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BIOLOGY AND MANAGEMENT OF WILD BEE AND DOMESTICATED HONEY BEE POLLINATORS FOR TREE FRUIT POLLINATION

by

Cynthia Diane Scott

B. Sc., Brandon University, 1980

M. P. M., Simon Fraser University, 1983

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
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ABSTRACT

The objective of this study was to investigate the biology, management and pollination efficacy of wild bees and domesticated honey bees for tree fruit pollination. Observations were made and experiments conducted in the Okanagan Valley, B. C. from 1983 to 1985.

Although abundant in natural habitats, unmanaged wild bees are not reliable or predictable pollinators for orchards in the Okanagan Valley. However, the management of dominant wild bees species such as *Bombus terricola occidentalis* and *B. bifarius nearticus*, which display a strong tendency toward foraging on orchard crops, does have potential for fruit crop pollination. Although *Osmia lignaria propinqua* was not a dominant species in orchard habitats, it has potential for tree fruit pollination in the Okanagan Valley since it is indigenous to this area and management systems for its use in fruit tree pollination have already been established.

The results of a study comparing the relative pollination efficacy of honey bees and *O. lignaria* suggest that, although single *O. lignaria* visits produce fruits of a comparable size to those resulting from one to three honey bee visits, overall pollination efficacy is lower due to the greater number of seedless carpels per fruit and therefore an increased tendency toward asymmetrical apples. In addition, the data suggest that *O. lignaria* is less efficient at pollination since it spends significantly more time searching for and foraging on blossoms than do honey bees.

Predicting honey bee colony pollination potential in cherries, pears and apples utilizing such factors as colony characteristics, forager entrance counts and weather conditions is possible, but predictions will have to be made on an individual crop basis rather than by quantifying data to arrive at general recommendations for all tree fruit crops.

Colony characteristics and profitability were examined for three systems of honey bee management. Measurements of colony weight, sealed worker brood area and surplus honey production indicated that management systems which involved the most intensive colony management for pollination, honey production and bee production do not detract from overall colony vigour, yielded the best income, and can provide a new source of income through the sale of packages and nuclei.

DEDICATION

To John Corner, for his appreciation of people and the environment.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Pollination, the process of pollen transfer from anther to stigma, is one of the most critical stages in the production of a fruit crop. For pollination in tree fruit orchards to occur there are two major management requirements: 1) there must be an adequate source of pollen from a compatible pollenizer variety, and 2) there must be an adequate population of insect pollinators to transfer pollen (i.e. cross-pollination) while the blossoms are receptive (McGregor 1976).

Fruit varieties which produce an economic crop with their own pollen are termed self-compatible or self-fertile. Varieties that do not set an economic crop with their own pollen are termed partially self-compatible, or, if they fail to set fruit at all, self-incompatible. Most apple and pear varieties, and all sweet cherries are either self-incompatible or only partially self-compatible, and adequate cross-pollination by insects is essential for satisfactory cropping. To achieve this, one or more compatible pollinizer varieties must be interplanted amongst the main variety throughout the orchard (Humphry-Baker *et al.* 1975; McGregor 1976; Horticultural Education Association 1967). The distance over which cross-pollination by insects is likely to be effective is one of the factors in determining the spacing of pollenizer trees in an orchard planting scheme. However, orchardists want to plant a minimum number of pollenizer trees relative to the main variety. This has led to the extensive adoption of the "one-in-nine" system, in which each pollenizer tree is surrounded by eight trees of the main variety. Other pollenizer planting arrangements include solid rows of pollenizer trees (i.e. every third or fourth row to be planted with the pollenizer variety) and the "one-in-four" system (i.e. every second tree in every second row is a pollenizer) (Swales 1982; Horticultural Education Association 1967).

Much care must be exercised in choosing a pollenizer variety relative to the main variety including the following factors: 1) compatability of pollen with the main variety; 2) pollen viability; 3) regularity of flowering; 4) overlap of pollinizer flowering period relative to the main variety; and, 5) varietal efficiency relative to fruit set (Horticultural Education Association 1967).

Bee pollinators are the primary agents of cross-pollination ~~in~~ orchards. For cross-pollination to occur, bee pollinators foraging on blossoms of the main variety must be carrying and subsequently transfer pollen from a pollinizer variety to the stigmatic lobes of the main variety blossom they are visiting.

Historically, honey bee colonies were managed primarily for honey production, with crop pollination occurring incidentally. As field size increased, and plant monocultures became common, and the population of wild bees decreased, renting of honey bee colonies for crop pollination began. Currently, one million honey bee colonies are rented annually in the United States for the pollination of agricultural crops (McGregor 1976). In 1983, 6465 hives were rented for pollination services in British Columbia, with a total rental value of approximately $210,000. The pollination of food and forage crops provided by managed honey bee colonies in Canada has been estimated to be worth 10 times the value of the honey produced (Winston and Scott 1984).

In recent years, much attention has been directed toward the development of management systems for wild bee pollinators. Successful management systems for the alfalfa leafcutter bee, *Megachile rotundata* (F.), the alkali bee, *Nomia melanderi* Cockerell and the blue orchard bee, *Osmia lignaria propinqua* Cresson, have been initiated for the pollination of fruit and field crops in the U.S. (Parker and Torchio 1980).

Although bee pollinators play a vital role in the fruit growing industry, there is still much to know about plant pollination and the use of honey bees and wild bees to achieve maximum efficiency in pollination management systems and agricultural production. Monitoring of wild bee populations in agricultural areas to determine the abundance and diversity of indigenous populations has been limited. In addition, information on the comparative pollination efficacies of honey bees and wild bee pollinators relative to fruit quality is negligible. From the beekeepers' perspective, refining honey bee management systems to improve both pollination efficacy and income are essential in maintaining their livelihoods.

The objectives of the four major studies undertaken were to:

1. Determine the abundance and diversity of wild bee pollinators in orchards and uncultivated habitats in the Okanagan Valley, and to identify wild bee pollinators with potential use in tree fruit pollination;
2. Compare the pollination efficacies of an indigenous wild bee pollinator, *O. lignaria propinqua*, and honey bees on Red Delicious apples;
3. Investigate a means of determining pollination strength of honey bee colonies in orchards using forager entrance counts; and,
4. Investigate the biology and economics of honey bee management for pollination and determine the feasability of package bee and/or nucleus production in conjunction with pollination-based and honey-based management systems.

PART A

WILD BEE POLLINATOR DIVERSITY AND ABUNDANCE IN ORCHARD AND UNCULTIVATED HABITATS IN THE OKANAGAN VALLEY, BRITISH COLUMBIA

INTRODUCTION

In order for apples (*Malus sylvestris*), pears (*Pyrus communis*), and sweet cherries (*Prunus avium*) (with the exception of the self fertile variety Stella) to be pollinated, there must be present in the orchard 1) pollenizer varieties which produce pollen capable of fertilizing and producing fruit when the pollen is carried to the stigmas of the main tree fruit variety; and 2) an adequate supply of insect pollinators in the form of either managed honey bees or wild bees to ensure that cross-pollination occurs.

Bee pollinators are the primary agents for the transfer of pollen from one self-incompatible fruit cultivar to another. Wind and/or other animals are negligible factors in the pollination of apples, sweet cherries and pears (McGregor 1976). The flower structures found in these fruits are clearly adapted for bee pollination, and the requirement for bees has been shown by many experiments in which negligible fruit set occurs on trees screened to exclude them, whereas it was satisfactory on adjacent plants to which bees had access (Claypool *et al.* 1931; Free 1964, 1966; Stephen 1958).

The honey bee has several valuable qualifications for its role as the primary managed insect pollinator of agricultural crops, including:

1. Propagation - economically feasible management systems have been developed which are conducive to manipulations of colony populations;
2. Mobility - honey bees are maintained in colonies which can be transported when and where they are needed during the pollination period. Also, honey bee workers can reorient to new hive locations;
3. Fidelity to Plant Species - honey bees tend to visit only one species of flower during a given time period for pollen and/or nectar. Also, honey bees are not obligate visitors to any single plant species, as are some oligolectic wild bees;
4. Availability and Management by Apiarists - different crops have varying pollination

periods and honey bees can be made available throughout the entire season; and

5. Foraging Behavior - honey bees have a relatively long flight range, depending on weather conditions, and are insatiable pollen and nectar collectors.

Although honey bees have a number of advantages for their use in crop pollination, the importance of naturally occurring populations of wild bees for the pollination of fruit and other crops has also been well documented. In this paper, wild bees are defined as all members of the superfamily Apoidea other than the genus *Apis*. Satisfactory to excellent fruit set sometimes can be accomplished in the absence of honey bees (Fox-Wilson 1929; Loken 1958). Brittain *et al.* (1933) determined that in parts of Nova Scotia where there was a virtual absence of both bumble bees and honey bees, the natural populations of *Halictus* and *Andrena* species were sufficient for successful apple pollination.

The population levels of wild bee species have decreased substantially since the aforementioned studies were completed, primarily due to changes in agricultural practices which have resulted in extensive monocropped acreages, reduced plant diversity, increased use of pesticides, competition by honey bees and destruction of nesting habitat (Free 1980; Johansen 1972; Plowright and Thaler 1978; Eickwort and Ginsberg 1980; Roubik 1978; Wratt 1968; Dorr and Marten 1966; Marucci and Moulter 1977; Johansen and Shawa 1974; Morgan and Percival 1967; Cruden 1972; Heinrich 1975, 1976). Reduced populations and annual fluctuations in abundance patterns have made unmanaged wild bee species unreliable and unpredictable pollinators for agricultural crops, neccessitating the rental of honey bee colonies for crop pollination. However, a number of wild bee species have proven to be more efficient pollinators of certain crops than honey bees. For example, the alkali bee, *Nomia melanderi* Cock. and the leafcutter bee, *Megachile rotundata* (F.) are highly effective and efficient pollinators of alfalfa. The management and utilization of these wild bees as alfalfa pollinators has been studied and promoted for a number of years (Bohart 1958, 1967, 1970a, 1970b, 1972; Menke 1952, 1954; Stephen 1965; Stephen and Evans 1960; Hobbs 1964, 1967;

Klostermeyer 1964) and in many areas of the U.S. and Canada they are considered the primary pollinators of this crop. Several species of megachilid bees have proven to be efficient pollinators of fruit and nut crops. *Osmia lignaria propinqua* Cresson is a North American species in the final stages of development as a pollinator of almond (Torchio 1979, 1981a, 1981b, 1982a) and apple crops (Torchio 1976, 1982b, 1984, 1986). *Osmia cornifrons* (Radoszkowski) has been developed as a commercial pollinator of fruit trees in Japan (Maeta 1978; Maeta and Kitamura 1965a, 1965b, 1974, 1981) and has been imported to the eastern U.S. for apple pollination. *Osmia cornuta* Latr., has been imported into the western U.S. from Spain and is being tested as a potential pollinator of orchard crops such as apples (Torchio and Asensio 1985).

Several *Bombus* species (bumble bees) have also proven to be dependable pollinators of crops. For example, *Bombus terrestris* is being developed as a pollinator of kiwifruit in New Zealand (N. Pomeroy[1], personal communication). Bumble bees are important pollinators of red clover in northern Europe and efforts are made to grow this crop for seed in areas where bumble bees are abundant (Free 1980). *Bombus* spp. were imported for red clover pollination in New Zealand (McGregor 1976).

If we are to benefit from the pollinating activities of wild bee species it is essential that we begin to augment and maintain their populations. Before management programs for wild bees can be developed it is necessary to survey bee fauna in a particular area, not only to determine the relative abundance and diversity of individual species, but also to determine candidacy of particular species as natural and managed pollinators of target crops. The objectives of this research were to:

1. Determine the abundance and diversity of wild bee pollinators in orchard and uncultivated habitats in the Okanagan Valley, British Columbia;
2. Examine whether sufficient numbers of wild bees forage in the orchard habitats to

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[1] Department of Botany and Zoology, Massey University, Palmerston North, New Zealand.

provide adequate tree fruit pollination in the absence of honey bees; and

3. Determine the most abundant (dominant) wild bee species which forage in orchard habitats and their potential for domestication and management for commercial tree fruit pollination.

MATERIALS AND METHODS

The study was conducted in the Okanagan Valley of British Columbia from mid-April to early June 1984 and mid-April to the end of May 1985. Fourteen collection sites (Appendix 1) were used representing four habitat types: 1) Orchards: Far from Natural (OFN) - Sites were located in an orchard surrounded on all sides by other orchards.; 2) Orchards: Near Natural (ONN) - Sites were located in an orchard which was bounded on one or two sides by natural, uncultivated land.; 3) Uncultivated: Near Orchards (UNO) - Sites were uncultivated land bounded on one or two sides by orchards.; and 4) Uncultivated: Far from Orchards (UFO) - Sites were uncultivated land completely surrounded by natural habitat and > 0.5 km from the nearest orchard. The sites were located from Summerland to Oyama, and the same collection sites were used during both years of the study.

The Okanagan Valley has a xeric, cold temperate climate with an annual rainfall of 38.0 to 51.0 cm. All sites in the uncultivated habitat designations are classified as "ponderosa pine-bunchgrass" (Krajina 1969; Brayshaw 1970). The crops represented in the orchard habitats OFN and ONN were apples, cherries and pears. Collecting was done in one abandoned apple orchard which was designated UFO. Collection at orchard sites was coincidental with fruit crop and understory bloom such as *Taraxacum officinale* (dandelion). Uncultivated sites were sampled for the entire 6-week period. Bee pollinators were collected for 1 h intervals from 0900 to 1500 h at each site to allow within and between-habitat comparisons. Only wild bees foraging on blossoms were caught; honey bees were not collected.

DIVERSITY: To determine diversity of wild bee pollinators on an orchard crop or natural vegetation, a collector moved throughout the site for 1 h capturing as many bees as possible with either an insect net or jar. The plant on which the captured bee was foraging was also collected if it could not be immediately identified. Plant specimens were pressed, identified and cross-referenced with the bee captured while foraging on them. The bees were killed with ethyl acetate, taken to the laboratory, and pinned. In 1984, all wild bees collected were identified to genus and sent to the following specialists for species determination: Dr. T. Griswold, Bee Biology and Systematics Laboratory, Utah State University, Logan, Utah (Megachilidae); Dr. W. E. LaBerge, State Natural History Survey Division, Champaign, Illinois (Andrenidae, Megachilidae=*Mellisodes* species); Dr. G. C. Eickwort, Dept. of Entomology, Cornell University, Ithaca, New York (Halictidae); Dr. H. V. Daly, Division of Entomology, University of California, Berkeley, California (Anthophoridae=*Ceratina* species); Dr. R. W. Brooks, Dept. of Entomology, University of Kansas, Lawrence, Kansas (Anthophoridae). Voucher specimens have been retained by all of the above taxonomists and at Simon Fraser University. In 1985, all wild pollinators were identified to species at Simon Fraser University. In 1984 and 1985, all bumble bee specimens (*Bombus* spp.) and plants were identified to species at Simon Fraser University. Shannon-Wiener Diversity Indices were calculated from these data (Margalef 1958). Between-year similarity in foraging patterns was determined using Sorenson's Presence-Absence Similarity Index (Sorenson 1948). Analyses of variance were used to analyze within-year family and habitat comparisons.

ABUNDANCE: Collection methods have been described in the previous section. Collectors walked transects through each site collecting wild bees foraging on plants in close proximity to their path. There are a number of problems with this collection technique which could result in biases in the capture rate data: 1) individual collectors may have differed in the vigor with which they surveyed collection sites; 2) differences in topography between sites could have made it more difficult to collect in some sites compared to others; and, 3) variations in foraging behavior between wild bee species could have resulted in some bee species being more difficult to capture compared to other species. However, these problems would likely have occurred at all collection sites and therefore, I believe that the resultant capture rate data is representative of wild bee abundance in the Okanagan Valley. Abundance of wild bees at each habitat designation was determined by calculating the number of wild bees collected/collecting time, producing a capture rate/h (Bees/h). Capture rates were determined for each habitat. A two-sample t-test was used to compare total capture rates of each habitat between years.

RESULTS

I. Diversity of Wild Bee Species

All wild bees (Hymenoptera: Apoidea) collected were in the families Apidae, Halictidae, Andrenidae, Megachilidae, Anthophoridae, and Colletidae (Table 1). The families Oxaeidae, Mellitidae and Fideliidae were not represented in these collections.

Uncultivated habitats (UNO and UFO) showed higher total diversity of wild bee pollinators than the orchard habitats (OFN and ONN) in both years (Table 1), although in 1985 the differences were not as dramatic as in 1984. In 1984, a particularly low diversity was evident for the ONN habitat. The families Halictidae, Andrenidae, Megachilidae and Anthophoridae showed higher diversity in uncultivated habitats compared to orchard habitats in both years. In contrast, the Apidae in 1984 had lower diversity in ONN and UNO habitats than in OFN and UFO. In 1985, species diversity for the Apidae was low in the OFN habitats and high in the other three habitats (Table 1). Only two individual Colletidae (one species) were collected, both in the UNO habitat in 1985.

The higher species diversity on natural vegetation in both years was due primarily to the greater number of non-*Bombus* species collected in the uncultivated habitats in both years. Seventy-nine non-*Bombus* species were collected in the uncultivated habitats and only 12 in orchard habitats during 1984 (Table 2). In 1985, 50 non-*Bombus* species were collected in the uncultivated habitats compared to 27 at the orchard sites (Table 3). A total of 100 wild bee species were identified during 1984 and 1985.

Wild bees were collected from 24 different plant species in 1984 (Table 2). The number of plant species used as forage in uncultivated habitats was considerably higher than in orchard habitats. A similar trend was evident in 1985 (Table 3), although 31 different

Table 1 . Diversity (Shannon-Wiener Diversity Index, H'[a]) and abundance of wild bee families collected in orchard and uncultivated habitats in the Okanagan Valley during 1984 and 1985.

	Habitat Designations													
	Orchards: Far from Natural			Orchards: Near Natural			Uncultivated: Near Orchards			Uncultivated: Far from Orchards			Total	
Family	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Different Species
						1984 DATA								
Apidae	18	4	.55	33	3	.16	34	6	.39	33	12	.94	118	13
Halictidae	12	6	.69	0	0	n/c	194	19	1.06	192	20	1.01	398	21
Andrenidae	3	2	.28	2	2	.30	49	15	1.12	72	21	.98	129	28
Megachilidae	6	1	0[b]	0	0	n/c	22	11	.98	11	9	.88	39	19
Anthophoridae	44	1	0[c]	1	1	0	27	8	.66	48	10	.78	120	11
Colletidae	0	0	n/c	0	0	n/c	0	0	n/c	0	0	n/c	0	0
Total	83	13	.78	36	6	.31	326	59	1.63	356	68	1.54	801	92
						1985 DATA								
Apidae	32	4	.49	50	8	.80	39	11	.91	34	10	.81	155	15
Halictidae	5	5	.70	16	8	.79	48	12	.92	76	12	.90	145	13
Andrenidae	3	2	.28	4	3	.45	29	15	.98	63	12	.91	99	18
Megachilidae	4	3	.45	20	7	.78	21	8	.83	40	10	.86	85	16
Anthophoridae	16	2	.10	8	4	.47	21	4	.50	41	5	.55	86	7
Colletidae	0	0	n/c	0	0	n/c	2	1	0	0	0	n/c	2	1
Total	60	16	.93	98	29	1.31	160	50	1.49	254	47	1.60	572	70

[a] $H' = \Sigma p_i (\log p_i)$ where p_i = proportion of the i^{th} species in the sample
[b] 0 = Diversity Index Value - only 1 specimen of this family collected
[c] n/c = no specimens of this family collected

Table 2 . Diversity (Shannon-Wiener Diversity Index, H'^{a}) and abundance of wild bees on designated fruit crops and native flora in orchard and uncultivated habitats in the Okanagan Valley during 1984.

Plant Species	Orchards: Far from Natural			Orchards: Near Natural			Uncultivated: Near Orchards			Uncultivated: Far from Orchards			Totals		
	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Different Species	Diversity Index
ROSACEAE:															
Prunus avium (sweet cherry)	0	0	n/c	19	5	.40							19	5	.40
Malus sylvestris (apple)	5	1	0^{b}	17	2	.10				6	5	.68	28	6	.74
Malus sp.1 (crabapple)	63	8	.58										63	8	.58
Pyrus communis (pear)	0	0	n/c^{c}										0	0	n/c
COMPOSITAE:															
Balsamorhiza sagittata							6	5	.68	49	22	1.01	55	23	1.22
Taraxacum officinale	13	7	.75	0	0	n/c	164	37	1.22	199	42	1.17	376	62	1.53
Achillea millefolium							8	5	.65	1	1	0	9	6	.73
Antennaria microphylla							7	3	.35				7	3	.35
Antennaria neglecta										3	3	.47	3	3	.47
Erigeron philadelphicus							6	2	.20	17	11	.95	23	2	1.01

cont.

Table 2 . cont.

Plant Species	Orchards: Far from Natural			Orchards: Near Natural			Uncultivated: Near Orchards			Uncultivated: Far from Orchards			Totals		
	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Different Species	Diversity Index
COMPOSITAE: cont.															
Gaillardia aristata							11	9	.91	2	2	.30	13	10	1.00
Cirsium vulgare										1	1	0	1	1	0
BERBERIDACEAE:															
Berberis aquifolium							12	6	.73	18	8	.71	30	12	1.01
ROSACEAE:															
Fragaria virginiana	2	2	.30							38	9	.69	40	11	.71
Potentilla recta										8	5	.65	8	5	.65
LILIACEAE:															
Smilacina stellata							2	2	.30				2	2	.30
BORAGINACEAE:															
Lithospermum ruderale										3	3	.48	3	3	.48
Symphytum officinale							15	1	0				15	1	0

cont.

Table 2 . cont.

Plant Species	Orchards: Far from Natural No. Individuals	Orchards: Far from Natural No. Species	Orchards: Far from Natural Diversity Index	Orchards: Near Natural No. Individuals	Orchards: Near Natural No. Species	Orchards: Near Natural Diversity Index	Uncultivated: Near Orchards No. Individuals	Uncultivated: Near Orchards No. Species	Uncultivated: Near Orchards Diversity Index	Uncultivated: Far from Orchards No. Individuals	Uncultivated: Far from Orchards No. Species	Uncultivated: Far from Orchards Diversity Index	Totals No. Individuals	Totals No. Different Species	Totals Diversity Index
SCROPHULARIACEAE:															
Castilleja hispida							1	1	0				1	1	0
CRUCIFERAE:															
Capsella bursa-pastoris							22	10	.92				22	10	.92
Thlaspi arvense							52	18	1.14				52	18	1.14
LEGUMINOSAE:															
Astragalus miser							16	11	.65	5	3	.46	21	13	1.12
SAXIFRAGACEAE:															
Heuchera cylindrica										4	2	.26	4	2	.26

cont.

Table 2. cont.

Plant Species	Orchards: Far from Natural			Orchards: Near Natural			Uncultivated: Near Orchards			Uncultivated: Far from Orchards			Totals		
	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Different Species	Diversity Index
CORNACEAE:															
Cornus stolonifera							4	4	.60				4	4	.60
Total No. Different Plant Species		6			3			14			14			24	
Total No. Different Wild Bee Species		13			6			59			68			92	

$^{a}H'=\Sigma p_i$(lo[illegible]p_i)where p_i=proportion of the i^{th} species in the sample
^{b}0=Diversity Index Value - only 1 specimen of this family collected
^{c}n/c=no specimens of this family collected

Table 3 . Diversity (Shannon-Wiener Diversity Index, H'[a]) and abundance of wild bees on designated fruit crops and native flora in orchard and uncultivated habitats in the Okanagan Valley during 1985.

Plant Species	Orchards: Far from Natural			Orchards: Near Natural			Uncultivated: Near Orchards			Uncultivated: Far from Orchards			Totals		
	No.Individuals	No.Species	Diversity	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Different Species	Diversity Index
ROSACEAE:															
Prunus avium (sweet cherry)	16	4	.51	4	2	.24							20	5	.65
Malus sylvestris (apple)	28	8	.73	46	15	1.01				11	10	.99	85	18	1.32
Malus sp.1 (crabapple)	2	1	0[b]	17	10	.85							19	11	1.01
Pyrus communis (pear)	0	0	n/c[c]										0	0	n/c
COMPOSITAE:															
Balsamorhiza sagittata				1	1	0	27	19	1.19	100	25	1.19	128	32	1.49
Taraxacum officinale	14	13	.99	12	6	.71	26	17	1.16	64	18	1.06	116	34	1.55
Arnica cordifolia							1	1	0				1	1	0
Tragopogon dubius							5	3	.41	7	6	.76	12	8	.84
Crepis sp.										10	5	.53	10	5	.53
Antennaria neglecta							5	11	.96				15	11	.96

cont.

Table 3 . cont.

Plant Species	Orchards: Far from Natural			Orchards: Near Natural			Uncultivated: Near Orchards			Uncultivated: Far from Orchards			Totals		
	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Different Species	Diversity Index
BERBERIDACEAE:															
Berberis aquifolium							2	2	.30	1	1	0	3	3	.48
ROSACEAE:															
Fragaria virginiana							12	7	.72				12	7	.72
Rosa nutkana				1	1	0	16	10	.92	15	11	.98	32	17	1.28
Amelanchier alnifolia							4	3	.41	13	8	.84	17	9	.98
Crataegus columbiana							4	4	.60				4	4	.60
BORAGINACEAE:															
Lithospermum ruderale							4	3	.58	1	1	0	5	4	.58
Symphytum asperum				1	1	0							1	1	0
S. officinale							8	2	.16				8	2	.16

cont.

Table 3. cont.

Plant Species	Orchards: Far from Natural			Orchards: Near Natural			Uncultivated: Near Orchards			Uncultivated: Far from Orchards			Totals		
	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index
RANUNCULACEAE:															
Ranunculus glaberrimus							1	1	0				1	1	0
PRIMULACEAE:															
Dodecatheon pulchellum							7	5	.67				7	5	.67
SCROPHULARIACEAE:															
Castilleja miniata							8	4	.53				8	4	.53
C. hispida										2	2	.30	2	2	.30
CRUCIFERAE:															
Sisymbrium altissimum							8	6	.72				8	6	.72
Camelina microcarpa							3	3	.48				3	3	.48
Arabis sp.							1	1	0				1	1	0
1 species unknown				1	1	0							1	1	0

cont.

Table 3. Cont.

Plant Species	Orchards: Far from Natural			Orchards: Near Natural			Uncultivated: Near Orchards			Uncultivated: Far from Orchards			Totals		
	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index	No. Individuals	No. Species	Diversity Index
SAXIFRAGACEAE:															
Heuchera cylindrica							6	5	.68	4	3	.45	10	6	.88
LEGUMINOSAE:															
Medicago sativa							1	1	0	1	1	0	2	2	.30
Lupinus sp.				11	6	.71							11	6	.71
Astralagus miser				4	2	.24				22	10	.86	26	10	.95
RHAMNACEAE:															
Ceanothus sanguineus							1	1	0	3	2	.28	4	3	.45

Table 3 . cont.

Plant Species	Orchards: Far from Natural			Orchards: Near Natural			Uncultivated: Near Orchards			Uncultivated: Far from Orchards			Totals		
	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Species	Diversity Index	No.Individuals	No.Different Species	Diversity Index
Total No. Different Plant Species		6			7			21			14			31	
Total No. Different Wild Bee Species		16			29			51			49			70	

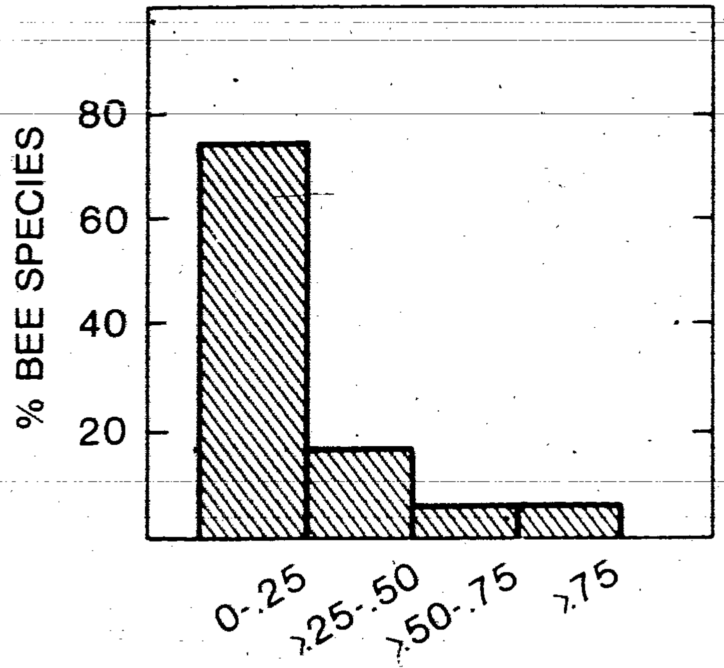
[a] $H' = \Sigma p_i (\log p_i)$ where p_i = proportion of the i^{th} species in the sample
[b] 0 = Diversity Index Value - only 1 specimen of this family collected
[c] n/c = no specimens of this family collected

plant species, 7 more than in 1984, were used as forage. An increase in the number of plant species in the UNO designation was evident between 1984 and 1985. Diversity of wild bees was higher on sweet cherry, apple and crabapple in 1985 than in 1984. In both years, no wild bees were collected on pears. Native flora, such as *Balsamorhiza sagittata* (spring sunflower) and *T. officinale*, had higher total diversity of bees foraging on them then any of the orchard crops in both years (Tables 2 and 3). *T. officinale* was particularly interesting since it is an understory vegetation in orchards and was found at all habitat designations during both years, except ONN in 1984. The remainder of the native flora listed in Table 2 and 3 were found in only one or two of the four habitat designations with the exception of *Rosa nutkana* which was found in three habitats in 1985. Comparisons made using Sorenson's presence–absence similarity index (Sorenson 1948) revealed that most species of bees (74.1%) were variable in their resource usage, with similarity values less than 0.25 (Fig. 1a). A large portion of plant species (76%) were visited by a highly variable forager population, also indicated by similarity values less than 0.25 (Fig. 1b). Sorenson's index was also used to determine the similarity of wild bee foraging patterns on orchard crops and two of the dominant native plants for 1984 and 1985 (Fig. 2). *Pyrus communis* was not included in this analysis since no wild bee pollinators were collected on this crop in either year. Wild bees were more variable in their usage of orchard crop resources (low similarity values) than of *T. officinale* and *B. sagittata* (high similarity values).

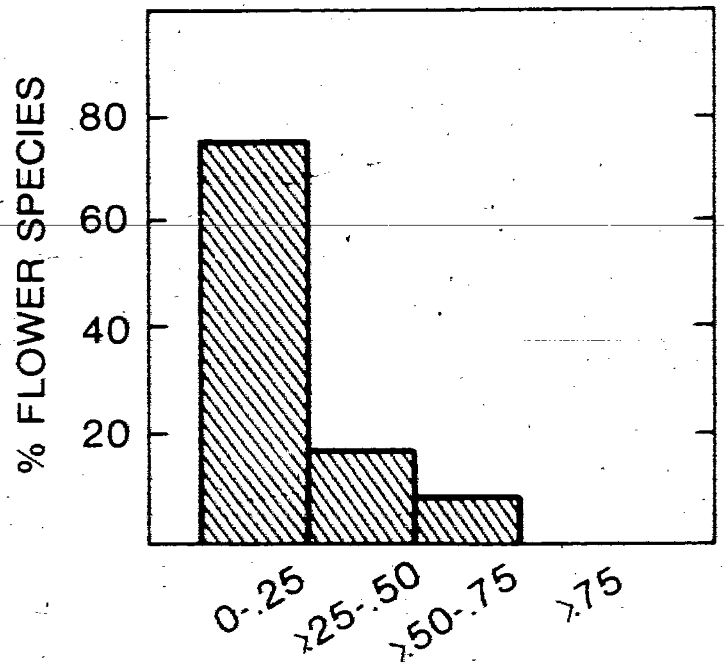
II. Abundance of Wild Bee Species

The most commonly collected (dominant) species at the orchard habitats during 1984 were *Bombus terricola occidentalis* (Apidae), *Bombus bifarius nearcticus* (Apidae) and *Hapropoda cineraria* (Anthophoridae). In uncultivated habitats, the most commonly collected species were the smaller halicitine bees. *Halictus confusus*, *Dialictus* sp. 2, *Dialictus* sp. 5 and *Dialictus* sp. 6 were most common in the UNO designation, while *D. laevissimus* and *D.*

Fig. 1. a) The distribution of resident bee species by their similarity in flower utilization between consecutive years, 1984–1985; b) the distribution of flower species by their between-year similarity in bee species visiting them during consecutive years, 1984–1985 (Sorenson's Presence–Absence Similarity Index, Sorenson 1948).

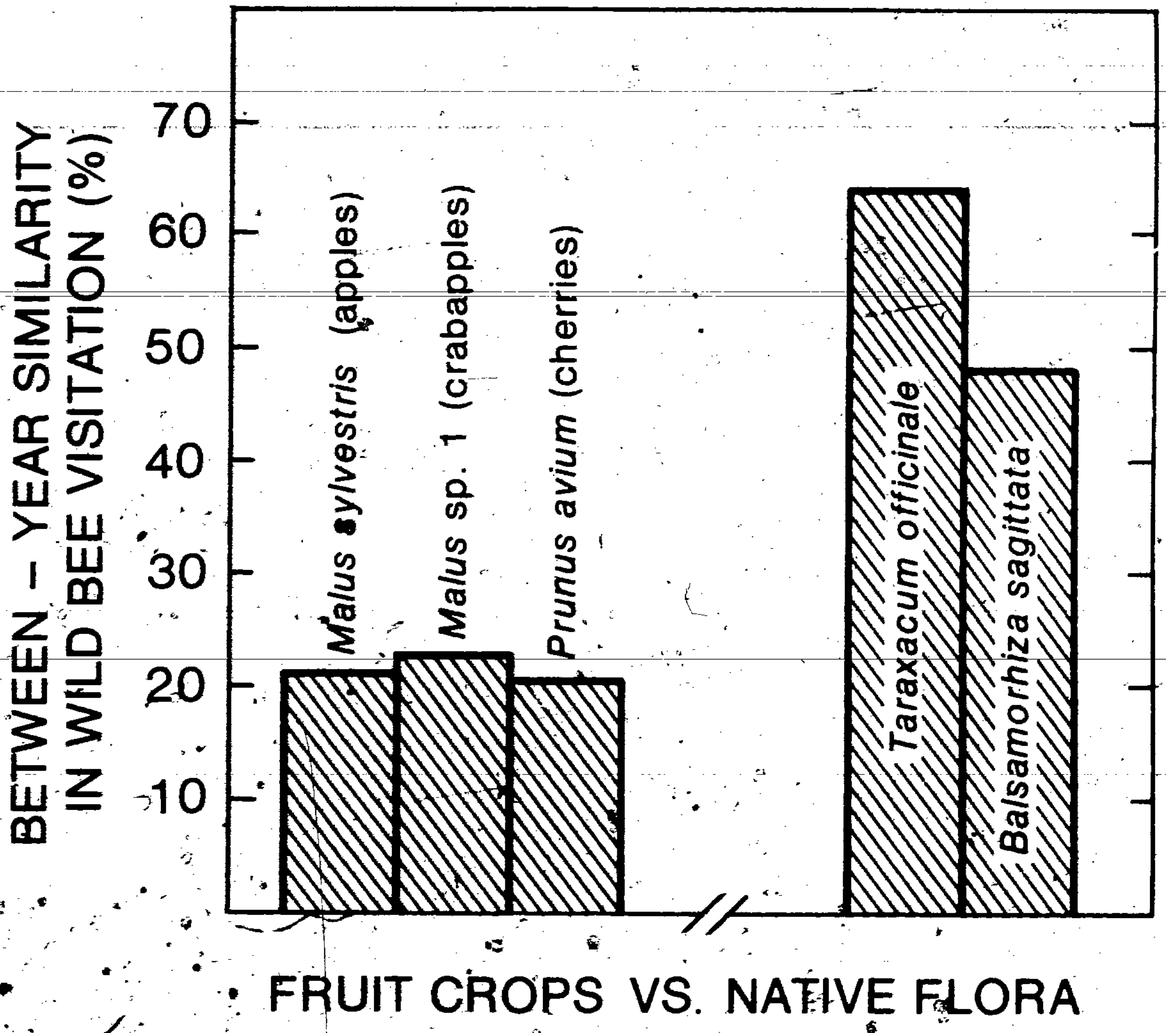


a) BETWEEN – YEAR SIMILARITY IN FLOWERS VISITED



b) BETWEEN – YEAR SIMILARITY IN BEE VISITATION

Fig. 2. A comparison of between-year similarity in bee visitation in fruit crops versus native flora found in three to four of the designated habitats. *Pyrus communis* (pear) was not included because no bee pollinators were collected on this fruit crop in either 1984 or 1985 (Sorenson's Presence–Absence Similarity Index, Sorenson 1948).


BETWEEN – YEAR SIMILARITY IN WILD BEE VISITATION (%)
70
60
50
40
30
20
10
Malus sylvestris (apples)
Malus sp. 1 (crabapples)
Prunus avium (cherries)
Taraxacum officinale
Balsamorhiza sagittata
FRUIT CROPS VS. NATIVE FLORA

pruinosus were most common at the UFO designation. In 1985, *B. t. occidentalis* and *B. b. nearcticus* were the most commonly collected bee species in the orchard habitats, while *H. confusus* and *D. pruinosus* were again dominant in the uncultivated habitats. A list of wild bee pollinators and their abundance in the habitats in which they were collected in 1984 and 1985 is given in Appendix II.

One useful factor in determining the potential value of the dominant wild bee species as pollinators on tree fruit crops is their preference within orchard habitats for understory vegetation or crop trees (Appendix II). Of all the wild bees collected in the orchard habitats, 75% of *B. t. occidentalis*, 43% of *B. b. nearcticus*, amd 54% of *H. cineraria* were captured while foraging on apples, sweet cherries and crabapples. Although none of the other bee families contained dominant orchard species, the Andrenidae and Megachilidae displayed a strong preference for tree fruit crops in orchard habitats, with 90% and 72% respectively collected while foraging on these crops. The Halictidae displayed a strong preference for understory plants with only 14% of all individuals captured while foraging on the target fruit crops. The Anthophoridae also prefered understory plants with the exception of 44 *H. cineraria* collected on orchard crops in 1984. No Colletidae were collected in orchard habitats in either year.

There was a strong preference for *T. officinale* by all dominant wild bee species in uncultivated habitats during both 1984 and 1985 (Appendix II). Of all the individuals collected, 48% of *H. confusus*, 60% of *Dialictus* sp. 2, 70% of *Dialictus sp. 5* , 76% of *Dialictus* sp. 6, 68% of *D. laevissimus*, and 69% of *D. pruinosus* were captured while foraging on *T. officinale*. In 1984 and 1985, 87% and 78% respectively of all wild bees captured were collected on native flora.

A between-habitat analysis of total capture rates in 1984 indicated significantly higher total capture rates in uncultivated versus orchard habitats (Table 4). In addition, the UNO

Table 4. Mean capture rates (bees/h) of wild bee families in orchards and uncultivated habitats in the Okanagan Valley during 1984 and 1985.

Family	Orchards: Far from Natural[a]	Orchards: Near Natural	Uncultivated: Near Orchards	Uncultivated: Far from Orchards
		1984 Mean capture rates (Bees/h)		
Apidae	.82 a	2.16 b	1.84 bc	1.18 a
Halictidae	.54 a	0 a	9.70 d	7.14 c
Andrenidae	.14 a	.13 a	2.60 c	2.66 b
Megachilidae	.18 a	0 a	1.30 b	.52 a
Anthophoridae	1.99 a	.06 a	2.01 bc	1.70 b
Colletidae	0 a	0 a	0 a	0 a
Total Capture[b] Rate	3.76 a	2.36 a	17.46 c	13.23 b
		1985 Mean capture rates (Bees/h)		
Apidae	1.38 c	2.94 c	2.44 c	1.58 b
Halictidae	.21 a	.94 b	2.68 c	3.75 d
Andrenidae	.12 a	.29 a	2.00 bc	2.57 c
Megachilidae	.21 a	1.18 b	1.58 b	2.12 bc
Anthophoridae	.67 b	.47 ab	1.52 b	1.58 b
Colletidae	0 a	0 a	.12 a	0 a
Total Capture[b] Rate	2.52 a	5.82 b	10.35 c	11.56 c

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

[b] Means within a row followed by the same letter are not significantly different ($P<0.05$ level; Duncan's (1951) multiple range test)

designation had a significantly higher capture rate than the UFO designation.

In OFN, the Anthophoridae had a higher capture rate than any of the remaining families. This can be accounted for by the fact that a large number (n=44) of *H. cineraria* were collected at one of four sites in this habitat designation. The Apidae had the next highest capture rate in OFN, although it was not significantly different from the Halictidae, Andrenidae and Colletidae. In ONN, the Apidae had significantly higher capture rates than the other families (Table 4). The Anthophoridae were scarce in this habitat designation compared to OFN. In the remaining two uncultivated habitats (UNO and UFO), the Halictidae had a significantly higher capture rate than any of the other families.

In 1984, capture rates for the Apidae fluctuated the least over the 4 habitats compared to the other families. Although no Colletidae were collected in 1984, this family is present in the Okanagan Valley, since two specimens were collected in 1985 (Table 1).

In 1985, total capture rates of the two uncultivated habitats were again significantly higher than both of the orchard designations (Table 4). Within the orchard designation, the total capture rate for ONN was significantly higher than OFN.

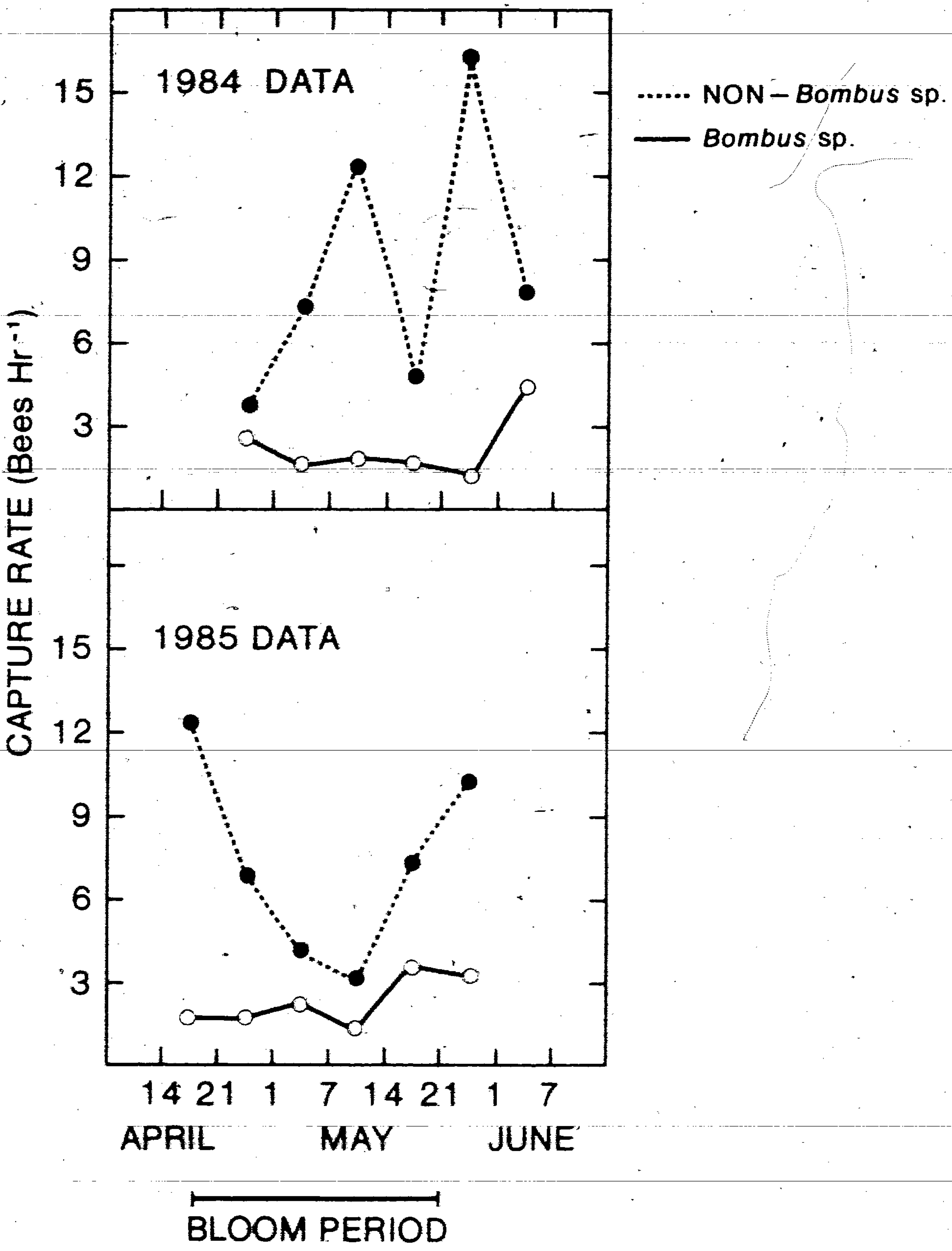
In OFN and ONN in 1985, the Apidae had significantly higher capture rates than any of the other families. The capture rate for the Anthophoridae in OFN dropped considerably compared to 1984 and was not dramatically different from the capture rate in ONN. In UNO, the family Halictidae had the highest capture rate although it was not significantly different from those of the Apidae and Andrenidae. In UFO the capture rate for Halictidae was significantly higher than for the other families. The higher capture rates of Halictidae in the uncultivated habitats in 1985 were similar although not as dramatic as those in 1984. As in 1984, capture rates of Apidae in 1985 were higher in the ONN and UNO than the other two habitats. There was a general trend in all families towards greater abundance in uncultivated habitats compared to orchard habitats. Capture rates of all families except

Colletidae were higher in 1985 than 1984.

Abundance patterns for *Bombus* species (bumble bees) were lower but more constant than for non-*Bombus* species (all wild bee species excluding bumble bees) during the collection periods 1984 and 1985 (Fig. 3). There was a gradual increase in the abundance of *Bombus* species and non-*Bombus* species towards June in both years. In 1984 and 1985, there was a reduction in the abundance of non-*Bombus* species during the combined blooming period for apples, cherries, and pears (15 April to 21 May). Since the collection period in 1984 started and ended a week later than in 1985, it is difficult to determine whether the peak in non-*Bombus* species abundance in mid-April 1985 would have been encountered in 1984. Furthermore, I cannot determine whether the reduction in non-*Bombus* species abundance apparent in the first week of June 1984 would have occurred in 1985. Weather conditions in April and May 1985 were warmer and drier than in the previous year, while conditions in June 1984 were cooler and wetter than normal (Table 5). The substantial reductions in non-*Bombus* species abundance during the middle of the bloom period in 1984 and 1985 and during the first week in June 1984, were not associated with unseasonal weather conditions. Low nightly temperatures from 22 April to 30 April 1984 resulted in heavy frost and the maximum daily temperature being reached in the early afternoon and could have been responsible for lower capture rates of non-*Bombus* species compared to 1985 data. It appears that *Bombus* species were not negatively influenced by the inclement weather near the end of April 1984, since capture rates were comparable in both years.

A between-year comparison of total capture rates within each habitat indicated ONN and UNO sites were significantly different between years, while OFN and UFO were not significantly different (Table 6).

Fig. 3. Overall capture rates of non-*Bombus and Bombus* species in the Okanagan Valley during 1984 and 1985. Bloom period refers to the combined pollination period for cherries, pears and apples.



1984 DATA
1985 DATA
CAPTURE RATE (Bees Hr⁻¹)
15
12
9
6
3
······ NON – *Bombus* sp.
—— *Bombus* sp.
14
21
1
7
14
21
1
7
APRIL
MAY
JUNE
BLOOM PERIOD

Table 5. Meteorlogical data recorded at the Kelowna, B.C., Municipal Airport Weather Station - Atmospheric Environment Service, during the collection periods of April and May 1984-1985 and June 1984.

Month/Year	Temperature Maximum C°	 Minimum C°	 Mean C°	Total Precipitation mm
April 1984	14.0	0.8	7.4	21.8
April 1985	15.5	0.4	8.0	12.6
April Average	14.9	0.0	7.5	17.7
May 1984	16.8	3.8	10.3	50.4
May 1985	21.9	5.4	13.7	29.2
May Average	20.3	4.2	12.2	28.0
June 1984	22.6	8.5	n/a	38.6
June Average	24.1	7.8	n/a	26.9

Table 6. A comparison of total capture rates of wild bees for each habitat between years.

Total Capture Rates, $\bar{x}$ number of Bees/h ± S.E.

Year	Orchards: Far from Natural	Orchards: Near Natural	Uncultivated: Near Orchards	Uncultivated: Far from Orchards
1984	3.76 ± 0.81	2.36 ± 0.16	17.46 ± 1.26	13.23 ± 1.05
1985	2.52 ± 0.23	5.82 ± 0.20	10.35 ± 0.27	11.56 ± 1.08
T-test probability between years	>0.05	<0.01	<0.001	>0.05

DISCUSSION

I. Species Distribution Patterns

The dominant wild bee species in both orchard habitats were the same in 1984 and 1985, *Bombus t. occidentalis*, *B. b. nearcticus* and *Hapropoda cineraria*. *B. t. occidentalis* and *B. b. nearcticus* are both potential fruit crop pollinators, while the value of *H. cineraria* has not been examined. Although *Osmia lignaria propinqua* were not abundant in either orchard or uncultivated habitats, those collected in orchard habitats exhibited a preference for apple blossoms. This species has been successfully managed as an apple pollinator (Torchio 1976, 1979, 1981a, 1981b, 1982a, 1982b). All of the dominant bee species in orchard habitats displayed a preference for apples, sweet cherries, and crabapples over understory vegetation, which further supports their potential as managed orchard pollinators.

The dominant wild bee species collected in the uncultivated habitats were Halictidae, and all species exhibited a preference for foraging on *T. officinale*. Of the dominant wild bees in uncultivated habitats, only *Dialictus pruinosus* and *Dialictus sp. 5* were also found in the orchard habitats. The susceptibility of these small wild bees to pesticides (Johansen 1972; Plowright and Thaler 1978) and their preference for foraging on the competitive understory orchard vegetation, *T. officinale*, reduces their value as pollinators of orchard crops in the Okanagan Valley.

Pears are generally not considered to be as attractive to honey and wild bees as other fruit crops due to the low concentration of sugar in the nectar, approximately 4 to 25 percent (apple=46%) (Vansell 1942; Stephen 1958; Tufts and Philp 1923). It is unlikely that wild bee species would be more efficient than honey bees in pollinating pears, considering the absence of wild bees in pears in both years and the unattractiveness of pear blossoms to both honey bees and wild bees.

A higher diversity and abundance of wild bee pollinators were found in uncultivated habitats than in the orchard habitats. The relatively low wild bee populations on apples, crabapples, cherries and pears, as well as annual fluctuations in both abundance and diversity suggest that unmanaged wild bees would not be effective or reliable pollinators of these fruit crops in the Okanagan Valley. These patterns of pollinator distribution on uncultivated and orchard habitats suggest that pesticide impact, competition with managed honey bees, and nest habitat destruction have probably decreased wild bee populations in the agricultural areas of the Okanagan Valley.

The low diversity of wild bees in orchard habitats when compared with uncultivated habitats in the Okanagan Valley was particularly striking in 1984, when 90 species of wild bees were collected in the uncultivated habitats and only 16 species on all four fruit crops. The higher diversity of wild bee pollinators in uncultivated habitats was primarily due to the 79 non-*Bombus* species collected, as compared to only 12 non-*Bombus* species in the orchard habitats. In 1985, 64 species of wild bees were collected in uncultivated habitats and 35 species in orchard habitats. Fifty non-*Bombus* species were collected in the uncultivated habitats, compared to 27 non-*Bombus* species in the orchard habitats. These results are similar to those obtained in a study in the Fraser Valley of B. C. on berry crops (MacKenzie and Winston 1984), where it was determined that higher diversity of wild bee pollinators on natural vegetation was due primarily to 38 non-*Bombus* species bees collected, as compared with only 9 non-*Bombus* species (only 2% of bees collected) on cultivated blueberry, raspberry and cranberry.

Human effects on and near agricultural ecosystems are also responsible for reducing the abundance and diversity of wild bees in orchard habitats. Pesticides such as azinphos-methyl (Guthion), diazinon and malathion are used extensively in orchards in the Okanagan Valley, and the impact of these pesticides on honey bees as well as wild bee pollinators is well-known (Kevan 1975; Kevan and LaBerge 1978). A greater susceptibility of smaller, wild bees to pesticides (Johansen 1972; Plowright and Thaler 1978) may account in part for the low diversity and abundance of wild bees in the orchard habitats.

Competition with honey bees may be another reason for low diversity and abundance of wild bees in orchard habitats, because most orchardists rent honey bee colonies during the blooming period for pollination. These pollination units are recommended at the rate of 3 to 5 colonies per ha, depending on the fruit crop to be pollinated. Although capture rates for honey bees were not calculated in this study, it was evident that more honey bees than wild bees were present at the orchard habitats during the bloom period, which is consistent with the hypothesis that competition with honey bees reduces wild pollinator populations (Eickwort and Ginsberg 1980; Roubik 1978; Wratt 1968).

A contributing factor in reducing wild bee populations in other areas has been nest habitat destruction (Dorr and Marten 1966; Marucci and Moulter 1977; Johansen and Shawa 1974; Martin 1966; Donovan 1980; Batra 1984; Morgan and Percival 1967). Changes in agricultural practices resulting in increased field size and monocultural operations have absorbed surrounding natural habitat and decreased the amount of land avaliable for wild bee nesting sites. The density of orchards and the growth of residential areas in the Okanagan Valley have probably reduced nesting sites and therefore wild bee populations.

Finally, low plant diversity in orchard habitats would likely result in reduced wild bee populations. The total number of plant species found in the orchard habitats was considerably lower than in uncultivated habitats in both 1984 and 1985 (Table 2 and 3). In addition, many wild bees specialize on a restricted number of closely related plant species and thus have a very short adult life and distribution synchronized with bloom periods of these plants (Cruden 1972; Heinrich 1975, 1976).

II. Annual Distribution Patterns

Mean capture rates for ONN and UNO were significantly different between years (Table 5), indicating substantial annual fluctuations in the wild bee populations in these two habitats. In late April 1984, unseasonal weather conditions resulting in six nights of heavy frost during full bloom in cherries and pink bud stage in apples may have accounted for population fluctuations in the ONN and UNO habitats. Available forage for honey bees and wild bees in orchards would have been substantially reduced, since a large percentage of the blooms were destroyed by frost. Consequently, competition for forage within orchards would have increased, possibly forcing wild bees to forage on the hardier native flora in adjacent uncultivated habitats. This change in habitat could have accounted for the significantly lower abundance of wild bees in ONN during 1984 compared to 1985 and the significantly higher abundance of bees in UNO during 1984 compared to 1985. Heavy rainfall also could have destroyed individual nests, nesting sites and brood at specific collection areas, resulting in population variations between habitats which may not occur on a regular basis.

The second factor affecting population fluctuations of wild bee pollinators may have been the instability of wild bees inhabiting an ecotone ("edge") or zone of intergradation between open pasture and orchard habitat. Ranney (1977) reviewed the major features of an "edge" between forested and non-forested land, an ecotone which is analogous to that between orchards and open pasture in this study. Steep gradients of wind flow, mositure, temperature and solar radiation occur between open and forested areas. Greater wind velocity and increased solar radiation at the forest edge creates warm xeric conditions in and around the zone of intergradation. Since wild bee populations are most abundant and diverse under warm temperate, xeric conditions (Michener 1979), the "edge" between orchards and open pastureland may be highly attractive to wild bee species for nesting and foraging. Furthermore, the close proximity of large patches of early spring forage, as represented by apples, cherries, pears, and crabapples, would also make UNO habitats highly attractive to wild bee species that emerge early in the season. These conclusions are supported in part by 1985 data which indicate higher diversity and significantly higher abundance of wild bee species in ONN compared to OFN sites (Table 4). However, abundance and diversity of wild bees in UNO and UFO sites were similar (47 and 50 species, respectively) despite the presence of ecotones in UNO sites (Table 4). In studies of this short duration it is difficult to ascertain which year represents the "norm" or "average" conditions in the community, but 1984 was likely more "abnormal" than 1985 because of the unusual weather conditions encountered.

Variable resource usage by wild polylectic bees in all habitats (Fig. 1a and 1b) make it difficult to predict floral visitation patterns. Therefore, orchardists cannot rely on a substantial and predictable contribution to pollination of fruit crops by unmanaged wild bee species.

Although capture rates were low for *Bombus* species in 1984 and 1985 (Fig. 3), fairly constant abundance patterns indicate that bumble bees would be more dependable pollinators than non-*Bombus* species in the Okanagan Valley. Inclement weather seems to affect activity of *Bombus* species less than non-*Bombus* species since the former are better able to regulate their body temperatures and are therefore capable of surviving and foraging in conditions which are less than optimal for either honey bees or non-*Bombus* species (Heinrich 1979). In a management system for *Bombus* species, the problem of low capture rates encountered under natural conditions could be improved by trap-nesting, rearing and overwintering them for release into target crops during pollination the following spring. Management of bumble bees for orchard crop pollination in the Okanagan Valley may be feasible since two of the dominant wild bees species in the orchard habitats were *Bombus t. occidentalis* and *B. b. nearcticus*.

Fluctuations in abundance for non-*Bombus* species in 1984 and 1985 (Fig. 3), with a substantial reduction in abundance in the middle of the bloom period, indicate that wild bees are unreliable as pollinators in orchards under natural conditions. Non-*Bombus* species are susceptible to inclement weather conditions which can occur during the spring in the Okanagan Valley. During periods of less than optimal weather conditions, non-*Bombus* species will refrain from foraging as they are unable to regulate body temperature as well as *Bombus* species. The first peak in non-*Bombus* species abundance during 1984 (7 to 14 May) (Fig. 3), possibly representing a spring emergence, may have been delayed by the unseasonal weather conditions encountered near the end of April and could correspond to the peak in non-*Bombus* species abundance encountered 14 to 21 April 1985.

III. Orchard Pollination Ecology

Brittain *et al.* (1933), collected 13.56–18.06 wild bees/h in apple orchards during the bloom period. They also determined that the average number of wild bees taken at all stations for all years indicated an effective pollinator population equal to that released by one honey bee colony per acre (one acre = 0.41 ha). In comparison, my studies indicated a much smaller population of wild bees foraging in orchard habitats in the Okanagan Valley. During 1984, capture rates in OFN were 3.76 bees/hr, and 2.36 bees/hr in the ONN (Table 4). In 1985, capture rates in OFN were 2.52 bees/hr, and 5.82 bees/hr in ONN (Table 4). According to Brittain *et al.* (1933), the number of wild bees present in my study would not have been adequate for fruit crop pollination.

However, in 1984 and 1985, respectively, we found that the abundance of wild bees in the uncultivated habitats were close to and slightly lower than the level suggested by Brittain *et al.* (1933) for adequate apple pollination. Capture rates in the uncultivated habitats suggest that there is a sufficiently abundant population of wild bees in natural habitats surrounding orchards to act as pollinators of fruit crops.

In both sweet cherries and apples, three to five honey bee colonies per ha of orchard are recommended for adequate fruit set to occur (McGregor 1976; Philp 1930, 1947; Stephen 1961). Considering this recommendation and Brittain *et al.*'s (1933) suggestion that 13.56–18.06 bees/h is equivalent to one honey bee colony per 0.41 ha of orchard, it is clear that there are insufficient numbers of wild bees in the Okanagan Valley orchards to pollinate apples and cherries (Table 4). Furthermore, the number of hives reccommended for pollination of pears is double that of apples and cherries (Corner *et al.* 1964), suggesting that even the number of wild bees available in uncultivated habitats of the Okanagan Valley would be insufficient for pear pollination.

Studies in the Fraser Valley of B. C., have determined that wild bees are not present in sufficient numbers to pollinate commercial blueberry, cranberry and raspberry crops (Winston and Graf 1982). The average capture rate of wild bees in blueberries, cranberries and raspberries were 2.08–12.76 bees/h, 5.33–10.89 bees/h and 1.20–2.10 bees/h respectively. All were well below the recommended levels of pollinators needed to adequately pollinate these crops (Wood *et al.* 1967; McGregor 1976; Kevan and LaBerge 1978). Although MacKenzie and Winston (1984) found capture rates of wild bees in 1982 to be significantly higher than in 1981 (Winston and Graf 1983), population levels were still well below those recommended for adequate pollination of these berry crops.

IV. Implications for Pollination Management

The results demonstrate that, although they are abundant in natural habitats, annual population fluctuations and lower numbers during the spring pollination period decrease the reliability and predictability of unmanaged wild bees for tree fruit pollination in the Okanagan Valley. However, the management of dominant wild bee species which display a strong tendency toward foraging on orchard crops does have potential for fruit crop pollination. *Bombus terricola occidentalis* and *B. bifarius nearcticus*, two of the dominant species in orchard habitats, are potentially manageable. Bumble bees have relatively stable populations from year to year regardless of weather conditions. Methods of rearing and management have been developed for several *Bombus* species and may be adaptable to pollination management systems (Plowright and Jay 1966; Morgan and Percival 1967). In addition, *Bombus* species possess several characteristics which are particularly suitable for tree fruit pollination in the Okanagan Valley:

1. They emerge earlier in the spring than most wild bees and can regulate their body temperatures (Heinrich 1979), enabling them to forage in colder weather than both honey bees and non-*Bombus* species. This characteristic is especially important since cold inclement weather is often encountered during the early spring pollination period for apples, cherries, and pears in the Okanagan Valley;
2. Bumble bees are less susceptible to pesticides than the smaller wild bees (Johansen 1977); and
3. Although precise studies on the foraging behavior of *Bombus* species on fruit trees are required, Brown (1951) and Menke (1951) both agree that bumble bees fly from tree to tree more readily than honey bees and are thus potentially better cross-pollinators. In addition, *Bombus* species are large and hairy, and make contact with the stigma on most visits whether collecting pollen or nectar.

Hapropoda cineraria, the other dominant wild bee in orchard habitats, may have limited potential as a tree fruit pollinator since all specimens captured were observed collecting nectar by hovering rather than landing on receptive apple and cherry blossoms, therefore decreasing the chances of pollen transfer. No *H. cineraria* were captured while collecting pollen from apple and cherry blossoms.

Although *Osmia lignaria propinqua* was not a dominant species in orchard habitats it has potential for tree fruit pollination in the Okanagan Valley since it is indigenous to this area and management systems for fruit tree pollination have already been established (Torchio 1976, 1982b, 1984, 1986). Additional information on the nesting behavior, nesting habitats and annual population levels of *O. l. propinqua* in the Okanagan Valley would be useful for successful adaption of the management system utilized in the western U.S.

The remaining dominant wild bee species, *Halictus confusus*, *Dialictus laevissimus*, *D. pruinosus*, *Dialictus sp. 2*, *Dialictus sp. 5* and *Dialictus sp. 6*, have minimal potential as tree fruit pollinators in this area because of infrequent foraging on orchard crops and reduced abundance during the bloom period.

In an effort to maintain indigenous populations of *Bombus terricola occidentalis*, *B. bifarius nearcticus* and *Osmia lignaria propinqua* in the Okanagan Valley for trap-nesting and utilization in fruit tree pollination management systems, enhancement of unculitvated habitat used by these species for foraging, nesting and hibernation should be encouraged. A number of measures could be taken to provide additional forage for managed bee pollinators, including honey bees and these wild bee species. The blossom period for orchard crops is of short duration, therefore providing forage for managed bee pollinators for a restricted period of the season. In addition, the reduced diversity of cultivated and native plant species in areas of intensive orchard production restricts the plants available as nectar and pollen sources for the remainder of the season. Alternative nectar and pollen sources could be made available to managed bee pollinators by using uncultivated land near orchards to maintain a continuous sequence of nectar and pollen-producing plants. Uncultivated habitats, in and around orchards, could be seeded with flowering perennials, providing managed bee pollinators with alternative forage for the remainder of the growing season following completion of the bloom period for tree fruit crops. Perennial plantings would maintain managed wild bee populations in close proximity to orchards, provide alternative forage in case of tree fruit blossom damage as occurred in April 1984 with frost-kill, and minimize the impact of a dearth on the following year's wild bee generation. There are a number of wild plants including *Rosa nutkana*, *Balsamorhiza sagittata*, *Berberis aquifolium*, *Fragaria virginiana* and *Amelanchier alnifolia* which could be planted or maintained in uncultivated habitats near orchards as alternative forage.

The planting of understory crops in orchards which would complement the flowering cycles of various fruit crops could also result in retaining populations of both managed wild bees and honey bees in and near orchards during the bloom period. There have been contradictory reports on the advantages and disadvantages of ***Taraxacum officinale*** (dandelion) as an understory crop in orchards (Free, 1968; Kremer 1950; reviewed by Jay 1986). It is generally recommended that dandelion be removed from orchards prior to the bloom period because it is considered to be a competitive rather than complementary vegetation, attracting a large number of foraging bees from the fruit bloom (Corner *et al.* 1964). The 1984 capture rate of wild bees on dandelion in orchard habitats was 10.57 bees/h, which was higher than the number of bees foraging on the target fruit crops (apples=3.74 bees/h; cherries=3.64 bees/h; crabapples=7.14 bees/h; pears=0.0 bees/h). Extensive damage to fruit blooms due to frost may have caused wild bees to forage on dandelion and late-blooming crabapples as alternative forage, thus avoiding the loss of a substanital number of bees. In support of this conclusion, capture rates in orchard habitats in 1985 indicated that dandelion (3.45 bees/h) did not distract foragers from visiting tree fruit blossoms (apples=8.28 bees/h; cherries=2.64 bees/h; crabapples=4.36 bees/h; pears=0.0 bees/h) and may have acted as a complementary crop by maintaining wild and honey bees in orchards. The wild bee species which I have recommended as potentially manageable and suitable for tree fruit pollination in the Okanagan Valley, *Bombus terricola occidentalis*, *B. bifarius nearcticus* and *Osmia lignaria propinqua*, do not exhibit a strong tendency towards foraging on dandelion when tree fruit blossoms are available, but will utilize this wild plant as alternative forage.

For management systems which utilize honey bees as the primary insect pollinators and in pear orchards which are less attractive to bee pollinators, I do not recommend the use of *T. officinale* as a complementary understory plant, since dandelions distract a large portion of the foragers from the tree fruit blossoms. However, the use of *T. officinale* as a complementary understory plant in apple and cherry orchards employing a multi-species pollinator system (managed wild bee species supplemented with honey bees) may be feasible, since the wild bee species I have suggested as manageable for tree fruit pollination in the Okanagan Valley will continue to forage on fruit blossoms in the presence of dandelion.

PART B

A COMPARISON OF THE POLLINATION EFFICACIES OF HONEY BEES, *APIS MELLIFERA* L. AND *OSMIA LIGNARIA PROPINQUA* CRESSON ON RED DELICIOUS APPLES

INTRODUCTION

The primary agents of cross-pollination in orchard crops are bee pollinators. Historically, the honey bee (*Apis mellifera* L.) has been relied upon for managed pollination of orchard and agricultural crops world-wide. In recent years, the management and utilization of wild bee species for crop pollination has also been promoted. *Osmia lignaria propinqua* Cresson is a North American species now in the final stages of development as a pollinator of almond (Torchio 1979, 1981a, 1981b) and apple (Torchio 1976, 1982b, 1984, 1986) crops. Since *O. lignaria* is indigenous to the Okanagan Valley, its domestication and management as an apple and possibly a cherry pollinator in this region is feasible. A comparison of honey bee and *O. lignaria* pollination characteristics which are considered beneficial for domesticated orchard pollinators would be helpful in determining the feasability of such a program (Table 7; for references in following discussion, see Table 7).

Pollination management systems for *O. lignaria* are more economical and less labor intensive than honey bee management systems. Since *O. lignaria* is an obligatory univoltine species, transportation of nesting populations throughout the summer is unneccessary, as is feeding and medication for overwintering populations. In comparison to honey bee colonies, *O. lignaria* nests and nesting materials are relatively light and require fewer pieces of expensive equipment than are required to move and transport honey bee pollination colonies.

Morphological characteristics and foraging behavior of these bees should be associated with their potential for transporting pollen between cultivars in orchard environments. Honey bees and *O. lignaria* carry large quantities of dry pollen which is available for transfer to receptive stigmatic surfaces. Unlike honey bee drones, male *O. lignaria* also forage on blossoms, thereby contributing to the foraging field force. However, they are less efficient at carrying pollen than female *O. lignaria* because they do not have a scopa on the venter of the abdomen.

Table 7. A comparison of honey bee, *Apis mellifera* L. and *Osmia lignaria propinqua* Cresson characteristics relevant for orchard pollination.

	Bee Pollinator	
Characteristic	*Osmia lignaria*	*Apis mellifera*
Pollination management systems	not labor intensive and relatively inexpensive (Torchio 1976, 1979)	labor intensive compared to *O. lignaria* (McGregor 1976; Waller 1980)
	univoltine, available only for early spring pollination (Torchio & Tepedino 1980)	with proper management, honey bees can be available throughout the entire pollination or growing season (McGregor 1976)
Crops pollinated	effective cross-pollinator of apples, prunes, almonds and potentially cherries (Torchio 1976, 1979, 1981a, 1981b, 1982a, 1982b, 1984; Kuhn and Ambrose 1984)	effective cross-pollinator of at least 100 crops including apples, prunes, almonds and cherries (McGregor 1976)
Morphology	females have scopae on venter of abdomen, carry pollen in dry state (Torchio[a], pers. comm.; Michener 1944)	plumose hairs on entire body retain large quantities of pollen in dry state (Gary 1982)
	males will also forage on blossoms (Torchio[a], pers. comm.; Kuhn & Ambrose 1984) but they do not have a scopa (Michener 1944); therefore they are less efficient at pollen transfer	drones do not forage and therefore are not involved in cross-pollination

Table 7. cont.

Characteristic	*Osmia lignaria*	*Apis mellifera*
Foraging Behavior	daily flight initiated at 13.2°C (Torchio 1986)	daily flight initiated from 10°C to 13°C (Gary 1982; Boyle-Makowski & Philogene 1985)
	polylectic bees, opportunistic foragers, collecting from mainly one source at a time and from other sources less frequently (Torchio 1976)	polylectic bees, opportunistic foragers, will forage on single species but shift throughout the season (Gary 1982)
	no sideworkers, both sexes land on the stigma of a flower to collect nectar and/or pollen (Torchio 1986)	sideworkers abundant especially on Red Delicious apples, not effective pollinators and reduce fruit set (Robinson & Fell 1981; Kuhn & Ambrose 1984)
	visits few blossoms/tree but many trees/foraging trip, facilitating cross-pollination (Torchio[a], pers. comm.)	visits many blossoms/tree but few trees/foraging trip (Horticultural Education Association 1967), but bee-to-bee pollen transfer within hives may facilitate cross-pollination (DeGrandi-Hoffman *et al.* 1984)
	individuals do not orient to particular trees or rows of trees during the collection of pollen and nectar resources (Torchio[a], pers. comm.)	within row foraging occurs in orchards (Momers 1948)

Table 7. cont.

Characteristic	*Osmia lignaria*	*Apis mellifera*
	flies short distances to collect nectar and pollen when bloom is adequate (Parker & Torchio 1980)	0.4 km is normal foraging distance from colony when collecting pollen (Eckert 1933)
	successfully competes with other pollinators (Parker & Torchio 1980)	successfully competes with other pollinators
Distribution	indigenous to western U.S. and southern Canada (Rust 1974)	not native, introduced and presently widespread in North America adapts to many climates including cold continental types (McGregor 1980)
Recommended numbers in orchards	as few as 618 nesting females will adequately pollinate one hectare of apples (247 trees/ha)(Torchio 1986)	3 colonies/ha of apples(247 trees/ha) = 14,400 field foragers is recommended (McGregor 1976; Mayer 1983; Humphry-Baker *et al.* 1975)

[a] P.F. Torchio, U.S.D.A. Bee Biology and Systematics Laboratory, SEA, Logan, Utah, 84322, U.S.A.

Honey bees collecting pollen walk on the anthers and usually are effective in transferring pollen to the stigma. Sideworkers are nectar collectors that slip their proboscis between the base of filaments and do not contact the anther or stigma except by accident. They are a major problem in Red Delicious apples and effectively reduce fruit set. There are no sideworkers in *O. lignaria* and both sexes contact the sexual column of blossoms to collect nectar and/or pollen.

The temperature at which flight and foraging are initated is very important, especially in fruit growing regions such as the Okanagan Valley which may experience relatively cool weather during spring pollination. Honey bee flight is initiated from 10°C to 13°C, while *O. lignaria* flight initiation begins at approximately 13°C. This gives the honey bee a slight edge, although minimal flight activity is observed below 12°C.

Foraging patterns in orchards are important because they determine whether pollinators will facilitate cross-pollination by contacting pollenizer varieties which are interplanted throughout the orchard. *O. lignaria* visits few blossoms per tree, many trees per foraging trip, and does not forage within rows. This behavior facilitates the chance of pollenizer contact and cross-pollination. In comparison, honey bees visit many blossoms per tree, few trees per foraging trip and tend to forage within rows, minimizing the likelihood of pollenizer contact and cross-pollination. However, recent studies have determined that bee-to-bee transfer of pollen within hives facilitates cross-pollination and alleviates the potentially detrimental effects of in-orchard foraging behavior.

Torchio (1986) indicates that as few as 618 nesting female *O. lignaria* would be necessary to adequately pollinate one hectare of apples (247 trees/ha). Comparable recommendations for honey bees would be three colonies per hectare containing approximately 14,400 effective field foragers, excluding sideworkers.

It is evident from the above comparison that honey bees and *O. lignaria* possess different advantageous characteristics which make them suitable pollinators for orchard crops. One factor which has not been investigated, however, is their relative efficacy per visit at pollinating apple blossoms. Many abiotic factors in orchards, including soil moisture and fertility, tree nutrition, tree spacing and pollenizer placement, have a role in fruit set and quality (Humphry-Baker *et al.* 1975). However, the efficiency with which pollen is transfered and deposited on the stigmatic surface of a receptive blossom by bee pollinators is generally considered to be of primary importance in fruit development (Free 1970).

Apple blossoms consist of five stigmas which unite to form a single style leading to the ovary. The ovary is divided into five carpels, each containing two ovules (four in the case of "Northern Spy") so that 10 (or 20 seeds in "Northern Spy") may develop (reviewed by McGregor 1976). Hormones produced in the seed affect fruit growth, fruit set and general hormonal balance of the tree (Luckwill 1949; Westwood 1978). It is not necessary in apples for all ovules to develop, and fruit may be produced with less than a full complement of seeds. In many varieties, including Red Delicious, low seed numbers are associated with the development of misshapen fruits, because the flesh cells of the fruit are preferentially stimulated in the region of the ovaries containing fertilized ovules (Schander 1955). Therefore, the shape of an apple is, to a large extent, dependent on the number of seeded versus seedless carpels per fruit (Free 1970), with misshapen fruit having one or more seedless carpels. In addition, the size and weight of fruit are influenced by seed number and the correlation is generally positive (Schander 1955; reviewed by Lane 1981).

A number of studies on various agricultural crops, including cantaloupes and watermelons, have determined that the numbers of visits by honey bees to blossoms results in increased seed production and fruit weight (reviewed by McGregor 1976; McGregor *et al.* 1965; Alderz 1966). For successful pollination of apple blossoms to occur the need for multiple bee visits may be necessary so that 1) an adequate amount of viable, compatible pollen will be deposited on the stigmatic surface of the receptive blossom, and, 2) a relatively uniform distribution of pollen grains over all stigmatic lobes occurs for the production of symmetrical fruit. This is the case for a number of other agricultural crops (Aldertz 1966; Mann 1943). Visser and Verhaegh (1980) found that by hand-pollinating apple cultivars twice with compatible pollen at an interval of one or two days, twice as many seeds per pollinated blossom resulted than from single pollinations. They suggested that the first pollen appears to pave the way for the second and was therefore called "pioneer pollen". From an economic standpoint, larger, symmetrical fruit are more marketable than stunted, misshapen fruit. Therefore, studies which attempt to determine the number of bee pollinator visits required to maximize fruit quality are not only necessary to compare pollination efficacies of different bee species, but will assist in maintaining or improving the market value of tree fruit crops.

The objectives of this study were to:

1. Compare the pollination efficacy of honey bees and *O. lignaria* on Red Delicious apple fruit set, weight and shape; and,
2. Evaluate the effect of multiple visits by honey bees to Red Delicious blossoms with regard to fruit set, weight and shape.

MATERIALS AND METHODS

On 24 April 1985, screened enclosures (3.7 x 3.7 x 2.1 m) were constructed around four mature semi-dwarf Red Delicious apple trees in a small orchard block of approximately 45 trees at the Agriculture Canada Research Station, Summerland, B. C. Trees were approximately 10 years old. It was originally proposed that eight treatments be tested on each of the four trees including one to three visits by honey bees, one to three visits by *O. lignaria*, and two control treatments. The controls were 1) Control A: blossom clusters were thinned leaving the king blossom (i.e. terminal blossom in a cluster) and two laterals and bagged to prevent pollination from occurring during the entire experiment; and, 2) Control B: blossom clusters were thinned as previously described but were allowed unlimited pollination throughout the experiment. Due to problems encountered with *O. lignaria* release and escape from the screened enclosures, only the one visit treatment by this bee was tested, reducing the total number of treatments in each screened enclosure to six.

Prior to the opening of the king blossoms, bags made of mosquito netting were placed over entire limbs and secured at both ends to prevent bee pollinators from contacting receptive blossoms. On 3 May 1985, one *O. lignaria* nesting shelter (as described by Torchio, 1979) was placed in each of the screened enclosures. Shelters were rectangular, plywood boxes (each 0.9 m wide, 0.61 m high, and 0.5 m deep) with one 0.9 m side open and facing south. Nesting shelters were supported 1.3 m above the ground surface by four wooden stakes driven into the soil and attached to the box.

Nests were prepared by cutting the top from two-litre milk cartons to form a rectangular box, 9.5 x 9.5 x 20 cm long. Squares of plywood (9.5 x 9.5 x 1.5 cm) with 25 holes (8 mm diameter) drilled through each unit were prepared and placed into the open face of the milk carton. Paper straws (19.7 cm long with a 7 mm inside diameter) were inserted into the milk cartons through the drilled holes. Nine nest boxes were placed in each of the nest shelters (225 nest holes/shelter).

Cocoons containing live, torpid adult *O. lignaria* (214 females and 345 males) arrived from Logan, Utah[2] on 18 March 1985. The torpid adults had been collected from trap-nests the previous fall, placed in individual clear, #000 gelatin capsules, and stored at a constant 4° C. This temperature was maintained during transportion to Simon Fraser University and following arrival. Prior to their release, torpid adults were placed at room temperature (21° C) until they had emerged from the cocoon but were still in the capsule. These capsules were then recooled to 4° C so that all adults would be at the same stage for release. On 7 May 1985, adults were left a room temperature for six hours and then removed from the capsules for release into the screened enclosures. The number of females and males released in each of the enclosures was 34 and 57 respectively. The percent mortality from the original shipment of adults was 36.4 and 34.2 percent for females and males respectively. In each screened enclosure 6.6 nest holes per female were made available, which is slightly more than the number Torchio (1979) recommends (4.6 nest holes/female). *O. lignaria* were allowed a 24 hr reorientation period prior to the commencement of pollinator visitation counts to receptive blossoms. All blossoms in the screened enclosures were bagged prior to the release of bees. Mating and foraging of *O. lignaria* were observed following their release in screened enclosures. No nest initiation occurred during the entire pollination period and the number of individuals in the screened enclosures decreased over the course of the experiment, possibly due to escape under the screened panels.

A small, four-frame nucleus of honey bees, containing a queen, one frame of brood, two frames of workers and one frame of honey was introduced into each of the four screened enclosures on the same day the *O. lignaria* were introduced. The honey bees were also allowed a 24 hr reorientation period.

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A thermohygrograph was placed in a Stevensons screen and positioned in the orchard on the same day the bee pollinators were released in the screened enclosures. A pan of water for the bee pollinators and a bouquet of crabapple varieties cross-compatible with Red Delicious apple were also placed in the enclosures. The bouquets provided a pollen source for cross-pollination since the honey bees and *O. lignaria* were restricted to the enclosures and would not have contact with other potential pollenizer varieties in the orchard. The crabapple varieties used were Gary, Hojer R15, Baccata Rosthern R15, and Red Splendor R15. Bouquets were replaced every 24 hr. Honey bees and *O. lignaria* were observed foraging on the bouquets of crabapples throughout the experiment.

A similar experiment was conducted outdoors in an orchard planted with standard rootstock Red Delicious and Spartan apple varieties, in Rutland, B. C. Trees were approximately 25 years old. Four treatments were tested on three Red Delicious apple trees including one or two honey bee visits and the same two control treatments used in the screened enclosures. *O. lignaria* were not observed in this experiment. Limb bagging of blossom clusters was completed on 12 May 1985. On 13 May 1985, three pollination colonies, as described in Part C, were placed in the orchard. These colonies were allowed a 24 hr reorientation period prior to the commencement of honey bee visitation counts.

Pollinator visit counting was started on 11 May in screened enclosures and 14 May outdoors. The procedure involved 1) removal of the bags to expose several blossom clusters, 2) watching the king blossoms constantly until a predetermined number of either honey bees or *O. lignaria* had visited the receptive blossoms and contacted the stigmatic surface, 3) removal of petals following the visits to deter further attraction of the blossom to bee pollinators, 4) removal of all except the king blossom and two laterals from the cluster to reduce potential competition between developing fruit, and 5) tagging of the king blossoms with metal plant tags. Orchardists prefer to have the king blossoms set in many apple varieties, including Red Delicious, because these blossoms open first and produce the best fruit (McGregor 1976). Pollinator visit counting was completed in screened enclosures on 15 May and on 17 May outdoors. The screened enclosures were dismantled on 16 May.

Pollinator visit times (PVT = flight time to receptive blossom + time spent in contact with the stigmatic surface) were recorded in the screened enclosures and outdoors for honey bees and in the screened enclosures for *O. lignaria*. PVT were recorded between 1000 and 1500 hr while blossom visits were being recorded.

On 28 and 29 September 1985, tagged apples were picked from the trees used in the screened enclosures and outdoor studies. This was approximately seven days prior to the average harvest date of Red Delicious apples in the Okanagan Valley. The tagged apples were transported to Simon Fraser University where they were weighed and halved horizontally to expose the carpels. The number of seeds per carpel and the classification of the seeds were determined. Three seed classifications were established including, 1) Viable Seeds - endosperm gorged, seed coat fully developed, and length normal; 2) Non-Viable Seeds - endosperm collapsed, seed coat fully developed, and length normal; and 3) Aborted Seeds - unfertilized and length abnormally reduced (0.1 - 0.3 mm). Carpels containing only aborted seeds were designated seedless since unfertilized embryos do not secrete hormones which stimulate flesh cell growth. (Westwood 1978).

For the purposes of this paper, pollination efficacy will be defined as the effect of pollination on percent fruit set, fruit weight, and fruit shape. A comparison of the relative pollination efficacy of honey bees and *O. lignaria* using the previously described components was completed for screened enclosures and outdoors. In addition, pollinator visit times and the pollination index (PI) were used to determined pollination efficacy of treatments. The PI (= number of seeds per pollinated blossom) is an overall expression of pollinator efficacy (Visser and Verhaegh 1980).

Data from the screened enclosure and outdoor experiments were subjected to analysis of variance, and means were compared using Student–Newman–Keuls multiple range test at the $P \leq 0.05$ level. Correlation analysis was used to determine relationships between the mean number of viable seeds per fruit and mean fruit weight.

RESULTS

Data from one of the trees in the screened enlcosure study was not used in the analysis since ANOVA indicated that mean fruit weight and mean number of viable seeds per fruit were significantly different from the other three trees ($p < 0.05$) . Fruit weight and number of viable seeds per fruit were not significantly different for the remaining trees, so data were pooled for analysis.

There were no significant differences between one OL visit or one to three HB visits in mean fruit weight and mean number of viable seeds per fruit ($p < 0.05$, Table 8). However, significant differences ($p < 0.05$) in these characteristics were found between controls and between controls and bee pollinator visitation treatments (Table 8).

Percent fruit set in screened enclosures was substantially higher than what is expected under normal pollination conditions (Table 8). Apple trees may shed 95 percent or more of their flowers and young fruits prior to harvest (Westwood 1978), but an economic yield from an acre of mature apples results when approximately 5 percent fruit set occurs (Horticultural Education Association 1967). Control A (32%) had the lowest fruit set of all treatments. One OL visit resulted in higher percent fruit set (65%) than any of the HB visit treatments. One HB visit resulted in higher percent fruit set (53%) than two or three HB visits (43% and 41%, respectively). Two and three HB visits resulted in fruit sets comparable to Control B (45%).

The pollination index (PI) for Control A (PI=1.43) was the lowest of any of the treatments in screened enclosures, while Control B had the highest (PI=2.85) (Table 8). One HB visit resulted in a higher pollination index (PI=2.72) than one OL visit (PI=2.35) and two (PI=2.32) or three HB visits (PI=2.18).

Table 8 . The effect of one to three honey bee (HB) and one *Osmia lignaria* (OL) visit on Red Delicious apple fruit weight, fruit set, mean seed set per fruit and mean seed set per blossom (PI[a]) in screened enclosures.

Treatment	No. of Flowers in Treatment	% Fruit Set (A)	$\bar{x}$ Fruit Weight (g) ±S.E.[b]	$\bar{x}$ No. Viable Seeds per Fruit ±S.E. (B)	$\bar{x}$ No. Viable Seeds per Blossoms (PI)
1 visit-OL	20	65	119.96±16.87 ab	3.62±0.91 a	2.35
1 visit-HB	119	53	120.71± 6.00 a	5.13±0.39 ab	2.72
2 visits-HB	113	43	98.78± 6.45 a	5.39±0.41 ab	2.32
3 visits-HB	94	41	108.03± 6.91 a	5.31±0.48 ab	2.18
Control A	60	32	93.43± 6.10 a	4.47±0.46 ab	1.43
Control B	60	45	155.29± 8.36 b	6.56±0.48 b	2.95

[a] PI=Pollination Index derived A x B

[b] Means within a column followed by the same letter are not significantly different ($P<0.05$ level, Student-Newman-Keuls test).

In the screened enclosures, one OL visit resulted in significantly more ($p < 0.05$) seedless carpels per fruit than Control B (Table 9). There were no significant differences ($p < 0.05$) in the mean number of seedless carpels found in one OL visit, one to three HB visits, or Control A, although a greater number of seedless carpels was evident for one OL visit. The mean number of seedless carpels per fruit was not significantly different ($p < 0.05$) for one to three HB visits and Control A (Table 9).

In the screened enclosure experiment, significant positive correlations ($p < 0.05$) were found when the number of viable seeds per fruit were correlated with fruit weight for one OL visit ($r=.693$), one to three HB visits ($r=.669$; $r=.623$; $r=.443$, respectively) and Control B ($r=.484$) (Fig. 4).

In the outdoor experiment, initial analysis of data indicated no significant differences ($p < 0.05$) between the three trees used in the study. Therefore, data were pooled for analysis. There were no significant differences between one and two HB visits or Control A and B in mean fruit weight and mean number of viable seeds per fruit ($p < 0.05$, Table 10).

Percent fruit set was lower for Control A than for any of the other treatments (7%) (Table 10). Two HB visits produced about the same fruit set (24%) as one HB visit (20%) or Control B (23%).

The pollination index for Control A was lower than any of the other treatments outdoors (PI=0.44) (Table 10). The pollination index for Control B was lower than either of the HB visitation treatments (PI=0.79). Two HB visits resulted in a slightly higher pollination index (PI=1.15) than one HB visit (PI=0.96).

In the outdoor experiment the mean number of seedless carpels per fruit was not significantly different ($p < 0.05$) for any of the four treatments (Table 9). However, Control B had the highest number of seedless carpels per fruit ($\bar{X}=1.93$), followed closely by one

Table 9. The effects of one to three honey bee (HB) and one *Osmia lignaria* (OL) visit on the mean number of seedless carpels per Red Delicious apple in screened enclosures and outdoors.

Location	Treatment	$\bar{x}$ No. of Seedless Carpels per Fruit ± S.E.[a]
Screened enclosures	1 visit - OL	2.38 ± 0.59 b
	1 visit - HB	1.42 ± 0.23 ab
	2 visits - HB	1.27 ± 0.21 ab
	3 visits - HB	1.49 ± 0.26 ab
	Control A	1.00 ± 0.32 ab
	Control B	.67 ± 0.19 a
Outdoors	1 visit - HB	1.56 ± 0.69 a
	2 visits - HB	1.22 ± 0.43 a
	Control A	.75 ± 0.48 a
	Control B	1.93 ± 0.45 a

[a] Means within a column followed by the same letter are not significantly different ($P < 0.05$ level, Student-Newman-Keuls test).

Fig. 4. Relationship of number of viable seeds per fruit and fruit weight for Red Delicious apples resulting from one of the following treatments in screened enclosures: one *Osmia lignaria* (OL) visit, one to three honey bee (HB) visits, Control A (blossom clusters thinned and no pollination allowed) or Control B (blossom clusters thinned and unlimited pollination allowed).

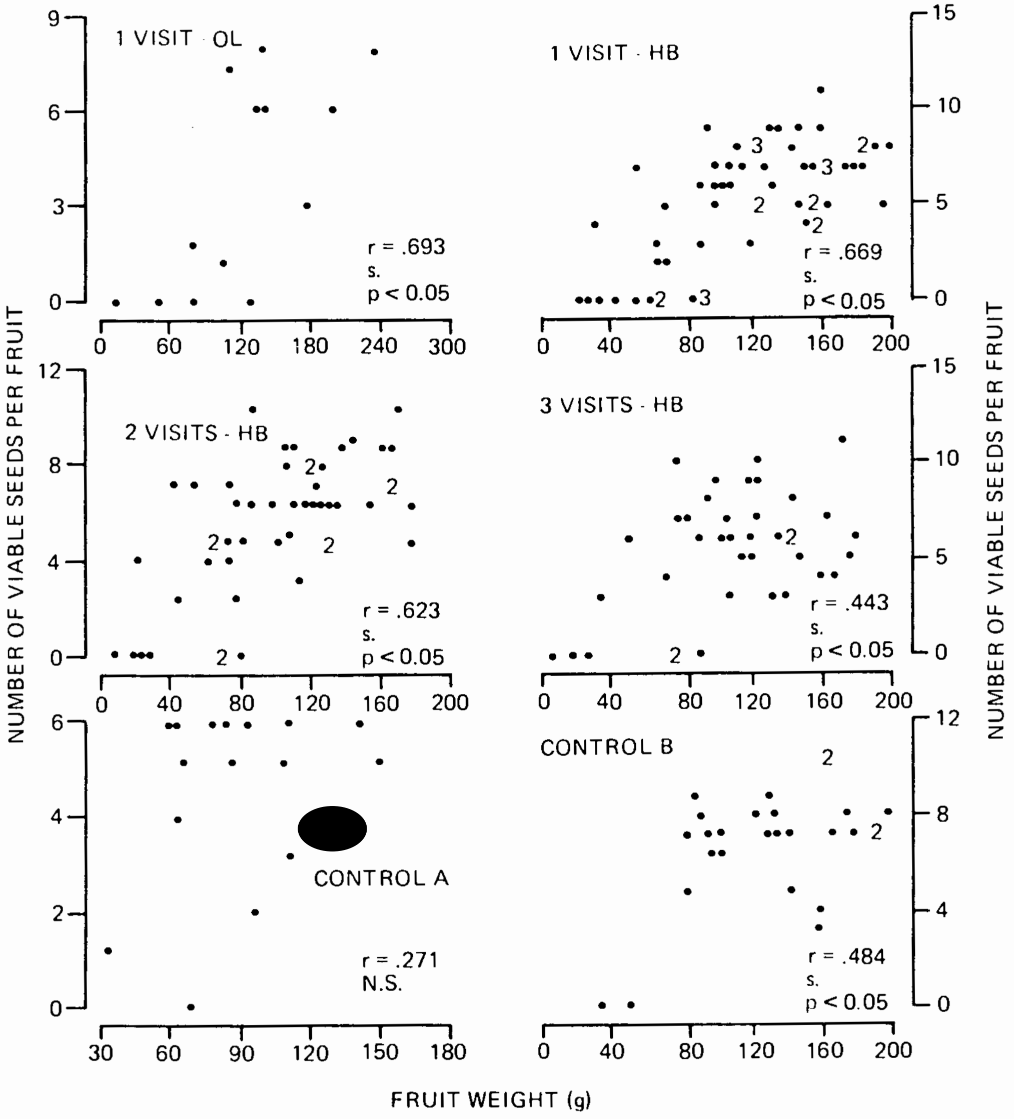

1 VISIT · OL
r = .693
s.
p < 0.05
1 VISIT · HB
r = .669
s.
p < 0.05
2 VISITS · HB
r = .623
s.
p < 0.05
3 VISITS · HB
r = .443
s.
p < 0.05
CONTROL A
r = .271
N.S.
CONTROL B
r = .484
s.
p < 0.05
NUMBER OF VIABLE SEEDS PER FRUIT
NUMBER OF VIABLE SEEDS PER FRUIT
FRUIT WEIGHT (g)
0
3
6
9
0
60
120
180
240
300
0
5
10
15
0
40
80
120
160
200
0
4
8
12
0
40
80
120
160
200
0
5
10
15
0
40
80
120
160
200
0
2
4
6
30
60
90
120
150
180
0
4
8
12
0
40
80
120
160
200

Table 10. The effect of one or two honey bee visits on Red Delicious apple on fruit weight, fruit set, mean seed set per fruit and mean seed set per pollinated blossom (PI[a]) outdoors.

Treatment	No. of Flowers in Treatment	% Fruit Set (A)	$\bar{x}$ Fruit Weight (g) ±S.E.[b]	$\bar{x}$ No. Viable Seeds per Fruit ±S.E. (B)	$\bar{x}$ No. Viable Seeds per Blossoms (PI)
1 visit	46	20	100.64± 8.34 ab	4.78±1.16 a	0.96
2 visits	37	24	127.84± 6.19 b	4.78±0.92 a	1.15
Control A	60	7	116.07±10.88 ab	6.25±0.85 a	0.44
Control B	60	23	93.61± 6.61 a	3.43±0.72 a	0.79

[a] PI=Pollination Index derived A x B

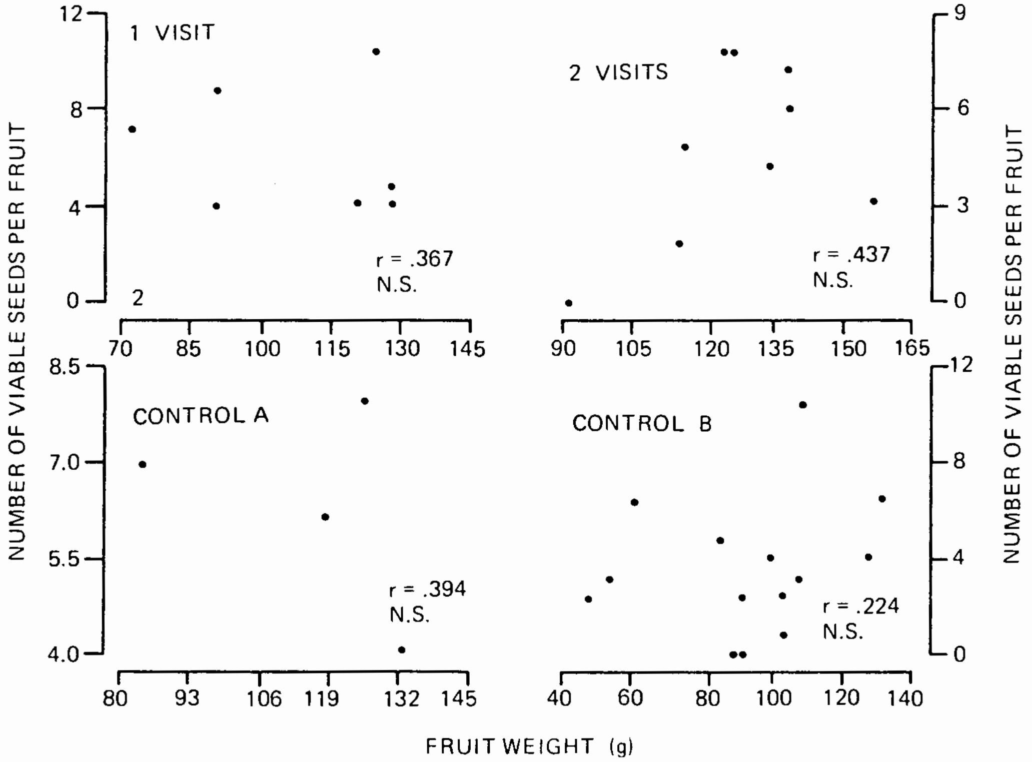
[b] Means within a column followed by the same letter are not significantly different (P<0.05 level, Student-Newman-Keuls test).

HB visit ($\bar{X}=1.56$).

In the outdoor experiment, no significant correlations were found when the number of viable seeds per fruit were correlated with fruit weight for any of the treatments ($p < 0.05$) (Fig. 5).

Honey bees in screened enclosures spent significantly less ($p < 0.05$) time searching for and collecting pollen from a receptive blossom than did *O. lignaria* (PVT, $\bar{X}= 13.9 + 0.92$ sec; PVT, $\bar{X}= 47.6 + 5.66$ sec, respectively). Honey bees outdoors spent significantly less ($p < 0.05$) time searching for and collecting pollen from a receptive blossom than either honey bees or *O. lignaria* in screened enclosures (PVT, $\bar{X}= 10.4 + 0.45$ sec)

Fig. 5. Relationship of number of viable seeds per fruit and fruit weight for Red Delicious apples resulting from one of the following treatments outdoors: one or two honey bee (HB) visits, Control A (blossoms clusters thinned and no pollination allowed) or Control B (blossom clusters thinned and unlimited pollination allowed).


1 VISIT
r = .367
N.S.
2 VISITS
r = .437
N.S.
CONTROL A
r = .394
N.S.
CONTROL B
r = .224
N.S.
2
NUMBER OF VIABLE SEEDS PER FRUIT
NUMBER OF VIABLE SEEDS PER FRUIT
FRUIT WEIGHT (g)
12
8
4
0
70
85
100
115
130
145
9
6
3
0
90
105
120
135
150
165
8.5
7.0
5.5
4.0
80
93
106
119
132
145
12
8
4
0
40
60
80
100
120
140

DISCUSSION

1. Treatment Effects

In the screened enclosure experiment, fruit set and weight and pollination indices were not different for one *O. lignaria* visit compared to one, two or three honey bee visits (Table 8). However, the results indicated a trend toward misshapened apples following one *O. lignaria* visit. Although the mean number of seedless carpels and viable seeds per fruit for one *O. lignaria* visit were not significantly different from one, two or three honey bee visits, there were substantially more empty carpels and fewer viable seeds than in the other treatments (Table 8 and 9). Misshapened fruit have one or more seedless carpels (Free 1970), and one to three honey bee visits all had at least one empty carpel, which also indicates a potential for assymmetrical fruit. However, the results for *O. lignaria* suggest that there is a proportionately greater possibility of this occurring compared to honey bees. As seeds develop following fertilization, they produce a sequence of hormones including indole auxins and gibberellins (Westwood 1978; Luckwill *et al.* 1969) which are related to fruit set and growth. Growth of the fruit cortex or tissue is stimulated to a greater degree if it is directly adjacent to ovaries containing developing seeds (Horticultural Education Association 1967). Therefore, lower seed numbers per fruit and increasing numbers of empty carpels would produce more severely misshapened fruit.

Pollinator visit times indicated that, in the confined conditions of the screened enclosures, *O. lignaria* spent a significantly longer time searching for and collecting pollen from receptive blossoms than did honey bees. This result, in combination with a substantially greater number of seedless carpels and lower number of viable seeds per fruit suggest reduced efficiency of pollen transfer to receptive blossoms by *O. lignaria*, and uneven distribution of viable, compatible pollen on the stigmatic lobes of the blossoms.

There were no significant differences between any of the fruit quality characteristics measured for the honey bee visit treatments in screened enclosures or outdoors (Table 8). A study by Visser and Verhaegh (1980) determined that hand-pollinating an apple blossom twice at an interval of one or two days on average doubled the seed set per pollinated blossom (PI) as compared to pollinating once. The results for one and two honey bee visits in the screened enclosure and outdoor experiments do not support the findings of Visser and Verhaegh (1980), possibly because the interval between the first and subsequent pollination visits were less than four hours at temperatures ranging from 9° C to 19.5° C. Visser and Marcucci (1983) determined that double pollinations could substantially increase seed production when the interval between pollinations was long enough (48 hr) at low (approximately 10° C) or short enough (7 hr) at high (approximately 20° C) temperatures. With shorter or longer intervals, the contribution of the second pollen to seed production diminishes.

Pollinator visit times for honey bees were significantly shorter outdoors than in screened enclosures, possibly because; 1) honey bees outdoors are more efficient at seeking and foraging on receptive blossoms than honey bees restricted to screened enclosures and/or 2) the high bee/blossom ratio in screened enclosures resulted in increased competition for individual blossoms and consequently a longer time spent searching for attractive nectar-bearing blossoms.

II. Treatment-Control Interactions

Control A was designed to test the efficiency of the bagging method and confirm the requirement for bee pollinators in apple pollination. Control B was designed to test the effect of unlimited pollinator visitations (i.e. possibly exceeding three visits) on fruit quality. In comparing the two controls, it was expected that Control A would have a lower overall pollination efficacy than Control B. This was so for all fruit quality measurements in the screened enclosure experiment (Table 8), including the absence of significant correlations between fruit weight and seed number (Fig. 4). However, some of the results in the outdoor experiment were converse to the results in the enclosures (Table 10). As expected, percent fruit set and PI were substantially lower for Control A than Control B, but fruit weight and number of viable seeds per fruit were substantially higher, though not significantly different from Control B. In addition, the mean number of seedless carpels per fruit was substantially lower, though not significantly different from Control B. However, this may have been due to the extremely small sample size in Control A; only seven percent of the blossoms used for Control A set fruit, producing only four apples. Fruit set in the Control A treatment in screened enclosures and outdoors was unexpected since these blossoms remained bagged for the duration of the experiment. Blossoms which were still viable when the bags were removed at the termination of the experiment could have been pollinated at that time.

A comparison of treatments and controls in the screened enclosure experiment indicates that the overall pollination efficacy of Control B was higher than all other treatments (Table 8). Because Control B received unlimited pollination, multiple visitations could have consisted of sequences of honey bee and/or *O. lignaria* visits to receptive blossoms in the screened enclosures. If so, a pollination management system which combines honey bee and *O. lignaria* visits may result in improved pollination efficacy on Red Delicous apples. Kuhn and Ambrose (1984) determined that pollination of Red Delicious apple blossoms by male and female *O. lignaria* resulted in significantly higher fruit set than sideworking honey bees. Since sideworking by honey bees in Red Delicious apples has been observed at levels as high as 86% of all foragers collecting nectar (Mayer 1983), the use of *O. lignaria* in a combined program could compensate for the potential reduction in fruit set. No sideworking has ever been observed for either male or female *O. lignaria* (Table 7, Torchio 1986). The honey bee may contribute to the combined system by reducing the chance of asymmetrical fruit

Mean fruit weight for Control B in screened enclosures was significantly heavier than one honey bee visit but not one *O. lignaria* visit even though fruit weight for one *O. lignaria* visit was slightly less than one honey bee visit. This result was likely due to the small sample size (n=13) and large variance (S.E.± 16.9) of the *O. lignaria* treatment compared to one honey bee visit (n=62; S.E.± 6.0).

A comparison of treatments and controls in the outdoor experiment indicates that the overall pollination efficacy of Control B was lower than the one or two honey bee visit treatments (Table 10). This is contrary to the findings of the screened enclosure experiment discussed previously. These results may have been due to poorer vigor (i.e. tree nutrition, soil fertility and moisture content) of the orchard where the outdoor experiment took place compared to the site of the screened enclosure experiment. This may also account for the absence of significant correlations between fruit weight and viable number of seeds per fruit for all outdoor treatments (Fig. 5).

III. Implications for Pollination Management Systems

The results of this study suggest that the pollination efficacy of one *O. lignaria* visit on Red Delicious apples was equal to that of honey bees in most respects, but resulted in a higher proportion of assymmetrical fruit. The pollinator efficacies of one to three honey bee visits were similar. Because of the symmetry factor, I would not recommend the use of *O. lignaria* as the sole pollinator of Red Delicious apples in the Okanagan Valley. However, a multi-species pollination system for Red Delicious apples, combining the foraging abilities of honey bees and *O. lignaria*, could potentially improve fruit set and quality.

There are several *O. lignaria* characteristics (Table 7) which could contribute to the success of a multi-species pollination management systems for Red Delicious apples in the Okanagan Valley. These characteristics include: 1) the absence of sideworkers and therefore, the ability to alleviate the detrimental effects of honey bee sideworkers and consequently improve fruit set (Kuhn and Ambrose 1984); 2) the ability to successfully compete with honey bees in an orchard situation (Parker and Torchio 1980); and, 3) management systems which are much less labor intensive and expensive than honey bee systems; beekeepers presently involved in honey bee pollination could easily adapt their operations to accomodate management of an additional species for concomitant use.

The superiority of several other *O. lignaria* characteristics has been presented by other authors (Table 7) but many of them have not been fully demonstrated. For example, the foraging behavior of *O. lignaria* in orchards involves visits to few blossoms per tree but many trees per foraging trip (P. F. Torchio[3], personal communication). This behavior pattern definitely facilitates cross-pollination by increasing the chance of contact with pollenizers interplanted throughout the orchard. Honey bee foraging behavior in orchards is more limited in between-tree visits than that of *O. lignaria* (Horticultural Education Association 1967), but recent studies by DeGrandi-Hoffman *et al.* (1984) suggest that bee-to-bee transfer of pollen within hives contributes greatly to the cross-pollination of apple orchards. Furthermore, in-hive pollen transfer would make the social behavior of honey bees much more effective for pollination of self-incompatible species such as apples than would the behavior of solitary bees.

Nest initiation by *O. lignaria* was negligible during the experiment in Summerland. Other researchers (D. F. Mayer[4], personal communication; Kuhn and Ambrose 1984) have also encountered problems in encouraging nest initiation of *O. lignaria* using the management methods developed by Torchio (1976, 1982b, 1984, 1986). Since mated *O. lignaria* females that have initiated nests and are provisioning cells are more vigorous pollen collectors than those not having initiated nests (P. F. Torchio, personal communication), overall contribution to

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cross-pollination may be reduced. A greater impact on fruit set and quality might be expected with more successful nesting. Torchio (1986) has determined that daily flight initiation by *O. lignaria* occurs when ambient temperatures reach 15.7° C. Flight temperatures at or above 15.7° C were recorded for only 2.5 hr during the screened enclosure experiment (8 to 15 May) which may have affected mating and nest initiation of *O. lignaria*. Management systems for *O. lignaria* may have to be adapted to the biotic and abiotic conditions indigenous to various fruit growing areas. The use of locally trapped *O. lignaria* in pollination management research in the Okanagan Valley should also be examined.

Torchio (1986) suggests that as few as 618 nesting females could adequately pollinate one hectare of apples (247 trees/hectare). In his study, *O. lignaria* were released in an isolated apple orchard, which received no honey bee pollination services. However, there is no mention of the abundance of wild pollinators in the orchard and their potential contribution to pollination in the apple orchard. Therefore, Torchio's estimate of 618 females per hectare may be an underestimate of the actual number of *O. lignaria* needed to provide adequate pollination of apples.

Future studies on the pollination efficacy and recommended numbers of *O. lignaria* needed in Red Delicious apples might be done in an isolated orchard, similar to the situation Torchio (1986) utilized, but the abundance, diversity and contribution to pollination by wild pollinators should be monitored prior to the release of *O. lignaria*. A mass release of *O. lignaria* would be necessary to ensure that enough individuals would be present in the orchard so that multiple visits to receptive blossoms could easily be achieved. Future studies should also investigate the effects of more than three bee visits on fruit quality, to allow a more comprehensive comparison of pollination efficacies of both honey bees and *O. lignaria*.

PART C

FACTORS USEFUL FOR THE PREDICTION OF HONEY BEE COLONY STRENGTH IN CHERRY, PEAR, AND APPLE ORCHARDS

INTRODUCTION

Apiarists involved in providing pollination services are aware that all honey bee colonies do not have equal pollination efficacy. Therefore, apiarists inspect colonies to determine their strength and potential value as pollinators of tree fruit crops prior to the commencement of tree fruit pollination. By utilizing a basic pollination management system for honey bees which involves the manipulation of colony demographics and population size, colony strength can be adjusted to ensure that orchards will receive adequate cross-pollination and an economic yield of fruit.

There are three essential features of a pollination colony which apiarists can manipulate to encourage equalization of colony strength. Colony strength refers to the internal colony characteristics (i.e. sealed and unsealed worker brood and adult population) most responsible for the foraging field force during pollination. They are the: 1) queen; 2) adult population; and 3) brood. An inspection of the brood pattern determines whether the queen is a suitable matriarch for the colony. If the brood pattern on each frame in the brood chamber is even and all stages of brood development (eggs to pupae) are represented, the queen is described as a good egg-layer and does not have to be replaced. The adult population provides the effective field force ultimately responsible for the transfer of pollen and consequently fertilization and fruit set. Most apiarists measure the adult population of a colony by counting the number of frames in a super (hive body) covered by adults. If the colony is too strong, adults may be removed and can be added to weaker colonies to adjust their strength. The presence of brood, specifically unsealed brood (eggs and larvae), stimulates foraging in general and pollen-gathering in particular, in addition to being an indicator of colony potential and eventual reinforcement to the adult population (Al-Tikrity *et al.* 1972; Free 1967, 1979; Free and Williams 1976; Todd and Reed 1970). Free (1967) suggested that unsealed brood, especially larvae, stimulates increased pollen-gathering due to a pheromone they produce which may be the same pheromone that inhibits ovary development of worker honey bees (Jay 1970). By providing small colonies with extracts of worker larvae, Jaycox (1970) determined that pollen collection is sometimes increased. In tree fruit crops such as cherries, pears and apples, honey bees collecting pollen are more efficient pollinators than those collecting nectar only, because they carry more pollen on their bodies and are more likely to transfer pollen to stigmas (Free 1970). It is, therefore, important that apiarists involved in pollination services manipulate colonies so that adequate amounts of all stages of brood are present to maintain individual colony pollination efficacy.

Provincial and state agencies, as well as local pollination associations, have established guidelines which define the minimum strength requirements for colonies to be used for tree fruit pollination. For example, the Okanagan Valley Pollination Association (O. V. P. A.) and the B. C. Ministry of Agriculture and Food – Apiary Program stipulate that pollination colonies should consist of eight to 10 combs of adult bees with five to six combs of brood (8000 to 9700 cm²) in all stages of development. A second super (both supers are generally Langstroth deep supers) is required for extra room while colonies are in the orchard. In Washington State, the official minimum standard required for colony strength certification for tree fruit pollination is six frames fully covered by adults and at least 11 frames of comb (20,000 cm²) in two supers (Burgett *et al.* 1984). In Oregon, two grades of colonies (Grade A and B) used for tree fruit pollination are defined. These grades recognize the natural growth of a honey bee colony throughout the pollination season. An Oregon grade A orchard colony should consist of two supers containing 11 frames (20,000 cm²) of comb of which 2.2 frames (4,000 cm²) should be occupied by live brood. In addition, adult bees should fully cover six frames. An Oregon grade B orchard colony is one which fails to meet requirements for a grade A orchard colony by not more than 25 percent on the amount of bees and brood but does meet all other requirements (Burgett *et al.* 1984). Both Washington's and Oregon's colony strength regulations stipulate the amount of comb required because different sizes of hive bodies and frames are regularly used. The pollination efficacy of colonies meeting any of these guidelines for strength requirements has been considered sufficient for tree fruit pollination.

The number of pollination colonies required for adequate cross-pollination to take place is recommended on a "per hectare" basis depending on the tree fruit crop to be pollinated (McGregor 1976). For example, in standard apple plantings (250 to 400 trees per hectare), 3 colonies per hectare are recommended. Five colonies per hectare are recommended on high density apple plantings of semi-dwarf rootstock (400 to 1000 trees per hectare) because of the greater number of blossoms per hectare and the increased tendency of honey bees to forage within a row (D. F. Mayer[5], personal communication). For sweet cherry pollination, 3 colonies per hectare are recommended for sufficient cross-pollination and adequate fruit set to occur. Five colonies per hectare are recommended for pear pollination due to the unattractiveness of pear blossoms to honey bees (Vansell 1942; Stephen 1958; Tufts and Philp 1923).

Presently, the only way to determine the strength of pollination units in orchards is to dismantle the colony and measure the amount of brood and adult population. These manipulations disrupt normal colony activity for several days during prime pollination periods, severely reducing the efficacy of pollination units. A method of utilizing forager entrance counts as an indirect measure of pollination unit strength would eliminate the need to dismantle colonies in orchards during inspection and would provide a more passive but accurate measure of colony potential for orchardists, apiarists and apiary inspectors.

Since previous studies have indicated that the proportion of pollen-gathering foragers increases with the amount of brood present (Al-Tikrity *et al.* 1972; Free 1967, 1979; Free and Williams 1976; Todd and Reed 1970) and the total number of foragers exiting the

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colony is an indication of available field force, these factors could be employed in a system which would indirectly determine colony strength. The objectives of this study were to:

1. determine which forager entrance counts (i.e. foragers entering, foragers exiting, and/or pollen-gathering foragers entering per colony) were most efficient in indirectly measuring the colony characteristics (unsealed and sealed brood and adult population) of pollination units used for cherry, pear and apple pollination in the Okanagan Vally; and
2. evaluate the effects of temperature, global solar radiation (G. S. R.) and relative humidity (R. H.) on honey bee foraging activity in cherries, pears, and apples.

MATERIALS AND METHODS

This study was conducted in the Okanagan Valley of British Columbia from 23 April to 16 May 1984 and 21 April to 19 May 1985. Forager entrance counts were recorded for honey bee colonies employed as pollination units for three tree fruit crops; cherries (*Prunus avium*), pears (*Pyrus communis*) and apples (*Malus sylvestris*). The same orchard sites were used for cherries (V. James Orchard, Old Vernon Road, Rutland) and pears (W. Cameron Orchard, Byrns Road, Kelowna) in 1984 and 1985, while in 1984 forager entrance counts in apples were conducted at the orchard of C. Day, Day Road, Rutland and in 1985 at Coldstream Ranch Orchard, Vernon.

All colonies were of equal strength, meeting minimum requirements for tree fruit pollination as set down by the Okanagan Pollination Association (O.V.P.A.) and the B. C. M. A. F.[5] – Apiary Program. Following placement in each of the fruit crops, the pollination units were allowed a 24 hr reorientation period before forager entrance counts commenced.

In 1984, forager entrance counts were determined for nine colonies in cherries, 17 in pears and four in apples. The number of foragers entering the hive per one minute interval was recorded, with three consecutive one minute measurements taken. Four repetitions were completed over two days. All entrance counts were recorded between 1000 and 1400 hr. A thermo–hygrograph was placed near the pollination units in each fruit crop to record ambient temperature (°C) and relative humidity (%) for the duration of the study. In addition to ambient temperature and relative humidity, global solar radiation (Langleys/hr) data for the area were obtained from the Atmospheric Environment Service[6]. Colony characteristics measured were sealed worker brood (cm^2) and area covered on frames by adults (cm^2). Immediately following the last entrance counts and prior to returning the pollination units to the apiary following pollination, the total area of sealed worker brood and adults per

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pollination unit were measured with a plexiglass grid marked with 5 x 5 cm quadrates.

Based on the 1984 results, changes in the experimental method were made in 1985 to include the measurement of both foragers exiting and pollen-bearing foragers entering per colony instead of foragers entering per colony. The use of pollen-bearing foragers as an index of pollination unit strength is supported by a number of studies which determined that the presence of unsealed brood (eggs and larvae) stimulated foraging in general and pollen-gathering in particular (Al-Tikrity *et al.* 1972; Free 1967; 1979; Free and Williams 1976; Todd and Reed 1970). Therefore, it was felt that pollen-bearing foragers might be a more accurate and effective measure of pollination efficacy. Foragers exiting per colony were recorded to determine overall adult population. The number of foragers exiting and the number of pollen-bearing foragers entering per colony per one minute interval were recorded alternately for three consecutive one minute periods each. Six repetitions were done for colonies used for cherry, pear and apple pollination; 10 colonies were used for each crop. The daily recording period and the three weather conditions recorded were the same as in 1984. Characteristics measured included unsealed and sealed worker brood and area of adults (cm^2) per colony. Brood and area covered on frames by adult workers (cm^2) were measured using the 1984 method. Colony characteristics were measured immediately following the last forager entrance counts and prior to returning the colonies to the apiary.

Linear regression analysis was used to determine the relationship between forager entrance counts and colony characteristics. Correlation analysis was used to determine relationships between forager entrance counts and weather data.

RESULTS

In 1984, no significant regressions ($p > 0.05$) were found for sealed worker brood or adult area versus foragers entering colonies in cherries and pears (Fig. 6). In apples, regressions were not significant ($p > 0.05$) for sealed brood and foragers entering colonies however, a significant regression ($p < 0.05$; $r^2 = .866$) was determined for adult area and foragers entering colonies. A significant correlation ($p < 0.05$) was found when foragers entering per colony were compared with temperature ($r = -.514$)in cherries (Fig. 7). In pears, significant correlations ($p < 0.05$) between foragers entering per colony and G.S.R. ($r = .535$) and R.H. ($r = .375$) were found (Fig. 7). No significant correlations between foragers entering and the three weather conditions recorded were found for apples in 1984 ($p > 0.05$) (Fig. 7).

In 1985, significant regressions ($p < 0.05$) were found for unsealed ($r^2 = .546$) and sealed worker brood ($r^2 = .695$) versus pollen-bearing foragers entering per colony, and adults ($r^2 = .560$) versus foragers exiting per colony in the colonies used for apple pollination (Fig. 8). Significant regressions between forager counts and colony characteristics were not found for cherries or pears ($p > 0.05$) (Fig. 9 and 10).

In cherries, significant correlations ($p < 0.05$) were found when foragers exiting per colony were correlated with R.H. ($r = -.287$) and temperature ($r = .504$), and when pollen-bearing foragers entering per colony were correlated with temperature ($r = -.291$), G.S.R. ($r = -.368$) and R.H. ($r = .364$) (Fig. 11). For pears, significant positive correlations ($p < 0.05$) were determined when foragers exiting per colony were correlated with G.S.R. ($r = .390$) and R.H. ($r = .263$), and when pollen-bearing foragers entering per colony were correlated with G.S.R. ($r = .443$) and R.H. ($r = .329$) (Fig. 12). No significant correlations ($p > 0.05$) between forager counts and the three weather conditions were found in apples for 1985 (Fig. 13).

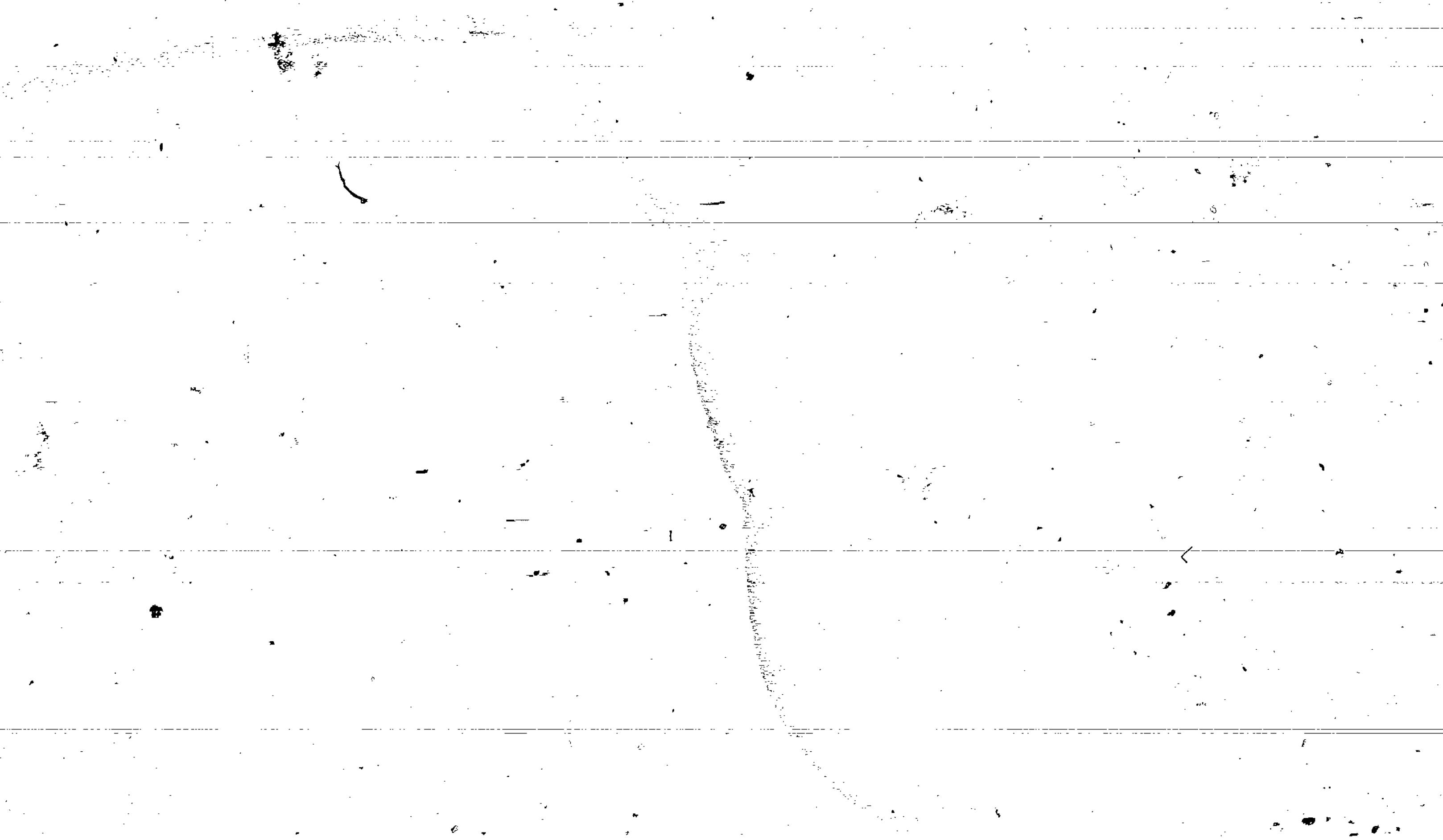


Fig. 6. Regression analyses of foragers entering per colony and two colony characteristics, areas of adults and sealed brood, recorded while colonies were located in cherries, pears or apples during the pollination period in 1984.

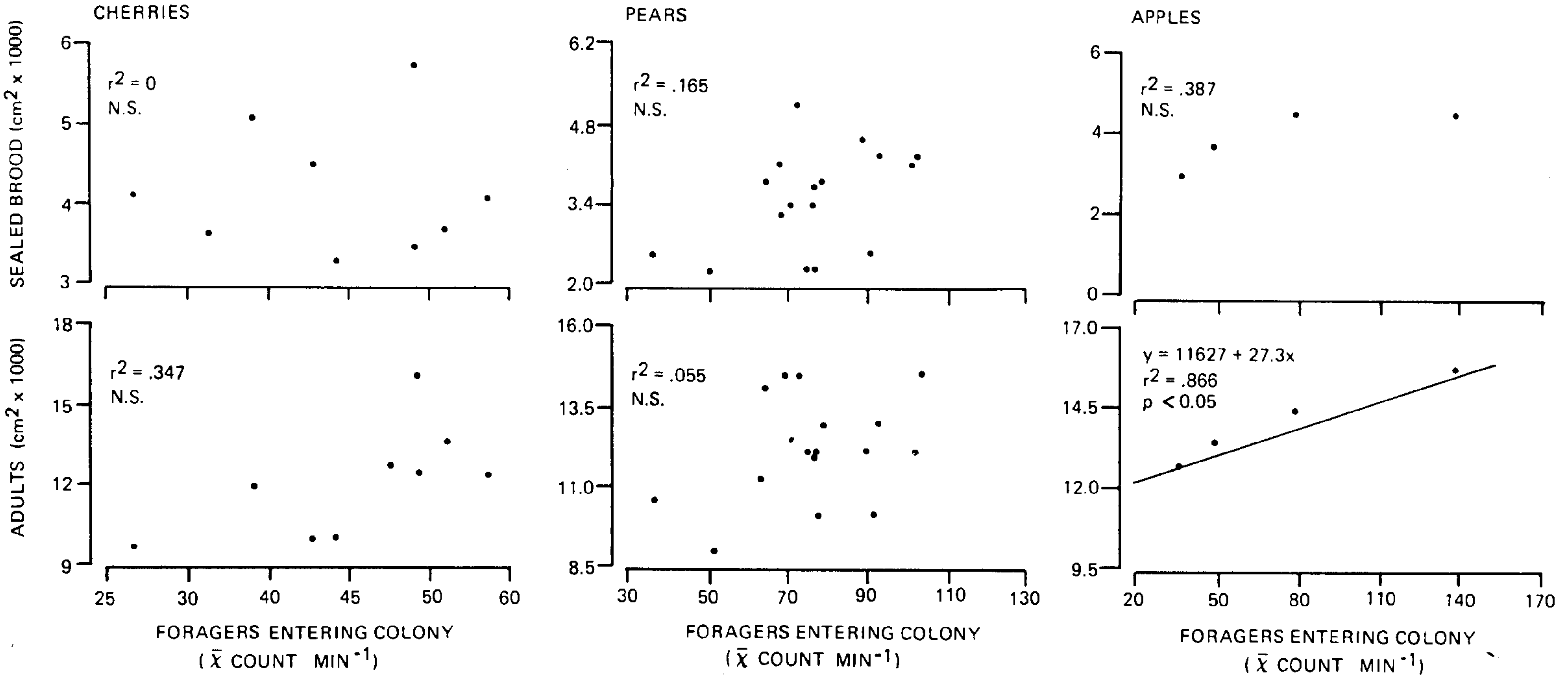

CHERRIES
PEARS
APPLES
SEALED BROOD (cm^2 x 1000)
ADULTS (cm^2 x 1000)
$r^2 = 0$
N.S.
$r^2 = .165$
N.S.
$r^2 = .387$
N.S.
$r^2 = .347$
N.S.
$r^2 = .055$
N.S.
$y = 11627 + 27.3x$
$r^2 = .866$
$p < 0.05$
6
5
4
3
6.2
4.8
3.4
2.0
6
4
2
0
18
15
12
9
16.0
13.5
11.0
8.5
17.0
14.5
12.0
9.5
25
30
40
45
50
60
30
50
70
90
110
130
20
50
80
110
140
170
FORAGERS ENTERING COLONY
($\bar{X}$ COUNT MIN^{-1})
FORAGERS ENTERING COLONY
($\bar{X}$ COUNT MIN^{-1})
FORAGERS ENTERING COLONY
($\bar{X}$ COUNT MIN^{-1})

Fig. 7. Correlation analyses of foragers entering per colony and three weather conditions, global solar radiation (G.S.R.), relative humidity (R.H.) and temperature, recorded while colonies were situated in cherries, pears or apples during the pollination period in 1984.

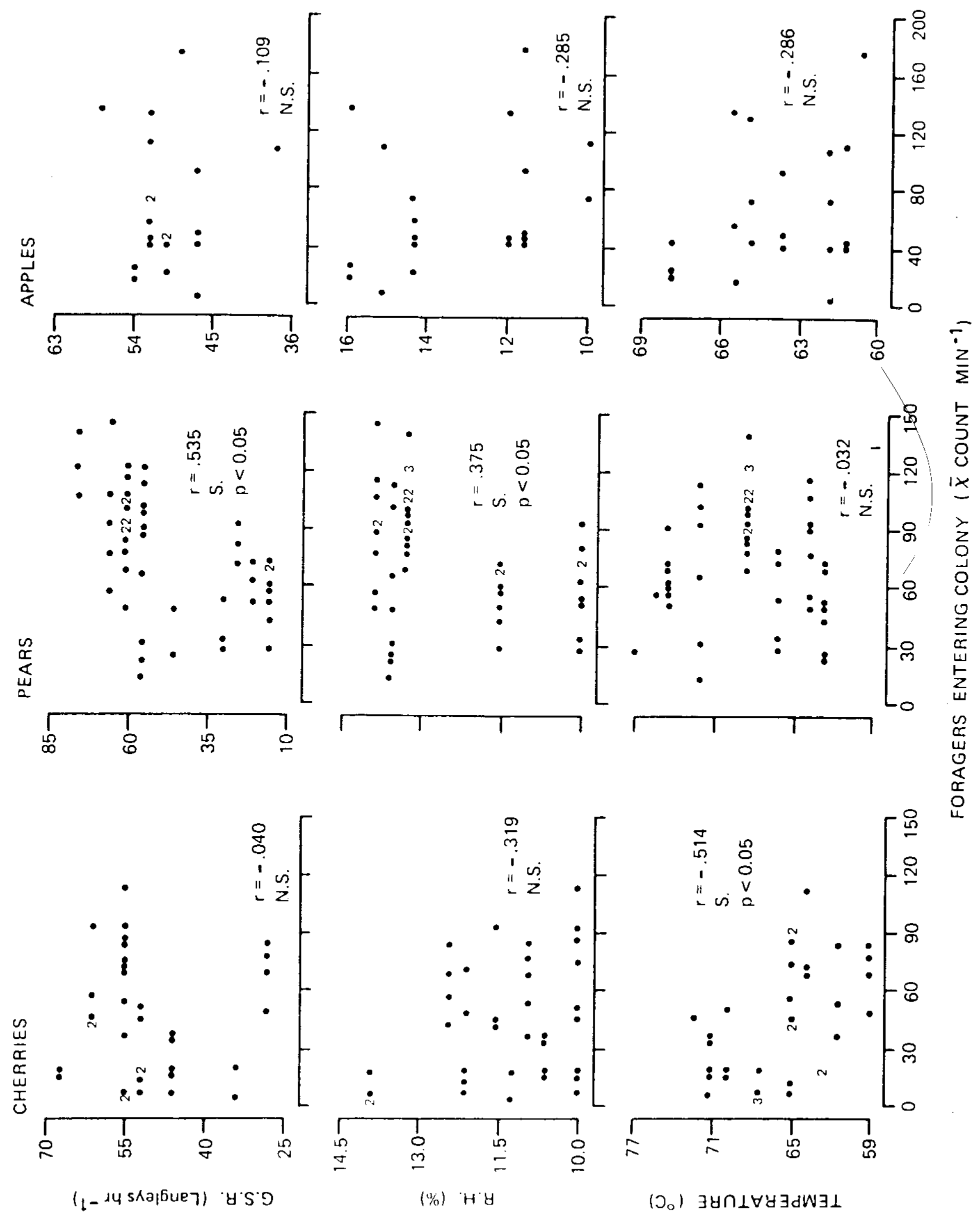

CHERRIES
PEARS
APPLES
G.S.R. (Langleys hr-1)
R.H. (%)
TEMPERATURE (C°)
r = -.040
N.S.
r = .535
S.
p < 0.05
r = -.109
N.S.
r = -.319
N.S.
r = .375
S.
p < 0.05
r = -.285
N.S.
r = -.514
S.
p < 0.05
r = -.032
N.S.
r = -.286
N.S.
FORAGERS ENTERING COLONY (X̄ COUNT MIN-1)

Fig. 8. Regression analyses of foragers exiting per colony and pollen bearers entering per colony versus three colony characteristics, areas of adults, sealed brood and unsealed brood. Data were recorded in 1985 while colonies were located in an apple orchard. Mean count per minute per colony was derived from a total of 18 one minute counts.

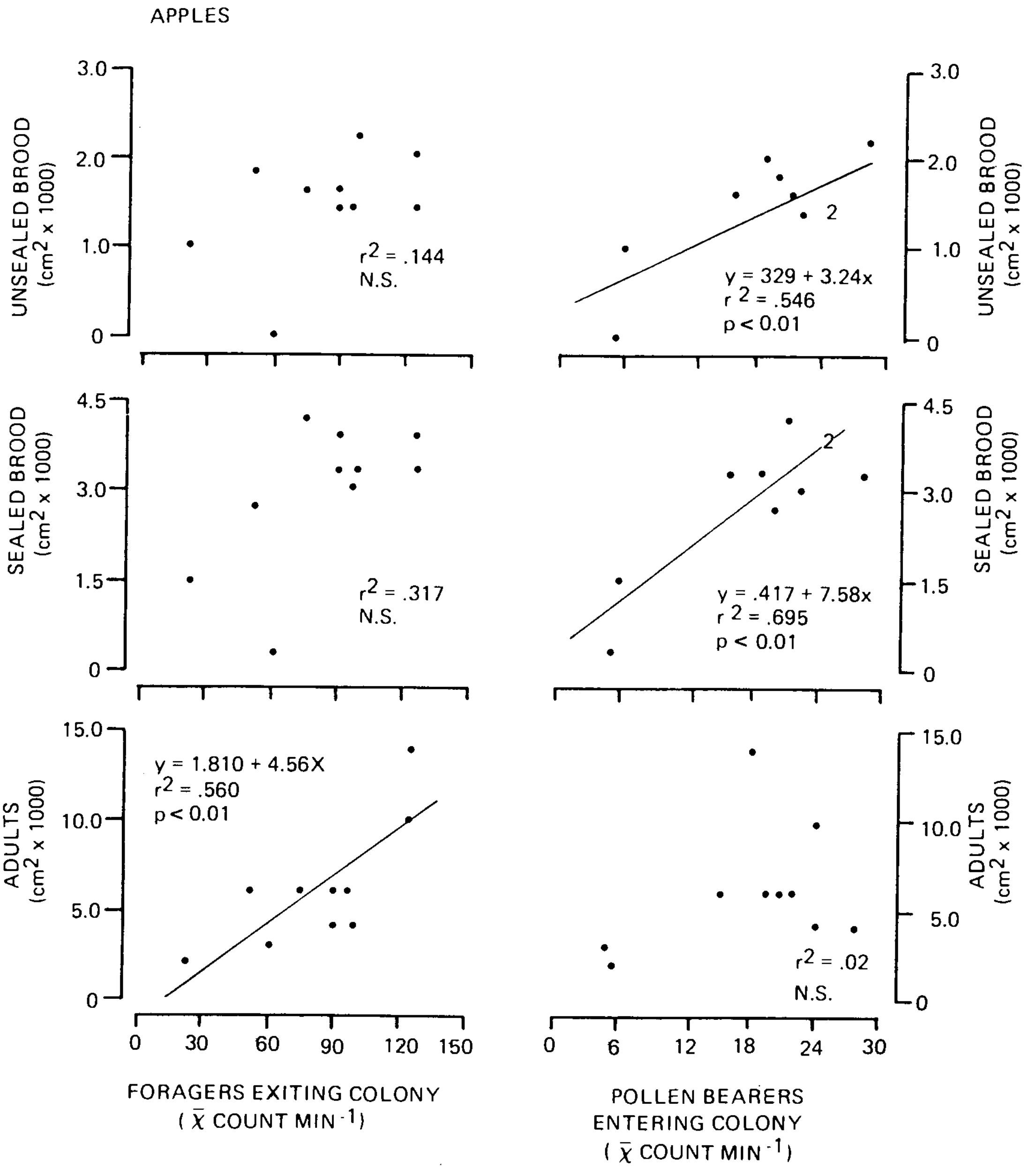

APPLES
UNSEALED BROOD (cm^2 x 1000)
3.0
2.0
1.0
0
r^2 = .144
N.S.
2
y = 329 + 3.24x
r^2 = .546
p < 0.01
SEALED BROOD (cm^2 x 1000)
4.5
3.0
1.5
0
r^2 = .317
N.S.
2
y = .417 + 7.58x
r^2 = .695
p < 0.01
ADULTS (cm^2 x 1000)
15.0
10.0
5.0
0
y = 1.810 + 4.56X
r^2 = .560
p < 0.01
r^2 = .02
N.S.
0
30
60
90
120
150
0
6
12
18
24
30
FORAGERS EXITING COLONY
($\bar{X}$ COUNT MIN^{-1})
POLLEN BEARERS
ENTERING COLONY
($\bar{X}$ COUNT MIN^{-1})

Fig. 9. Regression analyses of foragers exiting colony and pollen bearers entering per colony versus three colony characteristics, areas of adults, sealed brood and unsealed brood. Data were recorded in 1985 while colonies were located in a cherry orchard. Mean count per minute per colony was derived from total counts for 18 one minute intervals.

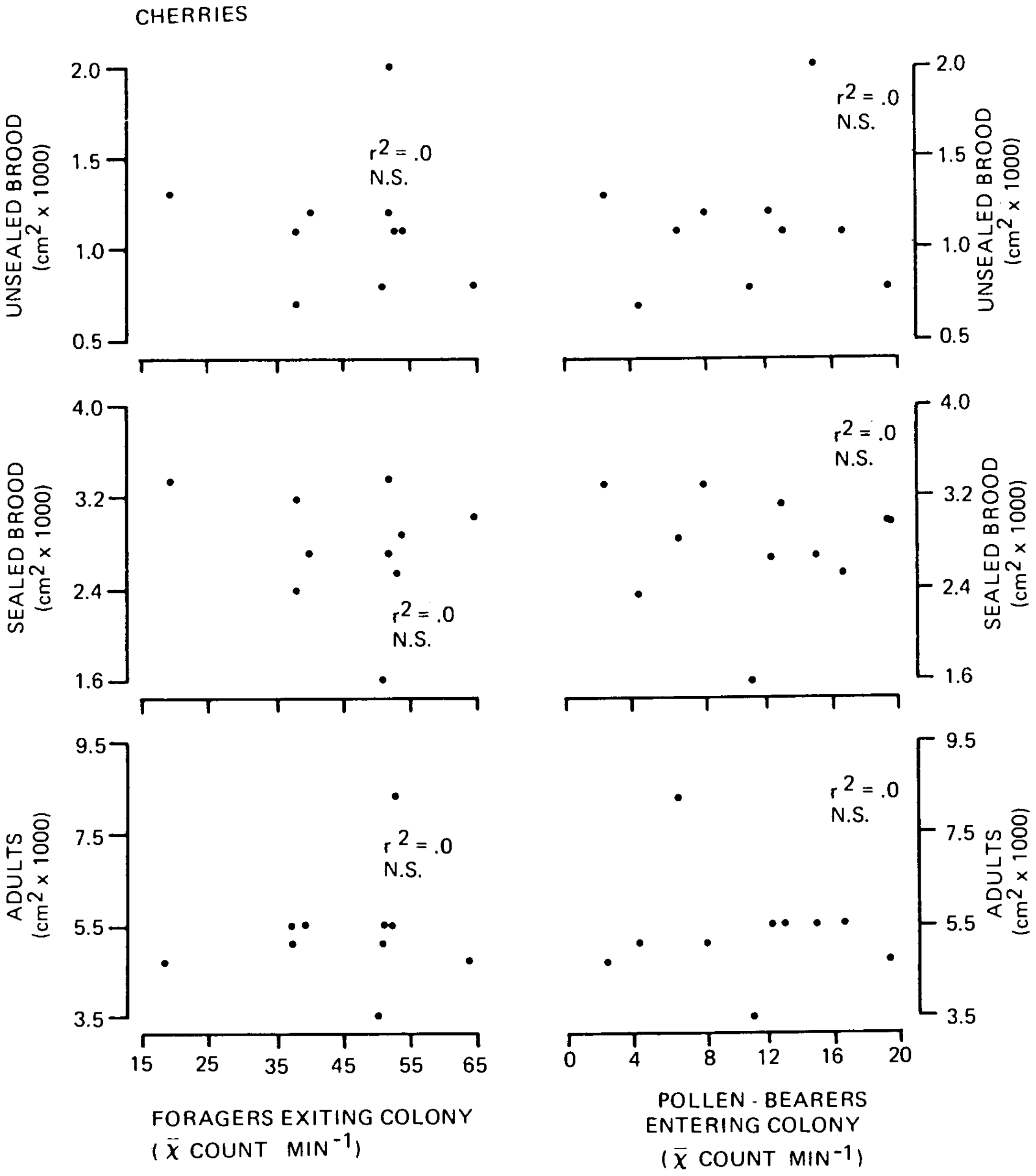

CHERRIES
UNSEALED BROOD (cm^2 x 1000)
2.0
1.5
1.0
0.5
$r^2 = .0$
N.S.
SEALED BROOD (cm^2 x 1000)
4.0
3.2
2.4
1.6
$r^2 = .0$
N.S.
ADULTS (cm^2 x 1000)
9.5
7.5
5.5
3.5
$r^2 = .0$
N.S.
15
25
35
45
55
65
0
4
8
12
16
20
FORAGERS EXITING COLONY
($\bar{X}$ COUNT MIN^{-1})
POLLEN - BEARERS
ENTERING COLONY
($\bar{X}$ COUNT MIN^{-1})

Fig. 10. Regression analyses of foragers exiting per colony and pollen bearers entering per colony versus three colony characteristics, areas of adults. sealed brood and unsealed brood. Data were recorded in 1985 while colonies were located in a pear orchard. Mean count per minute per colony was derived from total counts for 18 one minute intervals.

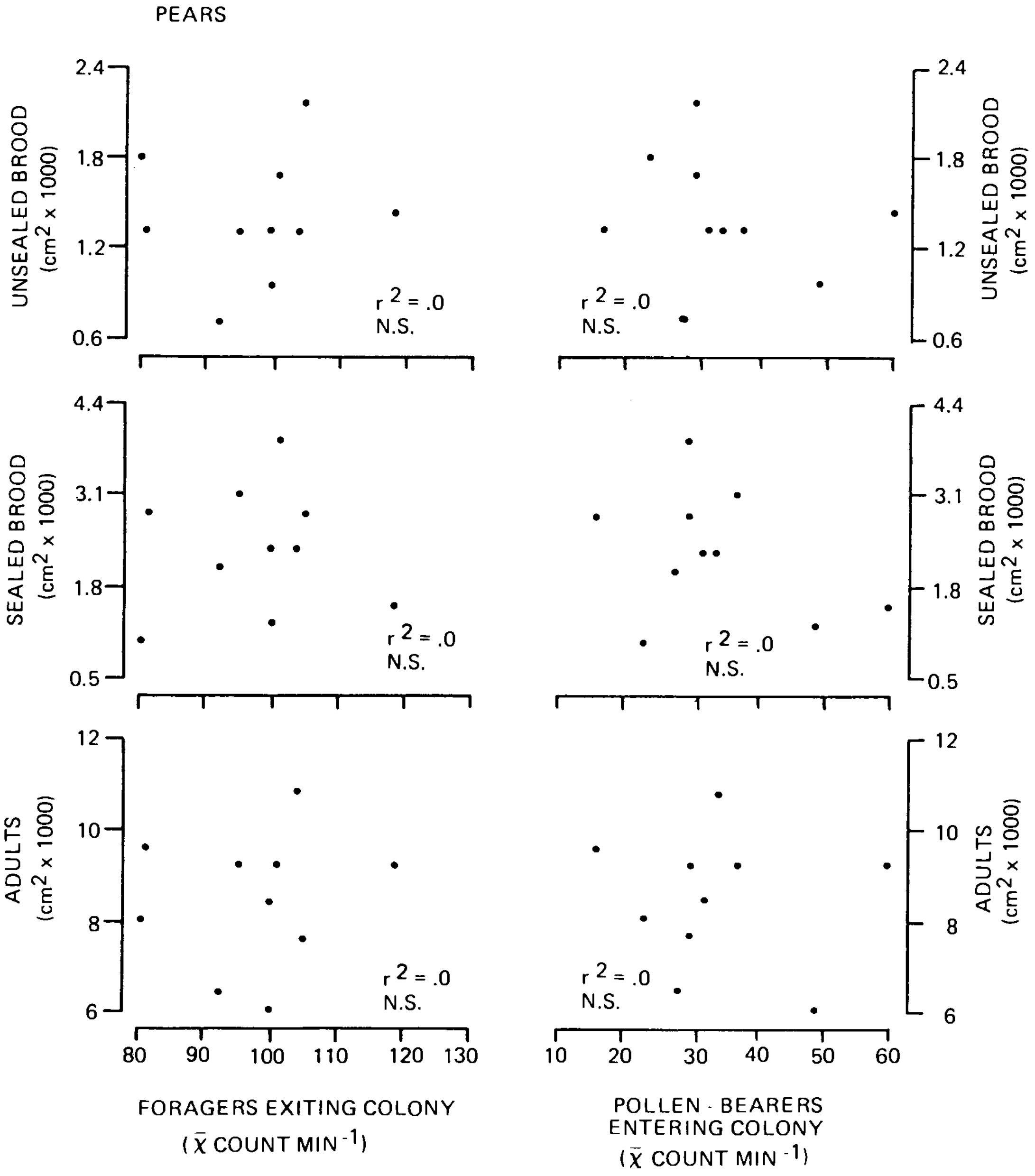

PEARS
UNSEALED BROOD (cm^2 x 1000)
2.4
1.8
1.2
0.6
SEALED BROOD (cm^2 x 1000)
4.4
3.1
1.8
0.5
ADULTS (cm^2 x 1000)
12
10
8
6
r 2 = .0
N.S.
80 90 100 110 120 130
10 20 30 40 50 60
FORAGERS EXITING COLONY
(X̄ COUNT MIN -1)
POLLEN - BEARERS
ENTERING COLONY
(X̄ COUNT MIN -1)

Fig. 11. Correlation analyses of foragers exiting per colony, pollen bearers entering per colony and three weather conditions, global solar radiation (G.S.R.), relative humidity (R.H.) and temperature. Data were recorded during the pollination period in 1985 while 10 colonies were located in a cherry orchard. Mean counts per minute were recorded for six repetitions per colony resulting in 60 data points for each correlation.

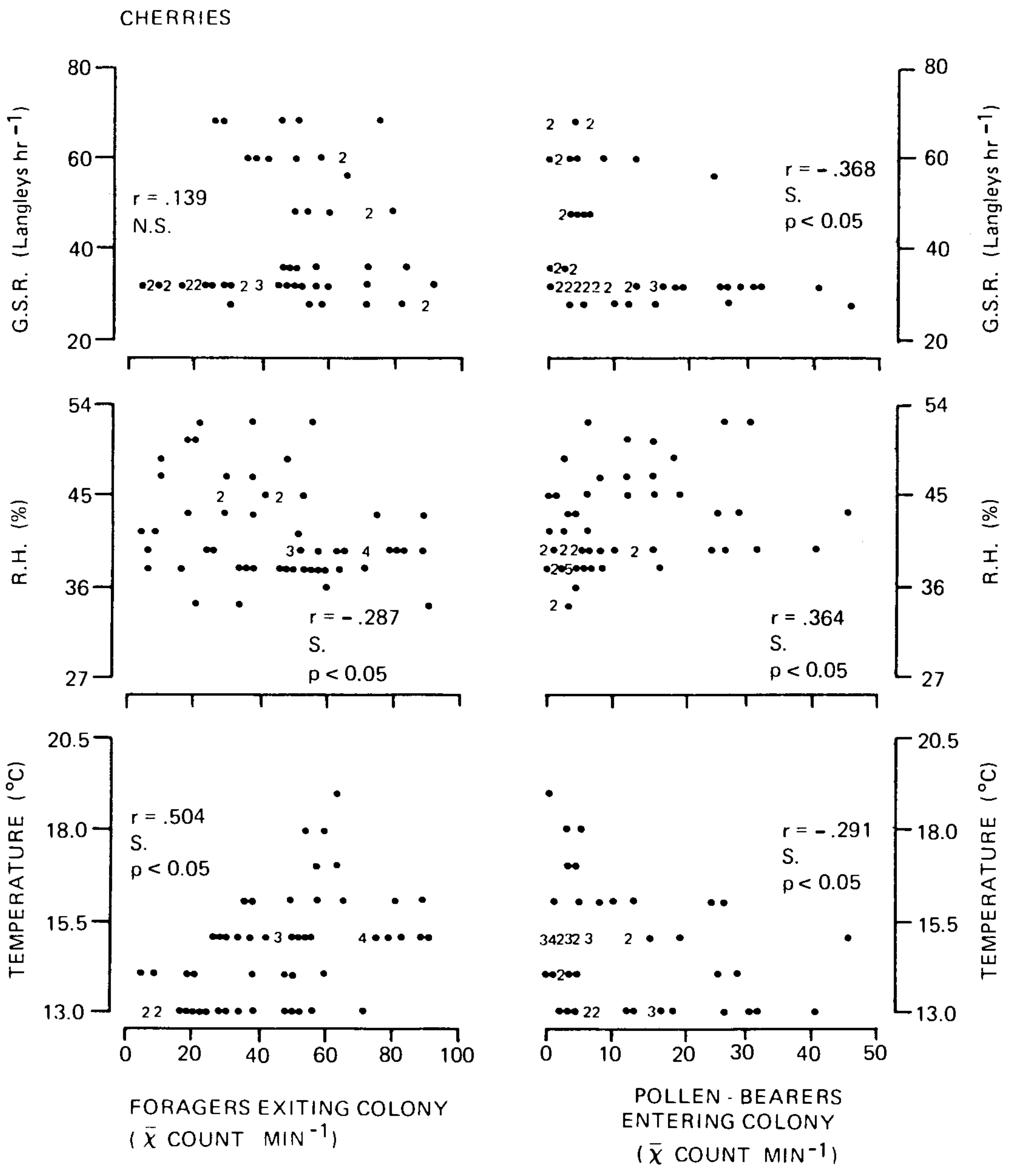

CHERRIES
G.S.R. (Langleys hr^{-1})
80
60
40
20
r = .139
N.S.
r = -.368
S.
$p < 0.05$
R.H. (%)
54
45
36
27
r = -.287
S.
$p < 0.05$
r = .364
S.
$p < 0.05$
TEMPERATURE (°C)
20.5
18.0
15.5
13.0
r = .504
S.
$p < 0.05$
r = -.291
S.
$p < 0.05$
0
20
40
60
80
100
0
10
20
30
40
50
FORAGERS EXITING COLONY
($\bar{X}$ COUNT MIN^{-1})
POLLEN - BEARERS
ENTERING COLONY
($\bar{X}$ COUNT MIN^{-1})

Fig. 12. Correlation analyses of foragers exiting per colony, pollen bearers entering per colony and three weather conditions, global solar radiation (G.S.R.), relative humidity (R.H.) and temperature. Data were recorded during the pollination period in 1985 while 10 colonies were located in pears. Mean counts per minute were recorded for six repetitions per colony resulting in 60 data points per correlation.

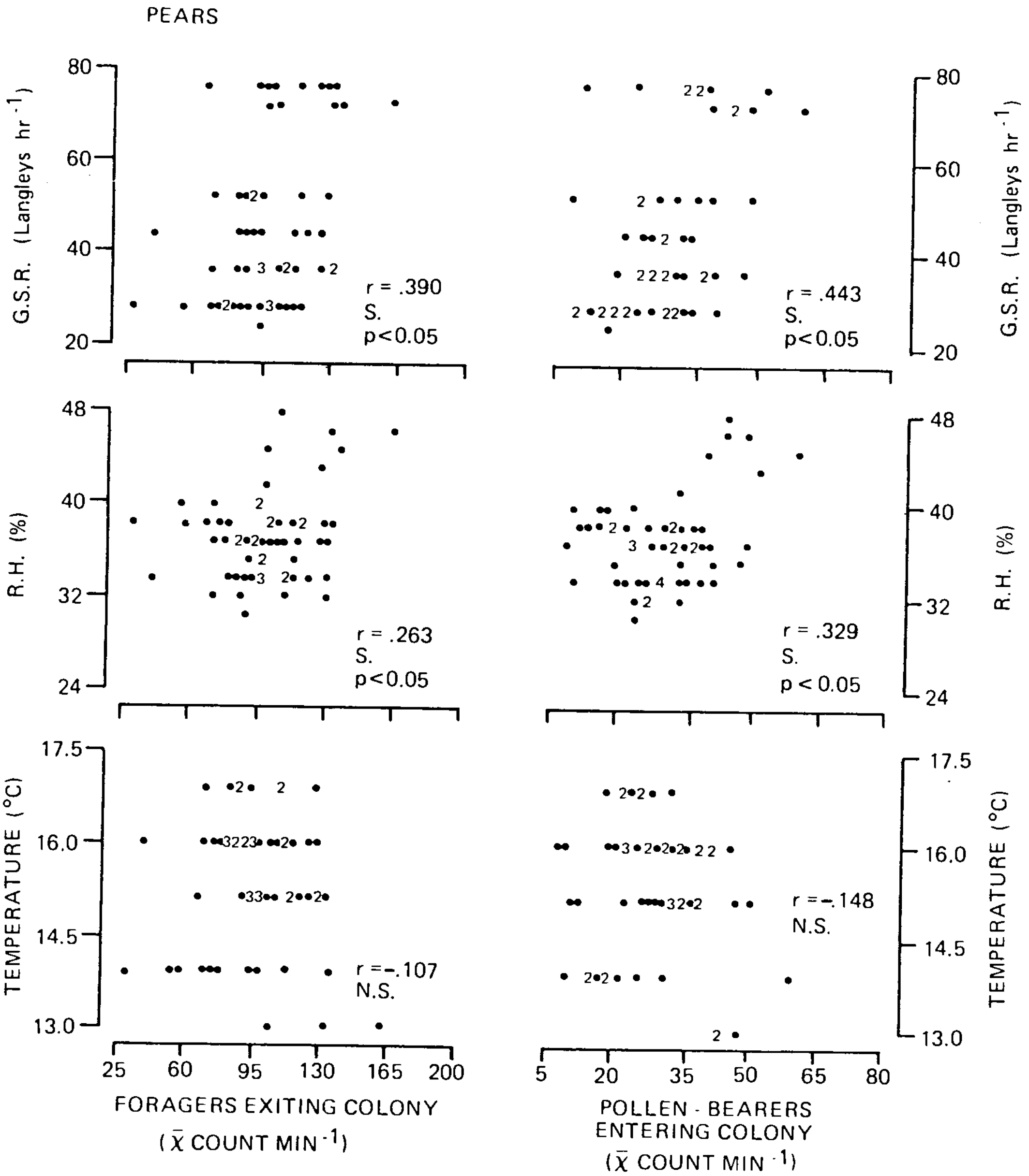
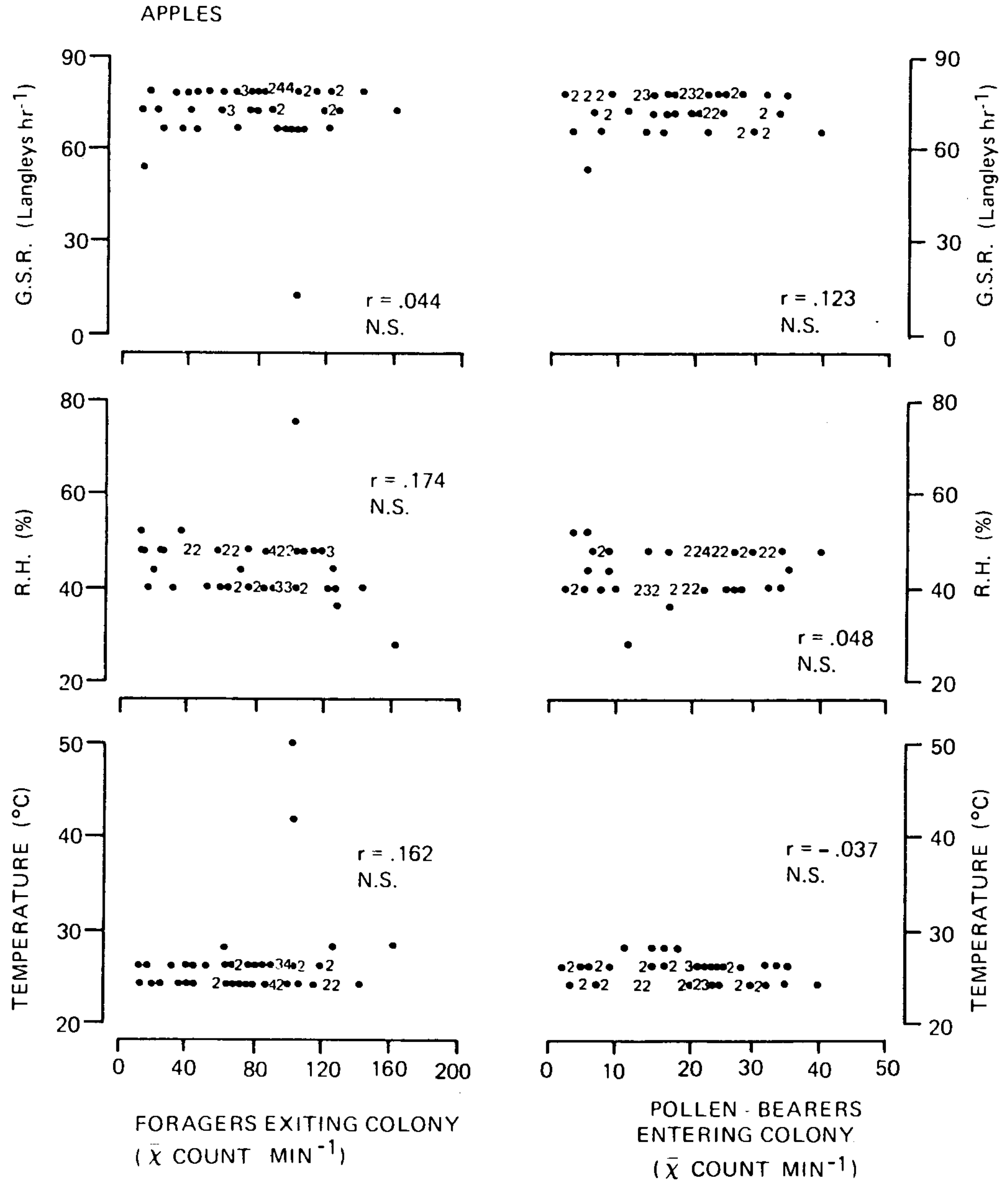

PEARS
G.S.R. (Langleys hr⁻¹)
80
60
40
20
r = .390
S.
p<0.05
r = .443
S.
p<0.05
R.H. (%)
48
40
32
24
r = .263
S.
p<0.05
r = .329
S.
p < 0.05
TEMPERATURE (°C)
17.5
16.0
14.5
13.0
r =-.107
N.S.
r =-.148
N.S.
25 60 95 130 165 200
FORAGERS EXITING COLONY
(X̄ COUNT MIN⁻¹)
5 20 35 50 65 80
POLLEN - BEARERS
ENTERING COLONY
(X̄ COUNT MIN⁻¹)

Fig. 13. Correlation analyses of foragers exiting per colony, pollen bearers entering per colony and three weather conditions, global solar radiation (G.S.R.), relative humidity (R.H.) and temperature. Data were recorded during the pollination period in 1985 while 10 colonies were located in an apple orchard. Mean counts per minute were recorded for six repetitions per colony resulting in 60 data points per correlation.


APPLES
G.S.R. (Langleys hr^{-1})
90
60
30
0
r = .044
N.S.
r = .123
N.S.
R.H. (%)
80
60
40
20
r = .174
N.S.
r = .048
N.S.
TEMPERATURE (°C)
50
40
30
20
r = .162
N.S.
r = -.037
N.S.
0
40
80
120
160
200
FORAGERS EXITING COLONY
($\bar{x}$ COUNT MIN^{-1})
0
10
20
30
40
50
POLLEN - BEARERS
ENTERING COLONY
($\bar{x}$ COUNT MIN^{-1})

DISCUSSION

Significant regression between foragers entering and adult area in colonies being used for apple pollination support the suggestion of Mayer (1983) that the strength of colonies used for apple pollination could be evaluated by counting the number of honey bees entering the colony during a one minute interval. Preliminary data from Mayer (1983) indicate that colonies being used for pollination are fairly strong if there are more than 100 incoming bees per minute at 18.5°C and winds less than 16 kmh. The difficulty with using foragers entering colonies is that only adult area in colonies can be predicted, and therefore one of the major components of colony strength, brood area, is not related to entrance counts. Forager entrance counts which would also predict sealed and unsealed worker brood area would be more useful as a measurement of colony strength.

In 1985, significant regressions for unsealed and sealed worker brood (Fig. 8) versus pollen-bearing foragers entering per colony were found in the colonies used for apple pollination. These results agree with a number of studies which determined that the amount of pollen gathered increases with the amount of brood (Free 1967, 1979; Al-Tikrity *et al.* 1972; Free and Williams 1976; Todd and Reed 1970). In addition, Free (1967) concluded that unsealed brood (eggs and larvae) were more effective stimulators of pollen collecting than sealed brood (pupae). My results indicate that unsealed brood ($r^2 = .546$) was not as effective at stimulating pollen-gathering as was the sealed brood ($r^2 = .695$) (Fig. 8). These results support previous studies which suggest that brood measurements are a good indicator of pollen-gathering and therefore pollination efficacy of colonies used for apple pollination. My results also indicate that, in colonies used for apple pollination, foragers exiting per colony is a more effective measure of total adult population than pollen-bearing foragers entering per colony (Fig. 8). A measurement of this type could estimate the potential foraging field force of a pollination unit and consequently the area of an orchard which could be effectively worked by an individual colony. If a colony did not meet adult strength requirements, it could then be adjusted accordingly.

The absence of significant regressions between forager entrance counts and colony characteristics for cherries and pears in both 1984 and 1985 (Fig. 6, 9 and 10) suggests that the foraging activity of honey bee colonies used for pollinating tree fruit crops which bloom earlier in the spring than some varieties of apples are more strongly influenced by factors other than internal colony characteristics. This statement is supported by the significant correlations between forager entrance counts and weather conditions for cherries (Fig. 11) and pears (Fig. 12) but not for apples in 1984 and 1985.

While the three weather conditions are naturally interrelated, foragers exiting and pollen-bearers entering per colony in cherries and pears appear to respond to each differently. In a study by Burrill and Dietz (1981) it was determined that temperature and G.S.R. appeared to be the major factors of weather influencing honey bee flight initiation (foragers exiting). Their results indicated a significant positive correlation between temperature and honey bee flight departures. In addition, Burrill and Dietz (1981) found that significant correlations with G.S.R. and honey bee flight departures were positive at solar radiation levels below 0.66 langleys, and negatively correlated above this threshold. In both years of my study, G.S.R. levels were greater than 0.66 langleys.

In 1985, the significant correlations found between foragers exiting and the various recorded weather conditions in cherries (Fig. 11) and pears (Fig. 12) partially agree with the findings of Burill and Dietz (1981). A positive correlation between temperature and a corresponding negative correlation between R.H., and foragers exiting per colony supports their previous findings. However, in pears the significant positive correlations between foragers exiting and G.S.R. (Fig. 12) do not agree with the findings of Burrill and Dietz (1981).

The significant correlations found in cherries and pears (Figs. 11 and 12) when pollen-bearing foragers were correlated with the recorded weather conditions suggests two explanations for the behavior of foragers in these tree fruit crops. For temperature and G.S.R. in cherries, significant negative correlations suggest that, as weather conditions become less optimal for foraging, honey bees are returning to their colonies for protection. In pears, however, the relationship between G.S.R. and pollen-bearing foragers was positive, indicating that in good foraging weather recruitment to pears as a source of pollen remains high. The second explanation for honey bee foraging behavior in cherries and pears is related to the positive correlations found between pollen-bearing foragers and R.H. in these two tree fruit crops (Figs. 11 and 12). Relative humidity and nectar secretion are positively correlated, but sugar concentration in the nectar is negatively correlated with R.H. (reviewed by Crane 1975). This phenomenon is due to the hygroscopic effect of the sugar contained in the nectar; nectar absorbs more water from a saturated atmosphere than from dry air (Beutler 1930; Shuel 1952). Since it is the sugar concentration in nectar which attracts honey bees to the blossoms, at a higher R.H. blossoms would become less attractive to foragers. The results of my research suggest that, when these weather conditions occur during cherry and pear pollination, there is a shift from nectar collecting to pollen-gathering. Pears are generally not considered to be as attractive to honey bees as other fruit crops due to low concentrations of sugar in the nectar (Vansell 1942; Stephen 1958; Tufts and Philp 1923). Based on the results of this study, weather conditions occurring during cherry and pear pollination which involve increased R.H. may improve pollination efficacy of honey bees in pears by stimulating pollen-gathering, and therefore facilitating cross-pollination.

The lack of significant correlations between forager entrance counts and weather conditions in late-blooming apples in the Okanagan Valley suggests that, by mid-May, honey bee foraging activity is more strongly influenced by internal colony characteristics than by external conditions such as weather.

In conclusion, it is evident from this study that predicting colony pollination efficacy in cherries, pears and apples utilizing such factors as colony characteristics, forager entrance counts and weather conditions is possible, but these predictions will have to be made on an individual crop basis rather than quantifying data to arrive at general recommendations for all tree fruit crops. The foraging behavior of honey bees in tree fruit crops such as cherries and pears, which bloom earlier in the spring than some apple varieties (i.e. Red Delicious) in the Okanagan Valley, are affected more by external weather conditions than internal colony characteristics. Furthermore, there are sufficient differences between the effects of weather conditions on forager entrance counts in cherries and pears to suggest that any methods developed to predict colony strength and pollination efficacy in these two tree fruit crops should be developed independently. These recommendations may have to be adjusted regionally due to variations in weather experienced during cherry and pear pollination in different tree fruit growing areas. In the late-blooming apples, colony strength is dependent on internal colony characteristics more than external weather conditions and these factors should be emphasized in predictive systems developed to determine colony pollination efficacy in this tree fruit crop.

PART D

HONEY BEE COLONY CHARACTERISTICS AND PROFITABILITY OF POLLINATION MANAGEMENT SYSTEMS.

INTRODUCTION

There are two major requirements for planned pollination: 1) there must be an adequate source of pollen of another variety; and 2) there must be a large enough population of bees to transfer the pollen while the flowers are receptive (McGregor 1976). Current pollination management involves the use of overwintered honey bee colonies which are prepared for pollination in mid-April. The honey bee colonies (pollination units) are generally managed by beekeepers and not orchardists, and are moved to each fruit crop seasonally when the crop is in bloom. Following the pollination season, the pollination units are moved back to apiaries for honey production.

My research into pollination management was begun in response to a growing concern among beekeepers that their management systems could be more productive, thus yielding better income. They were particularly interested in the following areas:

1. Honey Production - The movement of bee colonies to orchards seriously disrupts colony growth during the critical spring population buildup period, since 15-35% of the foraging force may be lost due to disorientation within 7 days of a move (Nelson 1985). The effect of this disruption in colony growth patterns is likely to reduce the crop later in the season, but the extent of the loss of honey production is not understood. Data were needed to compare colony productivity in terms of brood area and honey production under pollination and non-pollination management systems.
2. Bee Production - Considerable interest has recently developed in bee production in Canada, including packages and nuclei (Winston 1983, 1986). A package of bees generally consists of 0.9 kg of workers and a queen, while a nucleus is a small colony of bees with a queen and enough workers to cover two to five frames of combs. Canadian beekeepers rely heavily on the importation of package bees from the southern United States each spring. In 1982, 350,000 packages were imported into Canada from

the U.S. with a total value of $10 million (Winston 1983). Recently, however, the Canadian beekeeping community has begun to examine alternatives to traditional management involving the importation of packages of bees and queens. This examination has been stimulated by both economic reasons and the possible reduction or outright ban on importation of bees from the U.S. as a result of the arrival of Africanized bees and two potentially serious mite pests of honey bees, *Acarapis woodi* (Rennie) and *Varroa jacobsoni* (Oudemans), into the package-producing areas of the U.S. (reviewed by Winston 1983). The need for bees in Canada each spring can be met by bee production in the relatively mild climate of southwestern British Columbia (Winston et al. 1985; Winston 1986). It may also be feasible for the Okanagan Valley beekeepers to produce either packages or nuclei as part of their pollination management for an additional source of income. However, no data were available concerning the impact of such bee production on either pollination or honey production, nor had there been research involving methods of bee production.

The objective of this study was to examine the biology and economics of 3 different bee management systems in the Okanagan Valley: 1) pollination (current system); 2) honey production without pollination; and 3) package and nucleus production with and without pollination.

MATERIALS AND METHODS

This study was conducted from April to August 1983 in the North Okanagan Valley, extending from Kelowna to Armstrong, B.C. A total of 60 colonies were used, 30 in each of 2 apiary sites 6 km apart near Armstrong. The apiary sites had similar honey yields in previous years which were considered average for the region ($\bar{X}=34.0$ kg/colony from 1974 to 1983, $\bar{X}=31.0$ kg/colony for 1983, B.C.M.A.F. 1984), and had comparable elevations (500–650 m) and spring forage nearby. Colonies were randomly divided into 6 management systems with 10 colonies/treatment, and 5 colonies from each treatment at each apiary. The 6 treatments were:

1. No package or nucleus removed and colony not moved for pollination (Control – Apiary);
2. No package or nucleus removed but colony moved for pollination (Control – Pollination);
3. Nucleus removed and colony not moved for pollination (Nucleus – Apiary);
4. Nucleus removed and colony used for pollination (Nucleus – Pollination);
5. Package removed and colony not moved for pollination (Package – Apiary); and
6. Package removed and colony moved for pollination (Package – Pollination).

Each manipulation is described below.

Controls: These colonies had no packages or nuclei removed in the spring, and were managed for honey production alone or for honey production and pollination.

Packages: Twenty of the colonies had between 0.6 and 0.9 kg of bees removed from them and shaken into packages on 18 April 1983. The criterion for the amount of bees removed was that the parental colonies were left at pollination unit strength after shaking. A standard pollination unit was considered to contain at least 8 combs of bees and 5–6 combs of brood; this is the minimum standard of the Okanagan Valley Pollination Association and the B. C. Ministry of Agriculture and Food - Apiary Program. Nine of the colonies were of sufficient strength to have a full 0.9 kg package (2 lb) shaken from them, while the others had 0.6 to 0.8 kg of bees removed from each. These packages as well as the nuclei described below were not used further in this study.

Nuclei: Twenty colonies had 4-frame nuclei removed from them on 18 April 1983. Nuclei consisted of 2 frames of brood, 2 frames of honey and pollen, and enough workers to cover all 4 frames. The parental colonies were maintained at pollination strength.

Pollination: Colonies destined for use in pollination were moved on 24 April 1983 to a block of Bartlett and Anjou pears (Benvoulin Orchards-Byrns Road, Kelowna, B.C., Owner: W. Cameron). On 2 May the pollination colonies were moved to a block of Red and Golden Delicious, Spartans and MacIntosh apples (T.L. Solmer Orchards Ltd.-Pooley Road x Rose Road, East Kelowna, B.C., Owner: T.L. Solmer). On 11 May, all pollination colonies were moved back to the apiary from which they originated. For the remainder of the summer colonies used for pollination were managed in the same manner as those remaining in the apiaries.

Apiary: These colonies remained in the apiary for the entire summer, and were used to produce honey alone, honey and a package, or honey and a nucleus. Management included swarm control, adding extra supers when necessary, honey storage, regular queen checks, etc.

Colony characteristics measured were: 1) net colony weight (Total colony weight - weight of empty equipment); 2) sealed worker brood area; and 3) surplus honey production. Sealed brood area and net colony weight were measured every 21 to 25 days (approximately the developmental period from egg to adult) from 3 March to 10 August 1983 and prior to major manipulations, including removal of packages and nuclei, moves to and from pollination, and extraction of honey. Sealed worker brood was measured by placing a clear plexiglass sheet marked with 5 x 5 cm quadrates over the frame. Honey production was measured by marking each frame and weighing them before and after extraction. Surplus honey production was only measured at the end of the season. Three measurement dates were chosen to describe the sealed brood and colony weight characteristics: at the end of the pollination period (13 May 1983), mid season (8 June 1983), and at the end of the season (18 August 1983). Surplus honey production was analysed using data collected from the single extraction date at the end of the season. Data were analysed using an ANOVA. Treatment means for colony weights and sealed brood were separated using the Student Newman–Kuels Test. Duncan's multiple range test was used to separate treatment means for honey yields.

Each colony characteristic and the gross profit/colony for each management system were ranked using August data to determine which system was the most productive. Gross profit/colony for each management system was determined by calculating possible profit (sale of package or nuclei, sale of honey, pollination contracts) minus expenses for each treatment as indicated in the Producers' Consensus Report (B.C.M.A.F. 1984).

Cost breakdowns used in determining profit/colony were as follows:

1. Honey profit:

   Mean honey yield/colony x price/kg = honey profit.

   In the Okanagan Valley in 1983, 60% of the honey was sold at an average price of \$2.53 kg (\$1.15/lb) to customers who have their own containers. The other 40% was sold in containers at \$2.75/kg (\$1.25/lb) to retail outlets. Honey profit for each management system was determined using this 60/40 cost breakdown (B.C.M.A.F. 1984).

2. Pollination fee:

   \$36.00/pollination colony/set x 2 sets = \$72.00.

   The pollination fees were based on those set by the Okanagan Valley Pollination Association in 1983; colonies are generally used for 2 sets.

3. Package profit:

   \$28.00/package – (\$8.00/queen + \$1.50/screened package) = \$18.50

4. Nucleus profit:

$36.00/4 frame nucleus - ($8.00/queen + $4.64/4 frames of foundation) = $23.36.

It was assumed that the purchaser of the nucleus would provide the nucleus box, which is the typical way of selling nuclei in B.C.

Colony characteristics and profit per colony were all weighted equally in determining the final ranking. Colony characteristics for each management system in August were ranked on a scale of 1 to 4 (1 indicating a first place ranking). Statistically similar characteristics were given equal rankings. The gross profit per colony was also ranked for each management system, again grouping similar treatments and giving the best systems the lowest ranking. Rankings for each colony characteristic and gross profit/colony were summed to give a final ranking.

RESULTS

In May and June, colony weights of the apiary treatments were significantly heavier than the pollination treatments. The "Colony - Apiary" treatment was significantly heavier than the "Nucleus - Apiary" treatment (Table 11). In August, there were no significant differences in the mean colony weights of any of the 6 treatments, although the 3 heaviest treatments were the "Apiary" colonies (Table 11).

In May, there were no significant differences in the mean amount of sealed worker brood in any of the treamtents, except that the "Nucleus - Apiary" treatment contained significantly less sealed brood than the "Control - Pollination" treatment (Table 11). There were no significant differences in the amount of sealed brood found in any of the 6 management systems in June (Table 11). In August, the mean area of sealed worker brood in the "Nucleus - Pollination" and the "Control - Pollination" treatments were significantly greater than the "Nucleus Apiary" and "Control - Apiary" treatments.

Analysis of honey yield indicated that the "Control - Pollination" management system produced significantly less honey than the other five management systems (Table 12).

Those systems involving pollination were more profitable than those remaining in the apiary (Table 12). Also, the two systems yielding the highest gross profit had a package or nucleus removed.

Based on biological and economic data the final rankings for the six management systems resulted in the three treatments involving pollination being the most productive (Table 13). The two best treatments included removal of a package or nucleus from colonies in addition to pollination.

Table 11. Biological data for 6 honey bee management treatments tested in the Okanagan Valley, British Columbia in 1983.

Management Treatment	Colony Characteristics (Mean ± S.E.)*					
	Net Colony Wt** (kg)			Sealed Worker Brood (cm²)		
	May	June	August	May	June	August
Control-Apiary	26.7±1.8 a	29.6±2.2 a	45.7±5.3 a	6733±448 ab	8000±655 a	4505±441 c
Control-Pollination	14.7±1.8 c	16.0±1.9 c	33.8±4.1 a	8417±488 a	8303±622 a	7812±360 a
Nucleus-Apiary	19.4±1.7 b	22.2±2.0 b	44.7±3.9 a	6370±404 b	7112±432 a	4820±571 c
Nucleus-Pollination	13.7±1.6 c	13.9±1.9 c	37.8±3.2 a	7712±476 ab	7872±301 a	7819±627 a
Package-Apiary	22.8±1.9 ab	26.1±2.0 ab	49.5±5.1 a	7345±476 ab	[illegible]538±554 a	5625±260 bc
Package-Pollination	16.6±1.5 c	18.3±2.0 c	44.0±4.1 a	7985±550 ab	9012±627 a	6790±549 ab

*Means were compared by the Student-Newman-Keuls test; means followed by the same letter in a column are not significantly different (P>0.05)

**Net colony weight = total weight - weight of empty equipment

Table 12. Economic data for 6 honey bee management treatments tested in the Okanagan Valley, British Columbia in 1983.*

Management Treatment	Honey Yield (kg)	Gross Profit/Colony
Control-Apiary	26.4 ± 2.4 a	$14.36
Control-Pollination	13.8 ± 2.4 b	$79.51
Nucleus-Apiary	25.1 ± 3.3 a	$37.01
Nucleus-Pollination	25.6 ± 5.7 a	$109.28
Package-Apiary	29.8 ± 3.1 a	$39.34
Package-Pollination	24.9 ± 2.7 a	$103.84

*Means were compared by Duncan's multiple range test (1951); means within a column followed by the same letter are not significantly different ($P<0.05$).

Table 13. Overall productivity ranking of 6 honey bee management treatments tested in the Okanagan Valley, British Columbia in 1983.*

Management Treatment	Biological Score		Economic Score		Overall Score (Biological-economic)
	Colony wt	Sealed Brood	Honey	Gross Profit	
Nucleus-Pollination	1	1	1	1	4
Package-Pollination	1	2	1	1	5
Control-Pollination	1	1	2	2	6
Package-Apiary	1	3	1	3	8
Nucleus-Apiary	1	4	1	3	9
Control-Apiary	1	4	1	4	10

* Low scores indicate the more productive treatments.

DISCUSSION

The results indicate that beekeeping management systems which involve the most intense colony management for pollination, honey production, and bee production do not detract from overall colony vigor and yield the best income. Futhermore, the most productive management systems (Table 13) can provide a new source of income through the sale of packages and/or nuclei.

Colonies involved in pollination treatments had lower values than apiary treatments in only one biological characteristic, colony weight in May and June; by August there were no significant differences in weight between pollination and apiary treatments. In May and June, the reduced weight of colonies used for pollination may have been due to worker disorientation and drifting (Free 1958; Jay 1969; Nelson 1985) in the orchards resulting in less nectar collection during pollination compared with apiary treatment colonies. It is also possible that the honeyflow was more intense at the apiary sites than in the orchards, since apiary treatment colonies gained an average of 15.0 kg during the 3 week pollination period compared to an average gain of 8.0 kg for the pollination treatment colonies.

However, moving colonies for pollination did not diminish brood rearing relative to apiary colonies, possibly because the concentrated pollen source available in orchards during the pollination period offset brood loss by 1) maintaining brood rearing at a level comparable to apiary colonies and/or 2) allowing for a rapid recovery in brood rearing. In fact, moving colonies for pollination may have actually stimulated brood rearing, since by August pollinating colonies had significantly greater brood areas than in the apiary treatments. The higher level of brood production in pollinating colonies may have been responsible for colony weights being similar to apiary colonies by August, partly due to the additional weight of more brood. Also, the additional worker population produced by more intense brood rearing in pollinating colonies would increase the rate of nectar collection, resulting in more rapid weight gain than in the apiary treatment colonies.

It is noteworthy that pollinating colonies from which a package or nucleus was taken produced as much or more honey and sealed brood as the apiary control colonies. The biological basis for this result is not clear, since removal of brood and/or adult workers in April might be expected to diminish subsequent brood areas and honey production. Relatively low levels of stress on colonies from bee production, and pesticides may actually stimulate brood rearing and honey production, but this phenomenon has not been investigated. A study by Winston and Fergusson (1985) offers one possible explaination. The results of their study showed lower longevities and ages when foraging commenced in colonies from which a majority of the workers had been removed. This simulated loss in worker populations is similar to naturally occuring colony events such as predation, disease, nest damage, swarming and/or management manipulations involving package and nucleus production or colony division. Winston and Fergusson (1985) suggest that shifts in life-span and foraging age indicate that workers may adjust their temporal caste schedule to respond to rapid changes in colony conditions. Other studies support these findings (Winston and Punnett 1982; Kolmes 1985; Winston *et al.* 1985; Winston 1986).

These results have two important implications for pollination management. First, they indicate that, although moving bees for pollination can reduce honey production, the increased income from pollination offsets any loss of honey. Further, the only significant reduction in honey production was found in colonies which were not used for bee production (Control - Pollination). Using pollination units for bee production as well as pollination resulted in honey yields comparable to control colonies not moved for pollination. These results support the continued use of honey bee colonies for pollination rather than solely for honey production in the Okanagan Valley.

Secondly, the results of our research indicate that Okanagan Valley beekeepers could produce packages and nuclei as part of their pollination management systems. Such bee production would provide an additional source of income as well as have an important role in reducing Canadian dependence on imported bees. An industry of this type would not only be advantageous to B.C., but may also be an important factor in the survival of the Canadian beekeeping industry. In addition to rising import costs the beekeeping industry faces three problems which are moving northward from Latin America, any of which could result in the limitation or cessation of bee importations from infested areas of the U.S. These problems are the mites *Acarapis woodi* and *Varroa jacobsoni* (DeJong *et al.* 1982) and the highly aggressive Africanized honey bees (Taylor and Spivak 1984; Winston 1983). The economic potential for B.C.-produced bees is promising, even without any restriction of importations. However, the possible reduction or outright ban on importations of bees from the U.S. in the future could result in B.C. supplying most of Canada's bees. The results of our research indicate that beekeepers in the Okanagan Valley could play an important role in this new industry.

CONCLUSIONS

The major conclusions of this thesis are:

1. Wild bees, although abundant in natural habitats, are not reliable or predictable pollinators for orchard crops in the Okanagan Valley;
2. Two of the dominant wild bee species in orchards, *Bombus terricola occidentalis* and *B. bifarius nearcticus*, display a strong tendency toward foraging on orchard crops and are potentially manageable for fruit crop pollination;
3. Although *Osmia lignaria propinqua* Cresson was not a dominant orchard species, it has potential for tree fruit pollination in the Okanagan Valley since it displays a strong tendency toward foraging on apples and is indigenous to the region. Also, management systems have already been developed;
4. A multi-species pollination system for Red Delicious apples, combining the foraging abilities of honey bees and *O. lignaria* could potentially improve fruit set and quality;
5. In an effort to maintain indigenous populations of *B. terricola occidentalis*, *B. bifarius nearcticus* and *O. lignaria* for trap-nesting and utilization in tree fruit pollination, enhancement of uncultivated habitat used by these species for foraging, nesting and hibernation should be encouraged;
6. The planting of understory crops in orchards which would complement the flowering cycles of various fruit crops could result in retaining populations of both managed wild bees and honey bees in and near orchards during the bloom period;
7. The pollination efficacy of *O. lignaria* on Red Delicious apples was equal to honey bees in fruit quality characteristics including pollination indices and fruit weight and set, but was lower than one, two or three honey bee visits in fruit symmetry;
8. Predicting colony pollination efficacy in cherries, pears and apples utilizing such factors as colony characteristics, forager entrance counts and weather conditions is possible, but these predictions will have to be made on an individual crop basis;

9. The foraging behavior of honey bees on cherries and pears was affected more by external weather conditions than internal colony characteristics;
10. In late-blooming apples (i.e. Red Delicious) colony foraging strength is dependent on internal colony characteristics more than external weather conditions; and,
11. Beekeeping management systems which involve the most intense management for pollination, honey production, and bee production do not detract from overall colony vigor and yield the best income. Furthermore, the most productive management systems can provide a new source of income through the sale of packages and/or nuclei.

Honey bees will continue to remain the primary insect pollinators of tree fruit crops for many years to come. However, improvements to pollination management systems which result in increased efficiency and a higher economic return are important to both beekeepers and orchardists.

From the perspective of a beekeeper involved in the rental of honey bee colonies for pollination, increased income resulting from the sale of packages and/or nuclei and potentially from the rental of wild bee pollinators utilized in a multi-species system would be appreciated. The inclusion of bee production in pollination management systems in the Okanagan Valley has been well- received by beekeepers and has proven to be successful. Multi-species pollination systems will probably increase in importance as management systems for wild bee pollinators become more accessible to beekeepers. The management of multi-species systems already has proved successful for many western beekeepers who have added the alfalfa leafcutter bee *Megachile rotundata* (Fabricius), to their operations. Research to determine the pollination efficacies of prospective wild bee pollinators, including *B. terricola occidentalis* and *B. bifarius nearcticus* should be initiated in order to refine multi-species management systems.

From the orchardists perspective, pollination systems which are directed at improving fruit quality and yield are essential in maintaining or increasing incomes. Management systems that improve the pollination efficacy of bee pollinators in orchards will be readily accepted and utilized by growers.

Pollination colony strength determination using forager entrance counts is one area of pollination management research which should receive continued attention. It will provide orchardists and inspectors with a simple method of determining whether beekeepers have provided rental colonies which meet pollination strength requirements. Communication between beekeepers and orchardists is essential for continued improvement in pollination management systems.

APPENDIX I

Collection sites and their habitat designations for 1984 and 1985.

Definitions of habitat designation:

1) Orchards: Far from Natural = site is located in an orchard which is surrounded on all sides by other orchards

2) Orchards: Near Natural = site is located in an orchard which is bound on one or two sides by natural uncultivated land

3) Uncultivated: Near Orchards = site is natural uncultivated land bound on one or two sides by orchards

4) Uncultivated: Far from Orchards = site is natural uncultivated land completely surrounded by natural habitat and is >0.5 km from the nearest orchard

	Collection Site	Habitat Designation
1)	G.O. Robertson-Mathewes Rd., East Kelowna, B.C. (elevation: 450 m)	Uncultivated: Near Orchards
2)	W. Cameron-2050 Byrns Rd., Kelowna, B.C. CROP=Pears (elevation: 354 m)	Orchards: Far from Natural
3)	Dilworth Mt. Estates-Dilworth Mtn. Drive, Kelowna, B.C. (elevation: 600 m)	Uncultivated: Far from Orchards
4)	C. Day-Day Rd., Rutland, B.C. CROP=Apples (elevation: 570 m)	Orchards: Near Natural
5)	Sutherland Hills Park-Hall Rd., East Kelowna, B.C. (elevation 360 m)	Uncultivated: Near Orchards
6)	D. Claridge-Todd Rd., Oyama, B.C. CROP=Cherries (elevation: 500 m)	Orchards: Near Natural

Collection Site	Habitat Designation
7) Agriculture Canada Research Station, Summerland, B.C. (elevation: 454 m)	
a) Orchard Sites-apples, pears, cherries	Orchards: Far from Natural
b) Budwood Orchard (bound on 2 sides by uncultivated land) and Arboretum (bound on 2 sides by uncultivated land and receives no chemical sprays)	Orchards: Far from Natural
8) V. James-Old Vernon Rd., Rutland, B.C. CROP=Apples, Cherries, Pears (elevation: 420 m)	Orchards: Far from Natural
9) Knox Mtn. Park-Knox Mtn. Drive, Kelowna, B.C. (elevation: 637 m)	Uncultivated: Far from Orchards
10) Agriculture Canada Research Substation, Hart Rd., East Kelowna, B.C. CROP=Apples (elevation: 450 m)	Orchards: Far from Natural
11) Abandoned Apple Orchard-Haynton Crt. at Westside Rd., Westbank, B.C. (elevation: 330 m)	Uncultivated: Far from Orchards
12) Okanagan Centre Rd., Winfield, B.C. (elevation: 500 m)	Uncultivated: Far from Orchards
13) Oyama Lake Resort Road, Oyama, B.C. (elevation: 750 m)	Uncultivated: Near Orchards

APPENDIX II

The habitats and floral visitation patterns of wild bee species collected in the Okanagan Valley in 1984 and 1985.

Habitat description:

Habitat 1 = Orchards: Far from Natural

Habitat 2 = Orchards: Near Natural

Habitat 3 = Uncultivated: Near Orchards

Habitat 4 = Far from Orchards: Far from Orchards

Bee Species	Year		Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined)			
	1984	1985		Hab. 1	Hab. 2	Hab. 3	Hab. 4
APIDAE							
Bombus terricola occidentalis	x	x	*Taraxacum officinale*	2	3	3	
			Prunus avium (sweet cherry)	9	14		
			Fragaria virginiana	1			
			Balsamorhiza sagittata				7
			Malus sylvestris (apple)	6	26		2
			Malus sp. 1 (crabapple)	4			
			Rosa nutkana			1	1
			Berberis aquifolium		2		
B. fervidus	x	x	*T. officinale*			1	
			B. sagittata			2	
			Heuchera cylindrica				3
			Potentilla recta				3
			Astralagus miser			1	2

APPENDIX II cont.

Bee Species	Year 1984	Year 1985	Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined) Hab. 1	Hab. 2	Hab. 3	Hab. 4
B. centralis	x	x	*T. officinale*	1			3
			M. sylvestris	1	2		
			Malus sp.1	3	1		
			B. sagittata			1	4
			H. cylindrica			2	1
			Symphytum officinale			1	
			Dodecatheon pulchellum			1	
			P. avium			1	
			Astralagus neglecta			1	1
			Thlaspi arvense			1	
			Erigeron philadelphicus			1	
			Lithospermum ruderale				1
			Potentilla arguta			1	
B. bifarius nearcticus	x	x	*T. officinale*	1	4		7
			P. avium	4	3		
			M. sylvestris	5	1		
			Malus sp.1	6	1		
			B. sagittata			3	6
			D. pulchellum			2	
			Amelanchier alnifolia				2
B. californicus consanguineus.	x		*T. officinale*				1
B. californicus	x	x	*T. officinale*			1	
			B. sagittata				1
B. vagans	x	x	*Lupinus* sp.		1		
			R. nutkana		1	1	1
			Symphytum aperum		1		
			M. sylvestris		3	1	
			T. officinale			2	
			H. cylindrica			1	1
			S. officinale			22	
			L. ruderale			1	
			A. alnifolia			1	
			Castilleja hispida			1	
			T. arvense			7	
			B. sagittata				1
			A. miser			1	

APPENDIX II cont.

Bee Species	Year 1984	1985	Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined) Hab. 1	Hab. 2	Hab. 3	Hab. 4
B. melanopygus	x	x	*B. aquifolium*				1
			Malus sp.1			1	
			P. avium			1	
B. mixtus	x	x	*M. sylvestris*		4		1
			Malus sp.1	3			
			T. officinale				1
			P. avium		2		
			B. sagittata				1
B. appositus	x	x	*H. cylindrica*				1
			A. miser				1
B. rufocinctus	x	x	*M. sylvestris*		1		
			Castilleja miniata			3	
			B. sagittata				1
			Ceanothus sanguineus			1	
B. flavifrons flavifrons	x		*M. sylvestris*				1
B. edwardsii	x	x	*B. aquifolium*				2
			A. miser				1
B. frigidus		x	*C. miniata*			2	
B. sylvicola		x	*C. miniata*			1.	
			C. hispida				1
B. sitkensis		x	*Symphytum altissimum*			1	
Bombus sp.	x		*T. officinale*			1	
Psithyrus sp.	x	x	*T. officinale*	1		1	4
			B. aquifolium				
			M. sylvestris	3	10		
			B. sagittata			1	
			S. altissimum			1	
			Tragopogon dubius				1
			A. miser				1

APPENDIX II cont.

Bee Species	Year 1984	Year 1985	Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined) Hab. 1	Hab. 2	Hab. 3	Hab. 4
HALICTIDAE							
Halictus tripartitus	x		*B. sagittata*				1
			T. officinale	2		1	2
H. confusus	x	x	*T. officinale*	2	1	14	15
			Capsella bursa-pastoris			4	
			T. arvense			4	
			Smilacina stellata			1	
			Lupinus sp.		2		
			P. virginiana			1	
			R. nutkana			4	
			S. altissimum			3	
			A. alnifolia				2
			C. sanguineus				1
			Antennaria microphylla			5	
			H. cylindrica			1	
			D. pulchellum			1	
			L. ruderale			2	
			B. sagittata			2	2
H. ligatus	x	x	*T. officinale*	1	2	3	14
			P. recta				2
			E. philadelphicus				2
			Gaillardia aristata			1	1
			T. dubius				2
			B. sagittata				1
H. farinosus	x	x	*T. officinale*			1	1
			P. recta				1
			Malus sp.1		1		
			Medicago sativa			1	
			M. sylvestris				1
Evylaeus near *divergens*	x	x	*T. officinale*	1		1	3
			T. arvense			2	
			A. alnifolia				1
			T. dubius				1
E. near *quebecensis*	x		*T. officinale*	1			
			C. bursa-pastoris			1	

APPENDIX II cont.

Bee Species	Year		Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined)			
	1984	1985		Hab. 1	Hab. 2	Hab. 3	Hab. 4
E. near *foxii*	x		*T. officinale*			1	
Lasioglossum zonulum	x	x	*P. recta*				1
			R. nutkana			1	
			T. dubius				1
			G. aristata				1
L. sisymbrii	x		*T. officinale*				1
L. near *trizonatum*	x		*T. officinale*				1
			T. arvense			1	
Dialictus albipennis	x	x	*T. officinale*		1	1	12
			A. neglecta				1
			R. nutkana			2	
			A. alnifolia			1	
			B. sagittata				1
			T. arvense			4	
D. laevissimus	x	x	*Achillea millefolium*				1
			T. officinale			16	39
			P. virginiana				1
			A. neglecta				1
			T. arvense			4	
			A. alnifolia				1
			R. nutkana				1
			G. aristata			1	
D. cressonii	x		*T. officinale*			1	
D. pruinosus	x	x	*T. officinale*	6		5	33
			P. virginiana				1
			A. millefolium			1	
			E. philadelphicus				
			B. sagittata		1	1	1
			Brassicaceae		1		
			Lupinus sp.		4		
			Crepis sp.				6
Dialictus sp. 2	x		*T. officinale*			26	17

APPENDIX II cont.

Bee Species	Year		Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined)			
	1984	1985		Hab. 1	Hab. 2	Hab. 3	Hab. 4
Dialictus sp.5	x	x	*T. officinale*	1		19	1
			F. virginiana				1
			A. millefolium			1	
			S. stellata			1	
			Malus sp.1		1		
			A. neglecta			1	
Dialictus sp.6	x	x	*T. officinale*			27	3
			C. bursa-pastoris			3	
			F. virginiana				2
			R. nutkana			2	
			D. pulchellum			2	
			B. sagittata				6
Dialictus sp.	x	x	*T. officinale*	2		17	46
			C. bursa-pastoris			1	
			A. microphylla			1	
			T. arvense			6	
			Cornus stolonifera			1	
			A. millefolium			2	
			E. philadelphicus				1
			L. ruderale				1
			M. sylvestris		2		
			B. sagittata			2	10
			F. virginiana			1	
			R. nutkana			1	1
			S. altissimum			1	
			Crepis sp.				1
			G. aristata			1	
D. near *nevadensis*	x		*T. officinale*			3	6
			C. bursa-pastoris			1	
			A. microphylla			1	
Agapostemon texanus	x	x	*T. officinale*				2
			P. recta				1
			E. philedelphicus				1
			A. miser				1
			T. dubius			1	1
			S. altissimum			1	
			Crepis sp.				1
			M. sativa				1

APPENDIX II cont.

Bee Species	Year 1984	Year 1985	Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined) Hab. 1	Hab. 2	Hab. 3	Hab. 4
Sphecodes sp.	x	x	*F. virginiana*				1
			T. officinale			2	4
			A. neglecta				1
			A. miser				2
			Lupinus sp.		1		
			C. miniata			1	
			L. ruderale			1	
			C. hispida				1
			C. stolonifera			1	
Halictus sp.	x		*T. officinale*	3			2
			C. stolonifera			1	
			B. sagittata				1
ANDRENIDAE							
Andrena nigrocearula	x	x	*T. officinale*	1		4	1
			C. bursa-pastoris			5	
			M. sylvestris	1			1
			B. sagittata				1
			C. sanquineus				2
			R. nutkana				1
			Arabis sp.			1	
A. topazana	x	x	*T. officinale*			1	1
			T. arvense			5	
			Malus sp.1		2		
			A. neglecta			1	
			Crepis sp.				1
A. berberidis	x	x	*T. officinale*			2	1
			B. sagittata			2	10
			B. aquifolium			5	1
			R. nutkana				4
A. sladeni	x		*T. officinale*			1	
A. prunorum prunorum	x	x	*T. officinale*			1	1
			T. arvense			1	
			Malus sp.1		2		
A. astragali	x		*T. officinale*				2
			C. bursa-pastoris			1	

APPENDIX II cont.

Bee Species	Year 1984	 1985	Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined) Hab. 1	 Hab. 2	 Hab. 3	 Hab. 4
A. microchlora	x		*T. officinale*				1
A. nothocalaidis	x		*T. officinale*				1
A. melanochroa	x	x	*T. officinale*			2	9
			F. virginiana			5	21
			T. arvense			3	
A. laurencei	x	x	*T. officinale*			1	
			B. aquifolium			2	
			B. sagittata			3	19
			H. cylindrica				2
A. miranda	x	x	*T. officinale*				1
			F. virginiana				1
			T. arvense			7	
			Camelina microcarpa			1	
			A. cordifolia			1	
			A. neglecta			3	
			H. cylindrica			1	
			R. nutkana			2	1
			A. alnifolia			1	4
			Crataegus columbiana			1	
			B. sagittata				4
A. w-scripta	x		*T. officinale*				1
A. thaspii	x	x	*T. officinale*				1
			M. sylvestris				1
A. sigmundi	x		*T. officinale*				1
A. amphibola	x		*T. officinale*				1
A. salicifloris	x	x	*C. bursa-pastoris*			1	
			B. sagittata				2
			B. aquifolium			1	
			M. sylvestris		1		
			R. nutkana				1
A. candidiformus	x		*C. bursa-pastoris*			2	
A. schuhi	x		*P. avium*		1		
			B. sagittata				1

APPENDIX II cont.

Bee Species	Year 1984	Year 1985	Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined) Hab. 1	Hab. 2	Hab. 3	Hab. 4
A. milwaukeensis	x		*P. avium*		1		
A. nigrifrons	x	x	*T. arvense*			1	
			A. neglecta			1	
A. viericki	x	x	*B. sagittata*				1
			C. microcarpa			1	
			A. neglecta			1	
A. vicina	x		*M. sylvestris*				2
			B. aquifolium			1	
A. nivalis	x	x	*M. sylvestris*				1
			B. aquifolium				2
			R. nutkana				1
A. forbescii	x	x	*T. officinale*				1
			R. nutkana			1	
A. scurra	x	x	*T. officinale*			1	
			B. sagittata				1
Andrena (*Simandrena*) sp.	x	x	*B. sagittata*			1	6
			T. officinale				2
			R. nutkana				1
Andrena sp.	x	x	*T. officinale*			1	1
			C. bursa-pastoris			3	
			E. philedelphicus				1
			B. sagittata			3	3
			P. avium	1			
			A. neglecta			1	
			H. cylindrica			1	
MEGACHILIDAE							
Osmia odontagaster	x	x	*T. officinale*			1	
			S. altissimum			1	
O. iridis	x	x	*A. miser*				3
			T. officinale			3	2
			B. sagittata			1	--

APPENDIX II cont.

Bee Species	Year 1984	Year 1985	Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined) Hab. 1	Hab. 2	Hab. 3	Hab. 4
O. coloradensis	x	x	*T. officinale*	1		2	1
			G. aristata			1	
			M. sylvestris	1			
			Lupinus sp.		1		
			A. miser		3		3
			B. sagittata			1	
			A. neglecta			1	
			T. dubius			3	
O. texana	x	x	*Cirsium vulgare*				1
			A. miser				2
O. albolateralis	x	x	*T. officinale*	1		3	
			A. miser			1	1
			Malus sp.1		1		
			B. sagittata			2	5
			F. virginiana			1	
O. montana montana	x	x	*T. officinale*				1
			B. aquifolium			1	
			F. virginiana			1	
O. lignaria	x	x	*B. sagittata*				5
			M. sylvestris	6			
			B. aquifolium				2
			Malus sp.1		3		
O. pusilla	x	x	*T. officinale*			3	
			A. miser			2	1
			T. arvense			1	
			A. neglecta			1	
			B. sagittata			1	
O. californicus	x	x	*B. sagittata*			1	1
			M. sylvestris		5		
			T. officinale				1
O. kincaidii	x	x	*M. sylvestris*		3		
			D. pulchellum			1	
O. monilosmia n.sp. "B.C."	x		*B. sagittata*				1
			A. miser			1	
Megachile subnigra	x		*E. philedelphicus*				1

APPENDIX II cont.

Bee Species	Year 1984	Year 1985	Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined) Hab. 1	Hab. 2	Hab. 3	Hab. 4
M. pugnata	x		*E. philedelphicus*				1
M. melanophagea	x	x	*A. miser*			2	
			A. alnifolia				1
Megachile sp.		x	*T. dubius*			1	
Hoplitis hypocrita	x		*A. miser*			1	
Stelis montana	x	x	*M. sylvestris*		1		
			G. aristata			1	
Stelis sp.	x	x	*T. officinale*			1	
			A. miser			1	
			T. dubius				1
Osmia sp.	x	x	*E. philedelphicus*				1
			T. officinale			1	1
			B. sagittata				1
			A. miser			2	8
			M. sylvestris		1		1
			C. columbiana			1	
			C. microcarpa			1	
			Lupinus sp.		2		
			A. miser			1	
ANTHOPHORIDAE							
Nomada sp.	x	x	*B. sagittata*				3
			T. officinale		1	2	4
			A. neglecta			3	
			P. virginiana			2	
			R. nutkana			1	
			A. alnifolia			2	
			M. sylvestris				2
			A. miser				1
			Crepis sp.				1

APPENDIX II cont.

Bee Species	Year 1984	Year 1985	Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined) Hab. 1	Hab. 2	Hab. 3	Hab. 4
Ceratina acantha	x	x	*A. miser*		1	7	
			A. millefolium			3	
			T. arvense			2	
			C. stolonifera			1	
			E. philedelphicus			5	2
			T. officinale			2	
			A. neglecta			1	
			C. columbiana			1	
			B. sagittata				1
			R. nutkana				2
C. nanula	x		*T. officinale*			1	
			Erigeron sp.			1	
Mellisodes confusa	x		*E. philedelphicus*				5
			G. aristata			1	
Melecta relativa	x		*G. aristata*			1	
Neopasites fulviventris	x		*G. aristata*			1	
Melecta pacifica	x	x	*B. sagittata*			1	9
Hapropoda cineraria	x	x	*B. sagittata*			2	25
			L. ruderale				2
			T. officinale			1	1
			B. aquifolium				9
			M. sylvestris	1	3		
			P. avium		4		
			Malus sp.1	52	4		
			Ranunculus glaberrimus			1	
Epeolus sp.	x	x	*T. officinale*		1		5
			F. virginiana				7
			G. aristata			3	
			B. aquifolium				1
			M. sylvestris				1
Triepeolus sp.	x	x	*F. virginiana*				3
			T. officinale			2	2
			B. sagittata			3	

APPENDIX II cont.

Bee Species	Year		Plant(s) Visited	Number of Bees Collected (1984 & 1985 combined			
	1984	1985		Hab. 1	Hab. 2	Hab. 3	Hab. 4
Tetralonia frater	x		*T. officinale*				1
Anthophora sp.	x		*B. sagittata*				1
Mellisodes sp.		x	*M. sylvestris*		1		
COLLETIDAE							
Hylaeus sp.			*P. arguta*			2	

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