthidium manicatum* (Linnaeus). Shortly afterwards, I saw several more wool-carder bees flying amongst a large patch of woolly lamb's ears behind the Zoology Annex, a short distance from the weed garden. I resisted collecting additional specimens so as not to extirpate the species from the country. This "nets off" policy paid off, as the following year on June 14, 1991 I was able to collect 2 males and a female from the Zoology Annex site. I also found an additional male specimen in the University of Guelph Insect Collection. Its label reads: Ontario, Freelton, 23. Vi. 1984, M.T. Kasserra. Freelton is about 20 km south of the University of Guelph.

A. manicatum was named by Linnaeus as *Apis manicata* in his *Systema Naturae* of 1758. Fabricius defined the genus *Anthidium* in 1804 and Latreille later designated *A. manicata* as the Type-species in 1810. *A. manicatum* has an intrinsic talent for expanding its range. Originally just known in Europe, it is now established from Scandinavia to Morocco and from Great Britain east to oriental Siberia. In recent times it has been recorded at such diverse places as the Canary Islands, Uruguay, Argentina, southeastern Brazil from Rio Grande do Sul north to Minas Gerais and also New York state (Pasteels 1977; Severinghaus *et. al.* 1981; Bettina Blochtein pers. comm.). This is easily explained as *A. manicatum* is what one would call an "opportunistic nester" as it uses ready made holes to nest (Shuckard 1866, Severinghaus *et. al.* 1981). According to Kirby and Spence (1870) "Sir Thomas Cullum discovered the nest of one inside the lock of a garden-gate." Bettina Blochtein (pers. comm.) says that *A. manicatum* was introduced into Brazil last century in the furniture that Old World European immigrants brought with them. It is hypothesized that *A. manicatum* was introduced to the University of Guelph in construction materials originating in the United States. Bricks and their pallets used in the recent construction of the Environmental Biology-Horticulture Complex seem to be the most likely source. These may have harboured nests imported from Ohio. These new records could also represent a natural extension of *A. manicatum*'s increasing range in eastern North America (Severinghaus *et al.* 1981).

A. manicatum has a distinct habitus. The robust male is about 14 mm in length (the female, is, uncharacteristically for bees, somewhat smaller), the claws are bifid, the abdomen is edged laterally by curls of tan-coloured short dense hairs and the yellow maculations on the black abdominal terga become successively larger towards the apical segment (see Figure 1). Additionally, the male possesses two lateral processes on tergite 6 and three processes on the terminal tergite. According to Pechuman (1967) who translated Sitowski's work (1947), a male

[1] There seems to be some confusion in the literature as to the proper nomenclature of woolly lamb's ears. *Stachys lanata*, *Stachys olympica*, and *Stachys byzantina* (Labiatae) appear to be synonyms.

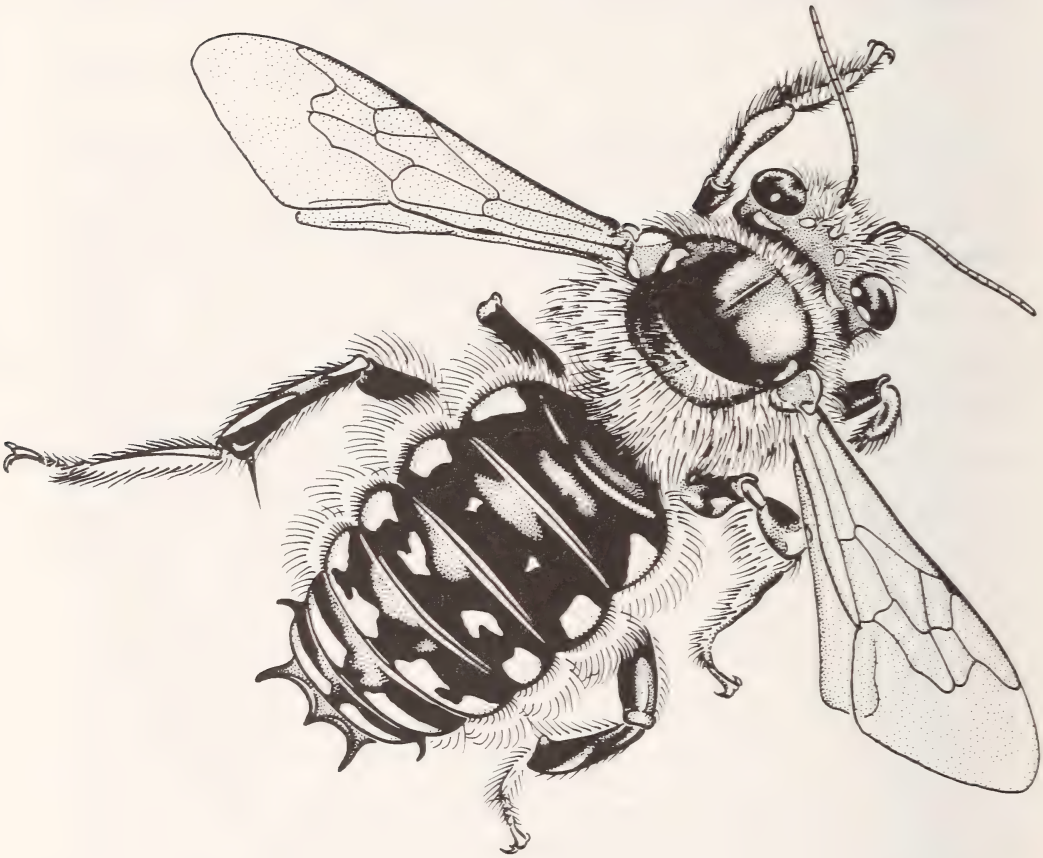

FIGURE 1. *Anthidium manicatum* (Linnaeus), male.

bee will drive out any intruder (except conspecific females) from his territory. Males have been observed knocking offenders to the ground. Bumble bees (*Bombus*) and honey bees (*Apis*) are frequent targets. *A. manicatum*'s ferocious attacks sometimes kills the trespassers or renders them unable to fly. *A. manicatum* uses its mandibles and abdominal processes as weapons during the deadly duels. The male also uses his abdominal spines to pull up the female's abdomen during

mating (Severinghaus *et al.* 1981). *A. manicatum* has an interesting natural history. Unlike other megachilid bees which line their nests with cut pieces of leaves, the female chews the silky hairs from the woolly lamb's ears leaves and then rolls them into a ball to be carried to the nest cavity. This is invariably a pre-existing cavity where she uses the material as a lining. Hence the name 'wool-carder' a reference to the process during wool manufacturing where the wool is "carded" between spiked brushes prior to spinning. In New York there are two generations per year (Severinghaus *et. al.* 1981). In Brazil, the males have been observed hiding in snapdragon flowers (*Antirrhinum majus*) to await unsuspecting females (Bettina Blochtein pers. comm.). The population at the University of Guelph appears to have become established at least for two years following its introduction. No other Canadian specimens of this bee were previously present in the extensive holdings of the University of Guelph, the Royal Ontario Museum, or the Canadian National Collection in Ottawa. It is hard to explain its absence except by its absence since it is such an obvious and attractive insect.

Acknowledgements

I would like to especially thank Dr. Peter G. Kevan and Dr. S.A. Marshall for their encouragement and guidance. In addition, I would also like to thank Bettina Blochtein, PUC University, Porto Alegre, Brazil and the many other people who responded to our query on the BITNET "BEE-L". Mr. D. Hamilton took photographs of the bees and J.T. Smith provided useful criticisms.

References

Fabricius, J.C. 1804. Systema Piezatorum secundum ordines, genera, species, adjectis synonymis, locis, observationibus, descriptionibus. Brunsvigae, Reichard, 439 pp.

Kirby, W. and Spence, W. 1870. An introduction to entomology or elements of the natural history of insects. 7th edition. Longmans, Green and Co. London, 607 pp.

Latreille, P.A. 1810. Considérationes générales sur l'ordre naturel des animaux composant les classes des Crustacés, des Arachnides et des Insectes avec un tableau méthodique de leurs genres disposés en familles. Schoell, Paris, 444 pp.

Linnaeus, C. (Carl von Linné). 1758-1759. Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis... 10th edition. reformata Holmiae, impensis L. Salvii. 2 volumes. Paged continuously.

Pasteels, J.J. 1977. Une revue comparative de l'éthologie des Anthidiinae nidificateurs de l'ancien monde [Hymenoptera, Megachilidae]. Annales de la societe Entomologique de France. Soc., 13(4): 651-667.

Pechuman, L.L. 1967. Observations on the behaviour of the bee *Anthidium manicatum* (L.) Journal of the New York Entomological Society, 75: 68-73.

Shuckard, W.E. 1866. British Bees: an introduction to the study of the natural history and economy of the bees indigenous to the British Isles. Lovell Reeve & Co., London, 371 pp. + 15 plates.

Severinghaus, L.L., Kurtak, B.H. and Eickwort, G.C. 1981. The reproductive behaviour of *Anthidium manicatum* (Hymenoptera: Megachilidae) and the significance of size for territorial males. Behavioral Ecology and Sociobiology, 9: 51-58.

Sitowski, L. 1947. [*Anthidium*, as an exterminator of bees and bumble-bees gathering honey.] Rocznik nauk Rolniczych i Lesnych, 49: 434-437. In Polish with an English summary.

(Received 3 September 1991; accepted 20 November 1991)

A NEW ONTARIO RECORD OF A SEED EATING BUG (HEMIPTERA: COREIDAE) AND OTHER EXAMPLES OF THE ROLE OF REGIONAL INSECT COLLECTIONS IN TRACKING CHANGES TO ONTARIO'S FAUNA

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Proc. ent. Soc. Ont. 122:109-111

Introduction

Regional insect collections, such as that at the University of Guelph, serve many roles. Fundamental research, education at several levels, data storage and reference immediately come to mind. Such roles demand that insect collections grow and improve in areas of research specialization, and are kept adequate for general reference and teaching. Tangible and important results, such as research publications and practical identifications, originate from actively maintained, specialized collections. Increasing the size and curatorial level of insect collections in a more general, less goal-oriented fashion is costly in terms of time, material, and space, often without the realization of short term results to justify this expense. In the long term, however, there is much to be gained through general collection development and growth through the addition of newly collected specimens, such as those submitted in student insect collections or accumulated through inventory work. It is the purpose of this note to illustrate the value of continually updated regional insect collections to the agencies and communities which support them.

***Leptoglossus occidentalis*: a formerly western seed eating bug which has spread into Ontario.**

Leptoglossus occidentalis Heidemann (Hemiptera: Coreidae) is a distinctive, univoltine leaf-footed bug which feeds on the seeds and cones of pines and other conifers. This species is a native pest in western North America, but has been expanding its range eastward since the 1950's (Schaffner 1967; Gall 1992). McPherson *et al.* (1990) record *L. occidentalis* from Illinois, Michigan and Indiana. Records in the University of Michigan Museum of Zoology show that it had been in that state at least since 1983. *Leptoglossus occidentalis* appears to have extended its range to Ontario shortly thereafter, and the first records in the University of Guelph collection are of specimens collected in houses in the Fall of 1985. This conspicuous species overwinters as adults in sheltered places and numbers of individuals often appear in houses or on south facing walls. Because of its large size and synanthropic habits, it often occurs in insect collections or is submitted to collection personnel for identification.

This potential pest was first recognised as present in Ontario due to general growth of the insect collection at University of Guelph. It was reliably identified to species on site because the collection included named specimens of *Leptoglossus* species from western Canada for definitive comparison. When this bug started to become common and was submitted to the collection by the OMAF diagnostic clinic, reference material and data concerning the entry and spread of the species was available in the collection. This large, conspicuous bug is only one of a very large number of insect species changing their distributions in response to climate change, habitat alteration or other factors. Insect collections allow for recognition of these changes, and provide the main source of historical insight into insect distributions.

The role of insect collections in tracking introduced insects.

Insect introductions, deliberate or accidental, are also tracked in the general collections. *Coccinella septempunctata* (L) (Coleoptera: Coccinellidae), for example, is a predaceous beetle intentionally introduced from Europe to United States to control aphids. Although the most recent introduction was 1971 (Gordon 1985) and to my knowledge this species has never been introduced to Ontario, records of this species in the University of Guelph collection date from 1982. *Coccinella septempunctata* is now among the most common ladybeetles added to the insect collection each year.

Leptoglossus occidentalis and *C. septempunctata* are just two of the thousands of species added to the collection annually, many of which will comprise our only record of the composition of, and changes to, Ontario's insect fauna. From a practical point of view, the value of insect collections in answering questions about the current distribution of potentially important predaceous, phytophagous or parasitic insects depends on the quality of their annual growth.

***Nicrophorus americanus*, *Polystoechotes punctatus*, and other losses to our fauna.**

Many conspicuous insects have apparently disappeared from our fauna. The giant lacewing, *Polystoechotes punctatus* (Fabricius) is represented by many specimens in the collection at University of Guelph, all collected before 1950. The most recent eastern North American specimen in the Canadian National Collection was collected in 1955. This spectacular insect may well have been extirpated from Ontario. The decline of the giant burying beetle, *Nicrophorus americanus* Olivier (Coleoptera: Silphidae), in North America is better documented (Davis 1980; Anderson 1982). Although this species is considered extirpated from much of eastern North America, there are specimens in the University of Guelph insect collection collected in southern Ontario as recently as 1972.

Conclusions

Most of our insects are far less conspicuous or well studied than the examples given above, in fact most of the insects in our insect collections are still very poorly known. Each well labelled specimen added to a regional insect collection represents new data of potential value. An insect collection is like a library, and the examples given here are comparable to picture books or "coffee table books". Just as the those types of books serve mainly as attractive indicators of the information held in libraries, the conspicuous insect examples given above merely indicate the irreplaceable volumes of information stored in growing and well maintained insect collections.

References

Anderson, R.S. 1982. On the decreasing abundance of *Nicrophorus americanus* Olivier (Coleoptera: Silphidae) in eastern North America. Coleopterist's Bulletin, 36(2): 362-365.

Davis, L.R. Jr. 1980. Notes on beetle distributions, with a discussion of *Nicrophorus americanus* and its abundance in collections (Coleoptera: Scarabaeidae, Lampyridae and Silphidae). Coleopterist's Bulletin, 34: 245-249.

Gall, W. 1992. Further eastern range extensions of *Leptoglossus occidentalis*. Great Lakes Entomologist, in press.

Gordon, R.D. 1985. The Coccinellidae (Coleoptera) of America north of Mexico. Journal of the New York Entomological Society, 93: 1-912.

McPherson, J.E., R.J. Packauskas, S.J. Taylor, and M.F. O'Brien. 1990. Eastern range extension of *Leptoglossus occidentalis*, with a key to *Leptoglossus* species of America north of Mexico (Heteroptera: Coreidae). The Great Lakes Entomologist, 23: 99-104.

Schaffner, J.C. 1967. The occurrence of *Theognis occidentalis* in the midwestern United States (Heteroptera: Coreidae). Journal of the Kansas Entomological Society, 40: 141-142.

(Received 4 January 1992; accepted 17 January 1992)

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