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UTILIZATION OF SYNTHETIC CODLING MOTH PHEROMONE

IN APPLE PEST MANAGEMENT SYSTEMS

by

Jerry Mathew Vakenti

B.Sc., Simon Fraser University, 1972

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

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of

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Utilization of Synthetic Codling Moth Pheromone in Apple Pest Management Systems.

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ABSTRACT

Traps baited with synthetic pheromone, trans-8, trans-10 dodecadien-1-ol, were used to sample codling moth, *Laspeyresia pomonella* (L.) populations in 7 commercial orchards in the Okanagan Valley during 1973 and 1974. Catches exceeding an average of 2 males/trap/0.4 ha. during 2 consecutive weeks indicated damaging populations. With sprays applied on this basis, a reduction of 43.1% in the number of preventative sprays which would have been applied was attained without increases in fruit damage.

Both influx of males and females were shown to influence interpretation of catches but additional traps placed around orchards reduced male influx and pinpointed *L. pomonella* infestations outside monitored orchards.

For 4.05 ha. commercial orchards, the economic threshold for *L. pomonella* damage was established at 3,978 apples (i.e. the number of apples which would have to be damaged before the costs of a spray were returned). Optimal control strategies are proposed whereby pesticide influences on *L. pomonella* populations could be further reduced, particularly during the spring generation. If comprehensive data were available on population dynamics of *L. pomonella* populations in commercial orchards, catches could be used to estimate potential damage levels on an economic basis during the spring and summer generations. More research is necessary in unsprayed commercial orchards before catches can be related more directly to potential damage occurring later in the season.

The results of this study indicated that monitoring of *L. pomonella* populations with pheromone traps should be promoted for use in commercial orchards. Costs of production and environmental effects would be substantially reduced with codling moth population monitoring.

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I thank Drs. H. F. Madsen and J. H. Borden for continuing advice and discussions throughout this study, Dr. M. D. (Jinx) Proverbs for allowing me to use some of his unpublished data, Mr. Francis Dolozar for photographs and Drs. J. S. Barlow and R. C. Brooke for many helpful suggestions in preparing the manuscript. I appreciate the assistance received from personnel of Agriculture Canada and the B.C. Department of Agriculture in trap collections and harvest sampling. The field work was completed while I was employed by Agriculture Canada.

INTRODUCTION

The codling moth, *Laspeyresia pomonella* (L.), has been recognized for many years as a 'key' pest in the development of pest management systems in apple and pear orchards (Barnes 1959; Madsen and Morgan 1970; Hoyt and Burts 1974). The injury caused by the larvae is direct. Infested apples may drop from the tree before harvest or harvested apples that are injured are culled at the packinghouse. Two types of direct injury occur: 1) stings are superficial penetrations made by first-instar larvae, and 2) entries indicate that the attacking larvae survived at least one moult and began tunnelling towards the centre of the fruit.

In the absence of satisfactory population sampling procedures, prophylactic calendar spray programs are usually recommended in most fruit growing areas. In the Okanagan Valley, yearly costs of such spray programs for codling moth control on an estimated 25,000 acres of apple orchard total approximately $852,000 based on an average of 2.5 sprays at $13.60/acre/spray (Appendix 1; M. D. Proverbs, personal communication).[1] Despite the obvious benefits of increased yield and quality obtained with the use of broad spectrum persistent insecticides, less desirable effects both to the environment and on secondary pome fruit pests have occurred in the past (Madsen and Morgan 1970; Newsom 1974; Croft and Brown 1975). Continually increasing costs of spray chemicals, and public and scientific concern over pesticide use and misuse has led to research toward alternative control strategies. These include management techniques (Pickett, Putman and LeRoux 1958; Stern et al. 1959; Bartlett 1964; Geier 1966;

[1] Summerland Research Station, Agriculture Canada, Summerland, B.C.

Beirne 1967), sterile insect releases (Proverbs, Newton and Logan 1966) and pheromonal, hormonal and genetic controls (Gaston, Shorey and Saario 1967; Williams 1956; Lavel 1969). The development and acceptance of new methods within the agricultural industry will depend on their meeting the current demands for higher crop yields and uniform high quality.

L. pomonella has two complete generations per year and a partial third in some years and locations in the Okanagan Valley of British Columbia. The life-cycle can be summarized as follows. Fifth-instar larvae complete development within the apple, exit and overwinter on the tree and in the ground. Pupation occurs in the spring with the adults emerging from late April to mid-July. These adults mate, females oviposit and the spring generation larvae enter and complete development in the maturing apple during the spring and early summer. Larvae leave the fruit, some entering diapause and the majority pupating. Adults of the summer generation emerge from July to mid-September, mate and oviposit. Their larvae complete development, with most entering diapause and overwintering. Some adults emerge to begin a third generation during September and October but the larvae do not reach maturity.

While the codling moth in the Okanagan Valley can be controlled effectively with the organophosphates, Guthion, Zolone and Imidan (Madsen 1970), the use of pesticides in the past has created many problems. Insecticide resistance, destruction of beneficial pollinators, predators and parasites, increased populations of phytophagous mites and soil contamination have followed pesticide use (Downing and Arrand 1968; Madsen and Morgan 1970; Proverbs 1970).

Classical methods of biological control tried against *L. pomonella* have been unsuccessful to date (Proverbs 1970). Integrated control and sterile moth releases are now being tried. A sterile moth release program is being planned for approximately 1,500 acres in the Similkameen Valley during 1976 (M.D. Proverbs, personal communication). A second program based on the principles of integrated control (Gonzales 1973) has been partially developed for *L. pomonella* in the Okanagan Valley (Madsen 1971). Three general recommendations before implementing integrated control strategies are (Gonzales 1973):

1) growers should become familiar with the pests and their predators and parasites;
2) numbers of pests and damage caused should be monitored to avoid treating on predetermined calendar dates; and
3) pesticides, appropriate dosages and timing of spray applications must be selected to produce little or no effect on natural enemies within each particular ecosystem.

The development of commercial integrated mite control programs in the Okanagan Valley of Washington (Hoyt 1969) and British Columbia (Downing and Arrand 1968) illustrates the above recommendations exceedingly well. Within these programs mortality of nature enemies of phytophagous mites, particularly *Typhlodromus occidentalis* (Nesbitt), was minimized by using selected chemicals at lower rates than previously recommended for *L. pomonella* control (Madsen 1970). A better understanding by growers that some pest populations can be limited by natural enemies and abiotic factors and some pest damage can be tolerated economically led to gradual acceptance of integrated mite control.

One of the most difficult steps in implementing an integrated program is to monitor population size and the damage caused by the pest. Population sampling difficulties are encountered in determining an "economic threshold" for *L. pomonella*. Sampling of larval stages is difficult because the low populations in commercial orchards would require large and time-consuming samples for reliable population estimates. Sampling of adults is preferable since it indicates potential fecundity which can be related to the economic injury caused by larvae during each subsequent generation.

The method most commonly used to monitor *L. pomonella* flight periods for timing chemical sprays has been to trap both sexes with fermenting bait pans or ultraviolet light traps (Madsen 1967). However, these methods reflect true population size only for very low or high densities (Madsen 1971). When substituted into a simulation model, catches in fermenting bait pans provided a direct estimate of high density populations (Geier and Hillman 1971).

Madsen and Davis (1971) tested the hypothesis that female-baited traps could indicate population levels and distribution within an area. Subsequent studies with traps baited with females or synthetic pheromone (Roelofs et al. 1971) indicated that male captures could be useful for estimating native populations (Madsen and Vakenti 1972, 1973a). When used in conjunction with visual observations for injured fruit, male captures indicated the need for chemical controls in commercial orchards, although not on a well-defined economic threshold basis.

My objectives were to obtain a reliable method for sampling adult *L. pomonella* populations and to correlate males captured in synthetic pheromone traps with the amount of damage occurring during each generation. The following hypotheses were tested during 1973-74:

1) that synthetic pheromone can be substituted for female moths in traps;
2) that the number of males captured is related to the number of females present and the amount of damage caused within an orchard;
3) that traps placed outside monitored orchards identify sources of infestations and reduce influx of males enabling traps within monitored orchards to reflect actual populations more clearly; and
4) that a mean male catch in the orchard traps of 2 males/trap/0.4 ha. during 2 consecutive weeks represents the economic threshold for codling moth damage.

GENERAL MATERIALS AND METHODS

Description of Orchards Studied and Previous History Relating To Climate, Codling Moth Populations, Seasonal Spray Programs, and Harvest Damage

Seven orchards were selected to represent the range of climate (Table I) and pest intensity within the major fruit growing regions of the Similkameen and Okanagan Valleys (Fig. 1). The production details in Table II are only estimates since most growers are continually removing trees, replanting with younger trees of different varieties and re-grafting trees. Also, young trees are coming into production each year. Since the orchards are commercially operated, the research was subject to a wide range of cultural practices such as chemical and hand thinning, different methods of irrigation, variable harvesting procedures and varying degrees of grower interest and knowledge of pest-damage relationships. Apple varieties and other fruits were interplanted in small blocks, often surrounded by additional blocks owned by the same or a different grower.

Synthetic Pheromone Trap Sampling Procedures

Synthetic Pheromone Formulations

In 1973, 1.0 mg synthetic codling moth pheromone, *trans-8, trans-10*, dodecadien-1-ol (Roelofs et al. 1971; Beroza, Bierl and Moffit 1974) impregnated in rubber caps (Pherocon, CM, Zoecon Corporation, Palo Alto, California) was suspended in traps (Madsen and Vakenti 1973a). The caps were

Table I. Altitude, temperature, growing period and precipitation for locations in the Okanagan and Similkameen Valleys, British Columbia[a]

Area	Altitude (m)	Mean July Temp. (°C)	Mean Yearly Temp. (°C)	Growing Period (Days)	Annual Precipitation (mm)
Coldstream, Vernon	482.3	19.4	7.2	200	60.8
Kelowna	353.7	20.0	8.3	200	49.1
Summerland	454.6	21.1	8.9	212	45.2
Penticton	341.8	20.0	8.9	217	47.6
Oliver	307.3	21.1	8.9	226	42.5
Keremeos	429.9	21.7	9.4	221	40.2

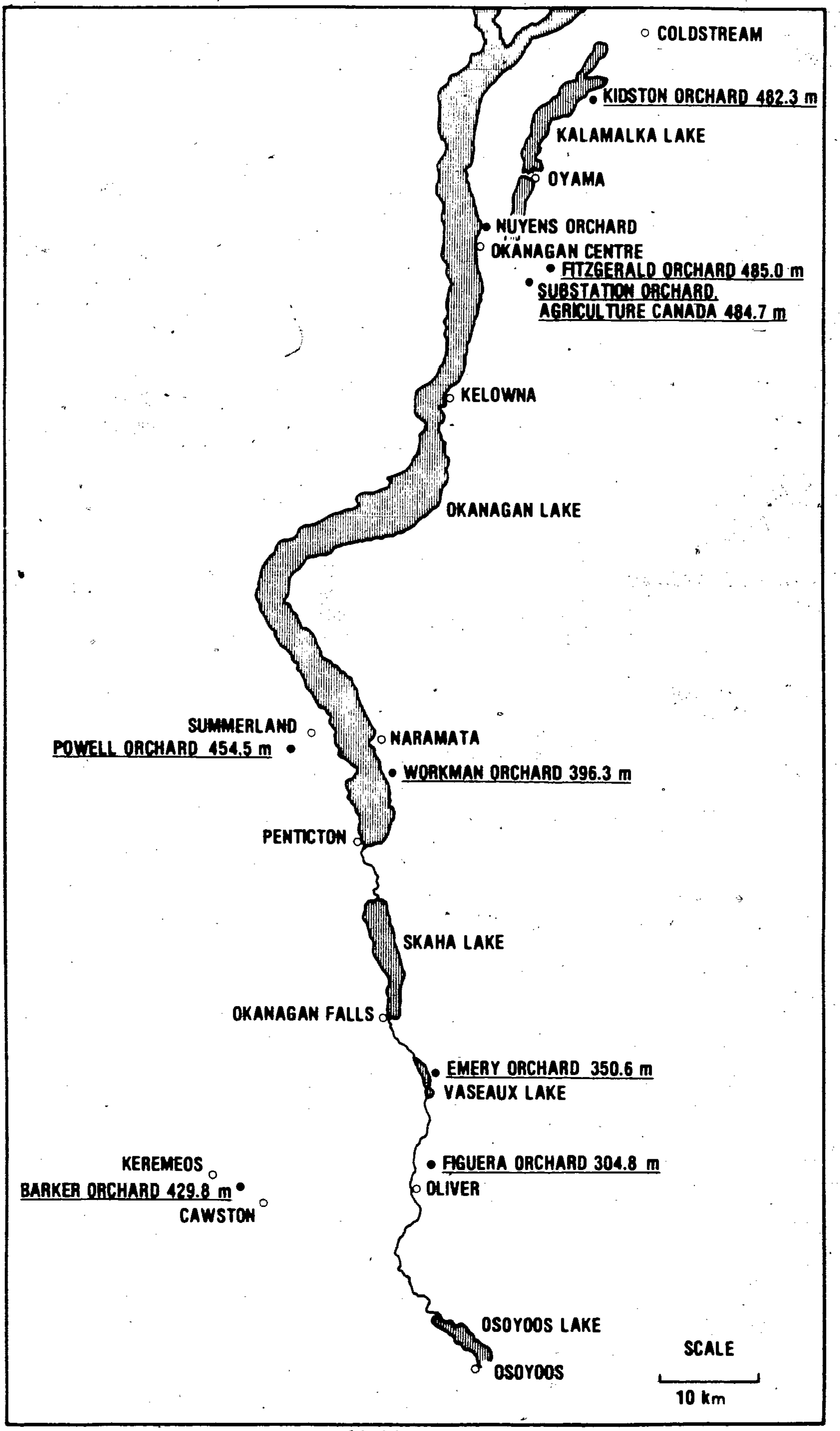
[a] Temperature and precipitation means are based on 10-20 year records maintained from 1931 to 1960 (Arendt 1972).

Table II. Production details from study orchards used during 1973-74

Orchard, Location	Study Acreage (Hectares)	Apple Variety	# of Trees	Age Range (Yrs.)	Planting Space (m)	Tree Size & Root Stock	# of Codling Moth Sprays 1972	% Harvest Damage 1972
Kidston, Vernon	4.05	Tydeman	250	14	5.18 x 4.57	Standard	2	0.43
		McIntosh	480	12	5.18 x 5.18	Medium (MII+MVII)		0.20
		Red Delicious	160	16	5.18 x 9.15	Standard		0.40
Fitzgerald, Kelowna	4.86	McIntosh	51	5-26	7.93 x 4.57	Semi-Dwarf	1	0.03
		Spartan	17	5-26	7.93 x 9.15	Semi-Dwarf		0.03
		Red Delicious	759	5-26	7.93 x 4.57	Standard		0.00
		Golden Delicious	176	5-26	7.93 x 4.57	Standard + Dwarf		–[a]
Workman, Naramata	4.05	McIntosh	–[b]	5-25	9.15 x 9.15	Standard	3	0.30
		Spartan	–[b]	5-25	9.15 x 9.15	Standard		0.70
		Red Delicious	–[b]	5-25	6.10 x 6.10	Standard + Dwarf		0.15
		Golden Delicious	–[b]	5-25	High Density	Dwarf + Standard		0.15
Barker, Keremeos	3.24	Red Delicious	84	25-38	9.15 x 9.15	Standard	2	1.30
		Spartan	115	12-14	6.10 x 7.62	Medium (EM-2)		–[a]
		Golden Delicious	46	12-14	6.10 x 7.62	Medium (EM-2)		0.15
		Bartlett Pears	241	15-39	9.15 x 9.15	Standard		0.00
Emery, Vaseaux Lake	4.05	Spartan	117	5-20	6.10 x 6.10	Medium (104)	3	–[c]
		Red Delicious	253	5-20	6.10 x 6.10	Medium (104)		–
		Golden Delicious	203	5-20	6.10 x 6.10	Medium (104)		–
		Winesap	20	5-20	6.10 x 6.10	Medium (104)		–
Powell, Summerland	4.05	McIntosh	191	5-25	6.10 x 9.15	Medium	2	–[a]
		Spartan	219	5-25	6.10 x 9.15	Medium		0.00
		Red Delicious	474	5-25	6.10 x 9.15	Medium		0.00
		Anjou Pears	132	5-25	6.10 x 9.15	Medium		0.00
CDA Substn., Kelowna	2.02	McIntosh	148	5-25	9.15 x 9.15	Standard	0	>10.0
		Spartan	148	5-25	9.15 x 9.15	Standard		

[a] Harvest samples not taken during 1972 (Madsen and Vakenti 1973a).
[b] McIntosh and Spartan trees totalled > 40 trees, Red Delicious > 200 trees, and Golden Delicious > 1,000 trees.
[c] Orchard not included in the study until Spring 1973.

Fig. 1. The location and elevation of each study orchard is shown in relation to the main population centres of the Okanagan Valley, British Columbia


COLDSTREAM
KIDSTON ORCHARD 482.3 m
KALAMALKA LAKE
OYAMA
NUYENS ORCHARD
OKANAGAN CENTRE
FITZGERALD ORCHARD 485.0 m
SUBSTATION ORCHARD, AGRICULTURE CANADA 484.7 m
KELOWNA
OKANAGAN LAKE
SUMMERLAND
POWELL ORCHARD 454.5 m
NARAMATA
WORKMAN ORCHARD 396.3 m
PENTICTON
SKAHA LAKE
OKANAGAN FALLS
EMERY ORCHARD 350.6 m
VASEAUX LAKE
KEREMEOS
BARKER ORCHARD 429.8 m
CAWSTON
FIGUERA ORCHARD 304.8 m
OLIVER
OSOYOOS LAKE
OSOYOOS
SCALE
10 km

replaced monthly. In 1974, identical pheromone-impregnated rubber caps were used in the Kidston, Fitzgerald and Substation orchards. Traps in the other four orchards were baited with 1 mg synthetic pheromone impregnated in polyvinyl resin bars (Pherocon CM-X, Zoecon Corporation, Palo Alto, California). Since this formulation was effective in the field in South Africa for at least 8 weeks (H. F. Madsen, personal communication)[2] the bars were replaced every 8 weeks. The bar was placed on the centre of the Stickem® surface of the trap.

Trap Designs, Placement and Density

A particular trap design must meet certain requirements such as trapping efficiency, field maintenance, cost and availability. A cylindrical cardboard carton with a replaceable liner (Fig. 2) similar to that described by Proverbs et al. (1966) was used in most instances. This trap meets all the above criteria (Madsen and Vakenti 1973b). Another trap (Pherocon ICP, Zoecon Corporation, Palo Alto, California) Figs. 3, 4) was substituted in all but the Kidston and Fitzgerald orchards during the 1974 season.

Traps or trap liners were replaced when the Stickem® surface became ineffective because of contamination with debris or moth wing scales (P. Westigard, personal communication).[3]

Trap placements in 1973 were at 1 trap/0.4 hectares. Based on

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[2] Agriculture Canada Research Station, Summerland, B.C.

[3] Research Scientist, Oregon State Experimental Station, Medford, Oregon.

Figs. 2-4. Traps used to monitor *L. pomonella* populations. Cylindrical carton trap showing Pherocon CM pheromone cap suspended in trap (Fig. 2). Pherocon ICP trap in operating position (Fig. 3) and separated to show location of Pherocon CM cap (Fig. 4). Arrow points to location of flap used in older design


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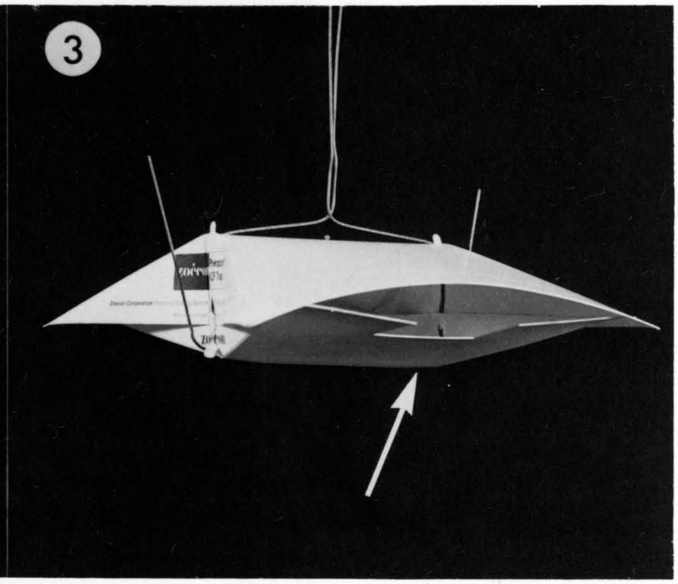
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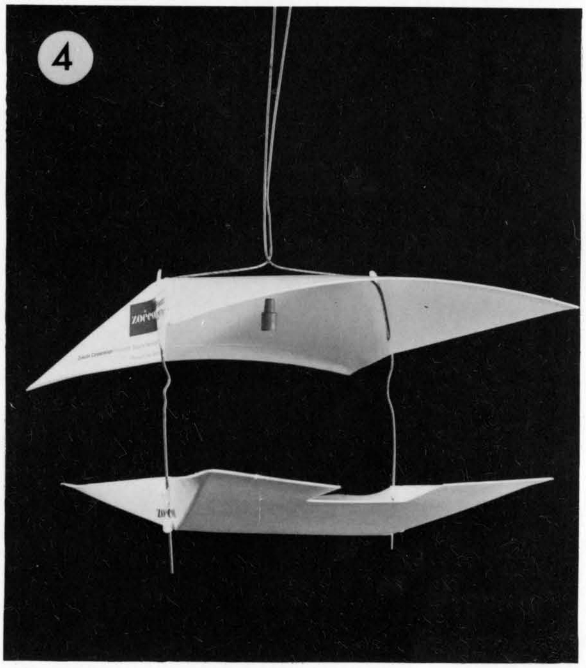
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results from South Africa (Myburgh et al. 1974) which showed that a single pheromone trap effectively monitored the population within 1 hectare, the 1974 traps density was changed to 1 trap/hectare in the Powell, Barker, Workman and Emery orchards. A slight modification was made in the Emery and Workman orchards: trap-monitored areas covered 0.4 hectares or 2 hectares on alternative halves of the orchard each week in order to test the area a single trap would monitor under B.C. conditions.

In 1973, traps were placed in adjoining orchards and residential areas to minimize codling moth attraction from these areas to traps located within the monitored orchards.

Population Treatment Levels Used to Determine the Need for Control Sprays

In previous experiments (Madsen and Vakenti 1973a), visual observations for codling moth damage were conducted when high male catches were recorded in orchards. With these supplemental visual observations, trap catches exceeding an average of 2 males/trap/week after petal fall indicated that fruit damage would probably occur during that generation. By utilizing traps located outside orchards (Figs. 5-14), a higher male catch level was tested during 1973-74 to indicate when treatment was necessary. A grower was advised to spray if traps within the monitored orchard captured 2 or more males/trap during 2 consecutive weekly samples. The margin for growers accepting damage during the study remained low so in some cases it was necessary to recommend or agree to sprays that were not considered necessary. Contracts were made with cooperating growers whereby they were reimbursed for codling moth damage exceeding 1% at harvest.

Sampling Procedures For Estimating Codling Moth Damage

During the growing season, codling moth infestations were estimated by using visual observations. These were conducted by one or more persons spending one minute per tree searching for damaged apples on trees selected throughout the orchard.

At harvest, damage was determined in the field by examining each apple variety in bins while picking was in progress. Usually, 250 apples (or approximately 10% of the crop) were checked in each bin, but as many as 500 were sampled per bin in some orchards (% of the total crop sampled varied from 4 to 70). The sample size/bin was increased to obtain satisfactory estimates of damage when growers inadvertently removed bins from orchards before they could be sampled. Except for the Emery orchard, Golden Delicious apples were not sampled in the orchard because they are susceptible to bruising. Cull apples were examined after they had been sorted at the packinghouse. In some orchards, large numbers of dropped apples were checked because pickers discarded insect-damaged apples. To counteract this, a number of trees were completely picked and checked for damage.

Damage distribution in each of the orchards was determined where possible by recording bin locations. Codling moth damage was categorized as follows wherever possible: spring generation entries, summer generation entries and stings. If larvae were found in the apples, the apples were dissected and the instar was estimated and recorded.

SYNTHETIC PHEROMONE TRAPPING METHODOLOGY

Influence of Trap Designs and Synthetic Pheromone Formulations on Determining a Standard Monitoring System

During the study, experiments were conducted to determine the best practical trapping unit to recommend for use in Okanagan Valley commercial orchards. Madsen and Vakenti (1973b) previously reported the Sectar 1 and Cylindrical carton trap designs as best in meeting the following criteria: trapping efficiency, field servicing, durability, commercial availability, and acceptable cost.

Additional trap designs were tested during 1973 using the methods outlined by Madsen and Vakenti (1973b). Three new designs were compared with the Cylindrical carton, Sectar 1 and U.C. Pherocon designs. These were the Pherocon ICM (same as the Pherocon ICP design shown in Fig. 3 except that the roof was aluminum), the Pherocon IC (same as the Pherocon ICP design except that plastic spacers were incorporated to keep the roof and bottom 5 cm. apart, similar to Fig. 4), and the Pherocon IC design modified by turning flaps on the bottom sticky surface upwards, Fig. 4).

The Cylindrical carton, Sectar 1 and Pherocon ICM designs captured significantly more males than the other designs (Table III). In this test, the Cylindrical carton trap was as effective as the Sectar 1 design. In the previous test (Madsen and Vakenti 1973b), this was not the case. Reasons for this disparity are not known since experimental methods were the same. Other experiments have yielded different results for the same trap designs tested in other fruit growing areas. Culver

Table III. Number of male *L. pomonella* captured weekly in traps of 6 designs baited with 1.0 mg synthetic pheromone (N = 5 replicates of each design)

Trap Design	Total Weekly Catch																Mean Male[a] Catch ± S.D.
	May				June				July					August			
	7	14	22	28	4	11	18	25	3	9	16	23	30	6	13	20	
Cylindrical Carton	15	40	148	13	28	30	21	31	34	19	40	100	39	46	26	27	41.06 ± 34.8[a]
Sectar 1 (white)	6	30	154	11	36	28	3	33	48	20	29	47	33	33	44	29	36.50 ± 34.0[a]
Pherocon ICM (aluminum top)	11	41	62	4	28	17	17	26	55	22	23	18	22	38	31	36	28.19 ± 15.35[a]
Pherocon IC (ends turned up)	9	22	39	5	24	7	3	15	12	5	7	16	17	35	10	19	15.31 ± 10.54[b]
U.C. Pherocon	14	8	10	2	0	1	0	3	5	0	0	33	34	44	16	15	11.56 ± 13.96[bc]
Pherocon IC (ends not turned up)	9	11	27	1	15	10	2	2	6	1	5	15	15	16	6	12	9.56 ± 7.07[c]

[a] Means followed by the same letter not significantly different, t-test, $P < .05$.

and Barnes (1973) reported no significant differences in male catches with Pherocon IC and Pherocon ICM traps in California. Howell (1973) found Sectar 1 and Pherocon ICM traps substantially better than Pherocon ICP, Howell open wing (Pherocon I) and Howell closed wing trap (Pherocon IC) designs. Madsen et al. (1974) reported Pherocon ICP traps to be effective in South African population monitoring experiments. Although no comparative tests have been conducted with the Pherocon ICP trap in British Columbia, the similarity of this design to the Pherocon ICM trap used in 1973 suggests that it would be as effective as the Cylindrical carton or Sectar 1 designs (Table III).

Response of codling moth males to a particular trap seems to depend upon an opening through which they can crawl after terminating flight on the exterior trap surface (Madsen and Vakenti 1973b; Riedl and Croft 1974; M. D. Proverbs, personal communication[1]). The Sectar 1, Cylindrical carton, Pherocon ICM and Pherocon ICP designs facilitate this behavioral response. Conflicting results obtained with trap designs tested in different regions could be the result of varying experimental design, slight genetically-based geographical behavioral differences in the moths (Bush 1973), or design- and environmental-dependent differences in the rate of evaporation and concentration around the trap openings (Shorey 1970). Excessive pheromone concentrations could cause sensory adaptation or arrestment prior to arrival at the pheromone source, thus reducing trap catches (Shorey 1970; Doane and Cardé 1973).

All the trap designs tested were ranked from 0 to 5 for each of the criteria mentioned earlier. The Cylindrical carton and Pherocon ICP designs ranked highest in meeting the criteria for a commercial trapping unit. Other designs met individual criteria better, particularly in field servicing but overall did not rank high enough to recommend their commercial use. The Sectar 1 design, although being highly efficient in trapping males, would not be suitable because frequent replacement of contaminated traps would increase costs to the grower.

The synthetic pheromone formulation used in the trap package must retain equal effectiveness during successive sample periods to give constant sampling capabilities and be long-lasting to save costs in renewing the lure. It must also outcompete native females particularly in high populations so that significant numbers of males are captured.

In an experiment, the Pherocon CM rubber cap impregnated with 1 and 2 mg synthetic pheromone was compared with 5 variations of the Pherocon CM-X formulation. These consisted of varying amounts of synthetic pheromone impregnated in 2.5x1.0x0.6 cm. pieces of polyvinyl covered in a resin formulation containing an anti-oxidant and either or both an U.V. absorber and a reducing agent stabalizer. The formulations, each with 3 replicates, were tested in Pherocon IC traps hung one per tree, 1.6 m. above ground on an outside limb. The traps were deployed in a randomized block design in a 0.5 hectare block of ornamental crab-apple trees containing 101 trees planted 6x6 m. apart. Trap catches were recorded weekly.

For patent reasons, the Zoecon Corporation did not divulge the identity of the anti-oxidant, U.V. absorber and the reducing agent stabalizer, nor the precise amounts of synthetic pheromone used in the Pherocon CM-X formulation. The number of males captured with 2 Pherocon CM-X lures and the Pherocon CM rubber caps did not differ significantly. More experiments comparing the effectiveness of the Pherocon CM and CM-X formulations are necessary before the Pherocon CM-X formulation can be recommended. In California, Culver and Barnes (1973) found the Pherocon CM and Pherocon CM-X formulations outcompeted native females for 4 and 8 weeks, respectively. The Pherocon CM-X formulation would reduce sampling costs but observations from other areas indicated this formulation lost attractiveness during unusually hot weather (C. Olson, personal communication).[4] Reasons for this are not known but this formulation is no longer being offered for commercial sale. More research is necessary to establish if the Pherocon CM formulation retains equal attractiveness from week-to-week during a 4 week period.

At present, the Pherocon CM formulation and the Cylindrical carton or Pherocon ICP trap designs are the best choices available for a standard, commercial trapping unit. By employing such a unit, some of the variables influencing male catches would be reduced.

Trap Placement Schemes

In this research, the objectives were to determine if:

1) the number of males captured in pheromone traps represent the population and damage distribution;

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[4] Zoecon Corporation, Palo Alto, California.

2) placing traps outside the monitored orchards reduced influx of males so that males caught in the orchard are related more meaningfully to absolute male density; and

3) the outside traps could identify external sources of infestation.

Results were limited by pesticide intervention and the incomplete harvest sampling procedures necessary in commercial orchards. However, captures and damage distribution in each orchard provided both direct and indirect information.

Madsen and Vakenti (1973a) report difficulties in interpreting the number of males captured in traps situated on orchard boundaries because the average weekly catches often exceeded the treatment level of 2 moths/trap/week. Therefore, visual checks of the orchards were necessary so that unnecessary sprays were not applied. As little damage was found along the borders of some orchards, it was concluded that males were attracted from external sources to the boundary traps.

To estimate the number of males which were still attracted to monitored orchards even with traps placed outside, the number of males trapped during each generation was compared with the number of males expected to emerge within the orchard (Table IV). The numbers of males estimated to emerge during the spring and summer generations were calculated using the following formulae (n varied from 2-5 varieties):

$$\text{Estimated number of males expected to emerge in the spring generation} = \sum_{i=1}^{n}\left(\frac{Kab}{c}\right)$$

Table IV. Comparison of the expected number of males emerging during each generation with the number of males trapped within the study orchards during each generation (with additional traps placed outside study orchards)

Orchard	Year	Estimated # Males Emerging/Hectare Spring Generation	# Males Trapped/ Hectare Spring Generation	Percent Available Males Trapped	Estimated # Males Emerging/Hectare Summer Generation	# Males Trapped/ Hectare Summer Generation	Percent Available Males Trapped
Kidston	1973	17.78	31.11	> 100	3.46	36.30	> 100
	1974	1.98	19.26	> 100	21.23	66.91	> 100
Powell	1973	0	16.05	> 100	0	20.0	> 100
	1974	0	19.75	> 100	3.70	8.40	> 100
Fitzgerald	1973	0	9.26	> 100	0	11.52	> 100
	1974	0	11.73	> 100	67.49	14.61	21.65
Workman	1973	50.62	10.37	20.49	14.81	37.53	> 100
	1974	39.51	23.70	59.98	51.60	70.86	> 100
Emery	1973	-	-	-	62.22	58.77[a]	94.46
	1974	49.88[b]	57.28[b]	> 100	38.52	57.04	> 100
Barker	1973	73.46	30.25	41.18	11.42	30.25	> 100
	1974	11.74	15.12	> 100	37.65	46.91	> 100
Figuera	1973	310.12	52.84	17.04	-[c]	-	-
Substation	1974	634.65	39.11	6.16	-[d]	-	-

[a] Includes late season flight so percent figure would be lower.

[b] Does not include larvae overwintering near pear trees.

[c] Program in this orchard discontinued after spring generation.

[d] Harvest sample incomplete.

Where *a* is the number of apples sampled in each variety which had summer generation larval exit holes the previous fall (Proverbs 1971), *b* is the total number of apples harvested the previous year in each variety, *c* is the number of apples sampled in each variety and K = 0.4, i.e., 0.8 x 0.5, based on a 20% overwintering mortality in successfully established larvae[5] (Proverbs 1971) and a 50:50 sex ratio in adults emerging during the spring.

$$\text{Estimated number of males expected to emerge in the summer generation} = \sum_{i=1}^{n} \left(\frac{dab}{c}\right) \qquad [2]$$

Where *a* is the number of apples sampled in each variety at the same-year harvest with spring generation larval exit holes, *b* is the total number of apples harvested in each variety, *c* is the same as in formula [1], and *d* = 0.5, based on a 50:50 sex ratio in adults emerging during the spring.

For formula [2], it is assumed that all larvae which leave the fruit during the spring generation find pupation sites and successfully develop into adults. Not included, is the estimated 15% of the spring generation larvae entering diapause (Proverbs 1971). These assumptions were made to provide a maximum estimate of males expected to emerge so there would be less chance to overestimate the influx of males.

In Table IV, over 100% of the males estimated to be emerging during the spring generation were trapped in 8 of the 13 orchards. The

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[5] In this equation, no mortalities are assigned to mature larvae searching for cocooning sites either on the tree or in the ground debris after leaving the apple. Clark et al. (1967) assigned a mortality of 70% when computing life systems for the codling moth in Australia and Nova Scotia.

exceptions were in orchards which had infestations exceeding 1% at harvest during the previous year and consequently a higher emerging adult population during the spring. In the Kidston, Powell, and Fitzgerald orchards it was particularly evident that males were coming in from adjoining areas. Influx of males was prevalent in the summer generation, as over 100% of the males estimated to be emerging were captured in 10 of the 12 orchards. The extensive influx of males was not surprising, considering the number of host trees in the surrounding areas (Figs. 5-14).

In the Kidston orchard in 1973 and 1974, the number of males caught outside the monitored block were consistently higher than within (Fig. 5). In both years, the codling moth spray programs on the apple blocks east, west and south of the Kidston block were the same as applied to the main block (a 3-spray program) except that a summer generation spray was not applied to the east block during 1973. The major influx of males appeared to come from neglected backyard trees located north of the block (traps 1, 1a, 2) (Fig. 5). Several trees with all the fruit infested with codling moth in both years were found in a resident's backyard. The infested fruit had not been picked from the trees in both years, and this could easily have accounted for the males captured in these traps. The 3-spray program was effective in keeping the number of adults emerging within the Kidston orchard low during each generation (Table IV).

In the Fitzgerald orchard block, no codling moth sprays were applied in either 1973 or 1974. In 1973, one spring generation spray was applied to the first apple block north of the Fitzgerald orchard (Fig. 6)

Fig. 5. Diagrammatic representation of the Kidston orchard area, Vernon, showing the location of outside and inside traps for 1973 and 1974 (trap number 1A added during 1974). Numbers beside trap locations refer to mean weekly catches for 1973 (upper figure) and 1974, respectively

KIDSTON AREA - VERNON BC

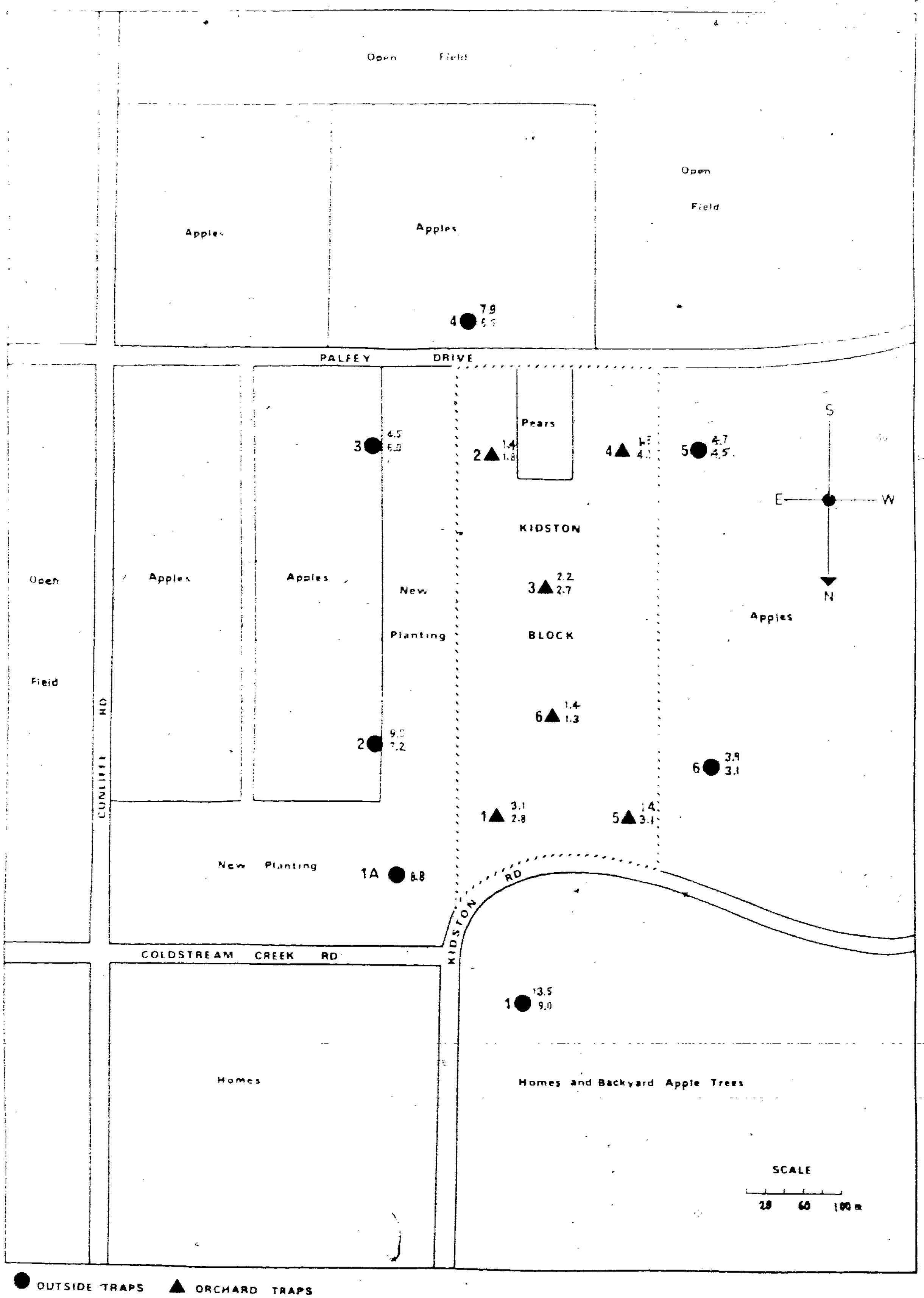
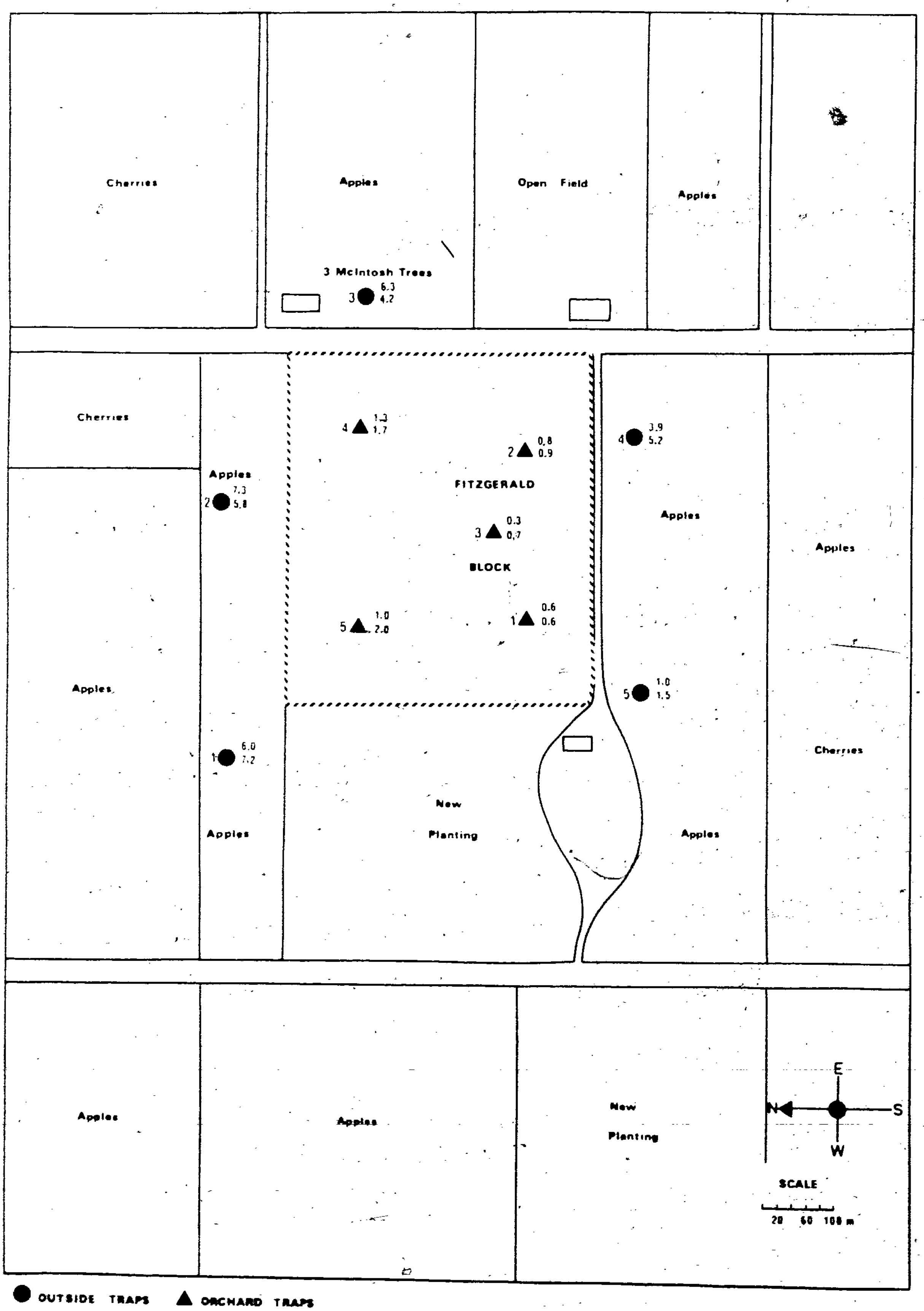


Fig. 6. Diagrammatic representation of the Fitzgerald orchard area, Kelowna, showing the location of outside and inside traps for 1973 and 1974. Numbers beside trap locations refer to mean weekly catches for 1973 (upper figure) and 1974, respectively

FITZGERALD AREA - KELOWNA B.C.



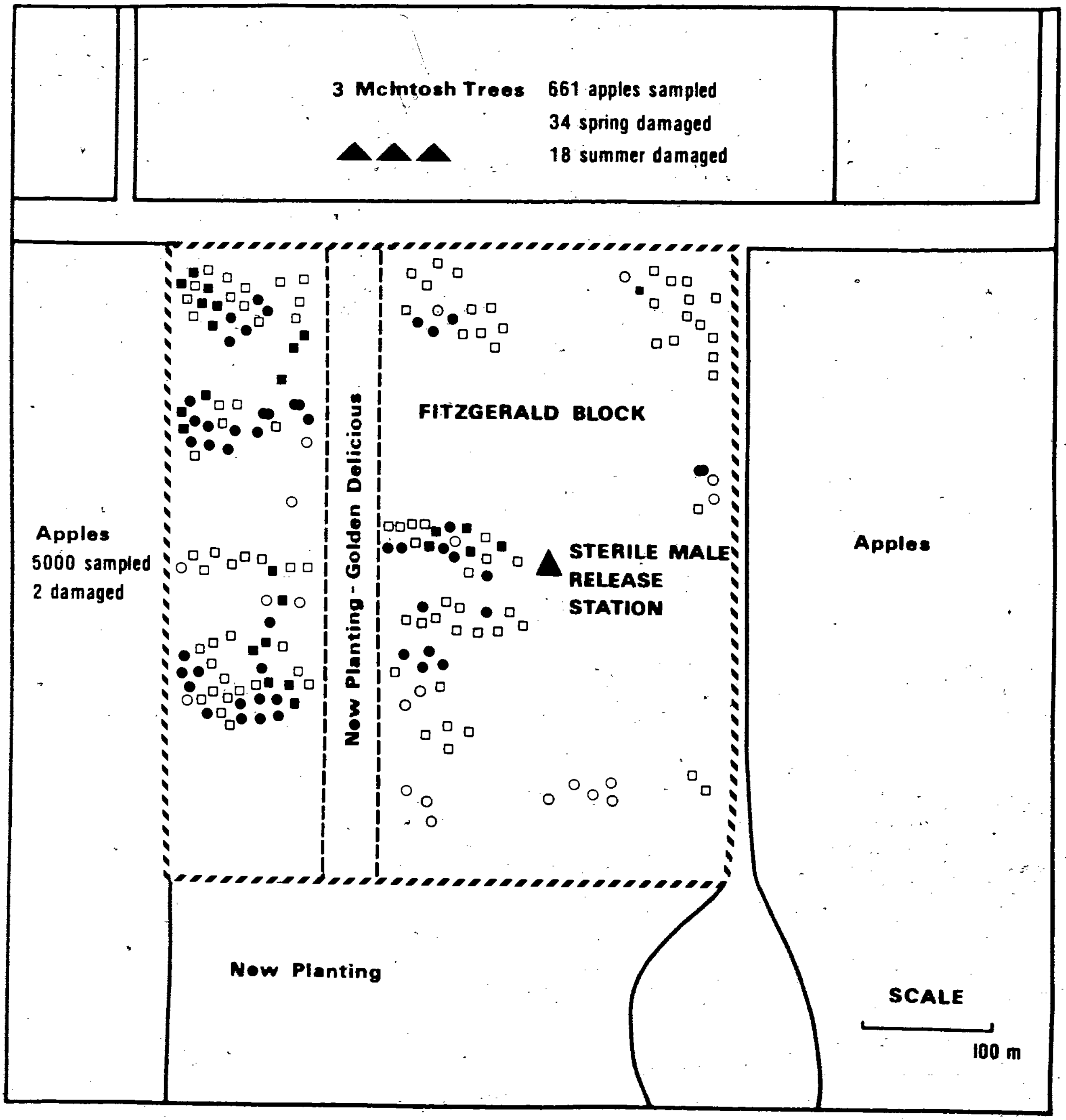
and to the old McIntosh trees bordering the east side of the study block (Fig. 6). The apple block adjoining the south border received a full spray program in both years. In 1974, the block immediately north of the Fitzgerald block was partially sprayed once on its north border. The 3 McIntosh trees along the east border were not sprayed during 1974.

The number of males trapped within the Fitzgerald orchard were low in 1973 (Fig. 6) but the number of males coming in from outside sources was considerable, based on the very low expected emergences within the orchard (Table IV). The high catches obtained in traps 1, 2 and 3 (outside traps) indicated infestation sources outside the block. An infested orchard was found north of traps 1 and 2, probably accounting for most of the males in these traps. The 3 trees adjoining the east border of the study orchard were not sampled at harvest in 1973. However, estimates at harvest of holes left by larvae of the spring generation in 1974 (5.14% spring generation damage) indicated a heavy infestation in 1973.

In 1974, catches in pheromone-baited traps were slightly higher than in 1973 within the Fitzgerald block but again during the spring generation males came in from outside, based on the number of males expected to emerge within the orchard. By plotting the distribution of damage by the spring and summer generations (Fig. 7), it was apparent that, particularly during the summer generation, females came in from the 3 unsprayed trees along the east border ovipositing on trees bordering the new planting area. In addition, a single row of Golden Delicious trees along the east border was infested as determined by visual samples

Fig. 7. Distribution of damage at harvest caused by spring and summer generation codling moth in the Fitzgerald block 1974 (% of crop sampled at harvest--4.4)

FITZGERALD AREA — KELOWNA B.C.



- ○ Spring damaged apples
- ● Summer larval exits
- □ Apples at harvest with 4 + 5th instar Larvae
- ■ Apples at harvest with larval instars 1—3

at harvest. As the infestation in the apple block immediately north was low (0.04% harvest damage), few females could have come from this block. Also, the infested orchard found during 1973 was sprayed during 1974 and little codling moth damage was detected at harvest in 1974. So the potential number of females dispersing from this orchard would be very low.

The influence of females moving from an infested area was indicated in the Workman orchard during the 1973 spring generation. Although catches within the orchard did not exceed the treatment level, increasing numbers of apples infested by codling moth were found both along the north border of the orchard and in the adjoining unsprayed apple block (Fig. 8). A potential dispersal distance of at least 200 m. for females was found by M. D. Proverbs (personal communication) because radio-active larvae were found near the edge of a 2 hectare block of apples nearly 200 m. from where females were released.

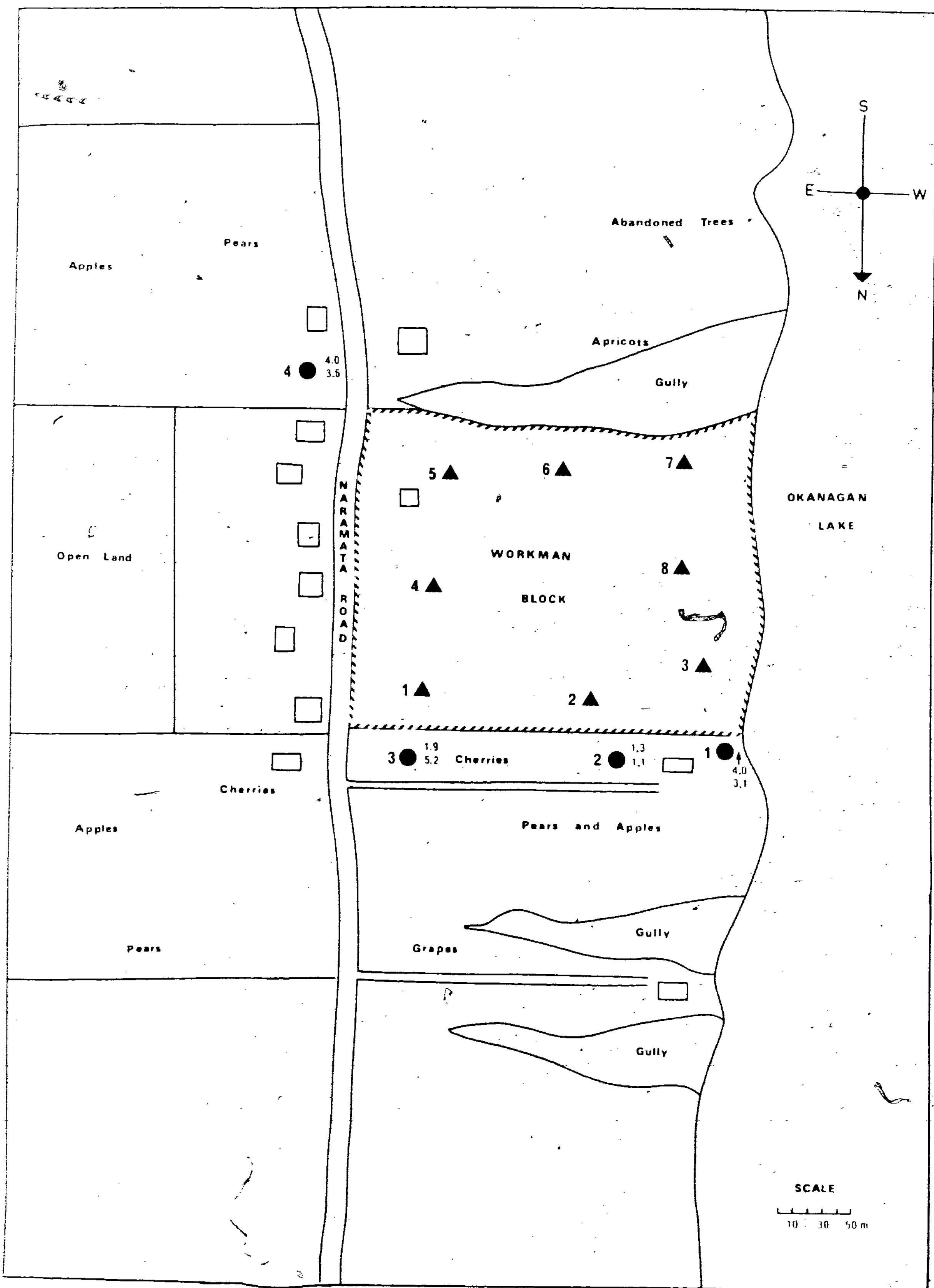
The catches within the Workman orchard during 1974 were higher reflecting an increased population density (Fig. 9). Although catches in the outside traps were similar to those recorded during 1973 (Fig. 8), little harvest damage was observed in the apple block bordering the Workman orchard. This suggests that males were moving out of the Workman block.

As part of a 1974 experiment conducted by M. D. Proverbs (personal communication), 1,000 virgin males (marked with fluorescent powder) were released July 31st from a ground release station in the middle of the south part of the Fitzgerald orchard (Fig. 7). On August 2nd, 1,200 additional males were released. Marked males captured in the Fitzgerald

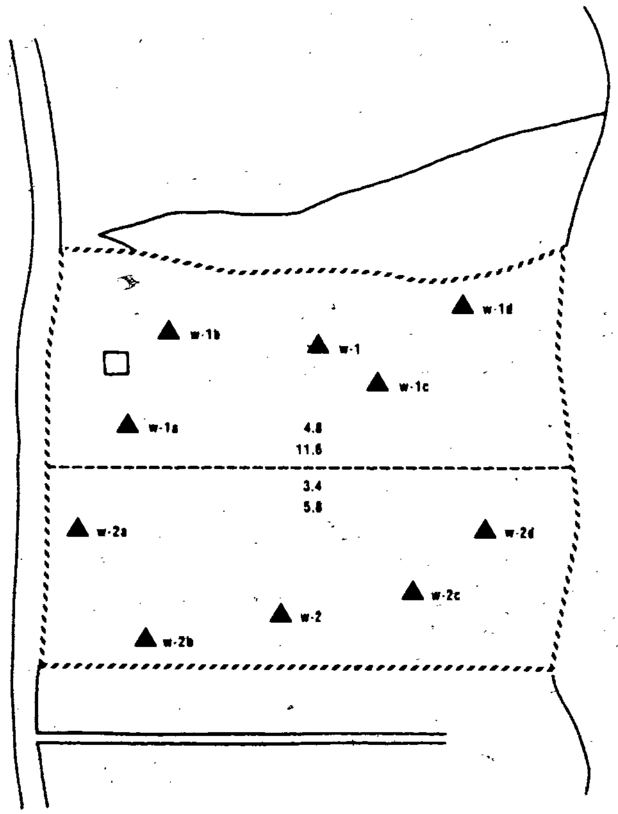
Fig. 8. Diagrammatic representation of the Workman orchard area, Naramata, showing the location of outside traps for 1973-74 and the inside traps for 1973. Numbers beside outside trap locations refer to mean weekly catch figures for 1973 (upper figure) and 1974, respectively.

Fig. 9. Location of inside traps for the Workman orchard 1974. Numbers in each quadrant refer to mean weekly catch for the area in 1973 (upper figure) and 1974, respectively (traps W-1, W-1 (a,b,c,d) and W-2 or W-2, W-2 (a,b,c,d) and W-1 functional on alternative weeks).

WORKMAN AREA - NARAMATA B.C.



● OUTSIDE TRAPS ▲ ORCHARD TRAPS


w-1d
w-1b
w-1
w-1c
w-1a
4.8
11.6
3.4
5.8
w-2a
w-2d
w-2c
w-2
w-2b

area traps were recorded from July 29th to August 5th (Table V). The results indicated that: (1) males could fly considerable distances without being intercepted by traps stationed inbetween their origin and a monitored orchard, and (2) some males could be expected to disperse out of a monitored orchard.

Another release-recapture experiment at the Substation orchard showed that influx of males could occur from sources heavily infested with codling moth. In this experiment (M. D. Proverbs, personal communication), 1,650 virgin marked males and 1,650 virgin, P_{32} labelled females were released on July 19, 1974 from a station located approximately 100 m. into the block of apples immediately east of the monitored block (Fig. 10). The numbers of males recaptured were recorded weekly from July 23rd to August 12th (Table VI). The results indicated that most of the released males intially stayed in the area where the high population of females was present (traps 1-3 outside). This was confirmed by the distribution of labelled larvae found at harvest (M. D. Proverbs, personal communication). Only later did more males disperse into the monitored orchard as indicated by catches on July 29th (inside traps 1-5). Although these were artificially-created populations, males would be expected to come from outside sources even where the native female population would be high enough to compete with pheromone-baited traps.

In the Barker orchard, the degree of which the influx of males influenced catches within the orchard (Figs. 11 and 12) was not as clear as in other orchards (Table IV). During the 1973 spring generation, an estimated 41.2% of the males emerging within the orchard were trapped. Some of these males probably originated in the semi-abandoned orchards

Table V. Number of sterile codling moths released and recaptured in traps located varying distances from a release station within the Fitzgerald orchard, July 29th to August 5th, 1974[a]

Trap Number[b]	Distance From Release Station (m)	Number Males Recaptured		
		Released July 31	Released Aug. 2	Total Recaptured
1 (inside)	200	55	45	100
2 "	150	138	5	153
3 "	100	75	8	83
4 (outside)	200	62	8	70
5 "	250	45	32	77
3 "	400	61	10	71
4 (inside)	300	3	7	10
5 "	300	13	14	27
1 (outside)	500	12	14	26
2 "	400	9	12	21

[a] Supplementary data from experiment conducted by M. D. Proverbs in which additional pheromone traps were deployed both inside and outside the Fitzgerald block.

[b] Pheromone trap numbers same as in Fig. 6.

Fig. 10. Diagrammatic representation of the C.D.A. Substation orchard showing the location of outside and inside traps and fertile moth releases for 1974. Numbers beside trap locations refer to mean weekly catches for the spring (upper figure), summer (middle figure), and season (lower figure)

SUBSTATION ORCHARD — KELOWNA, B.C.

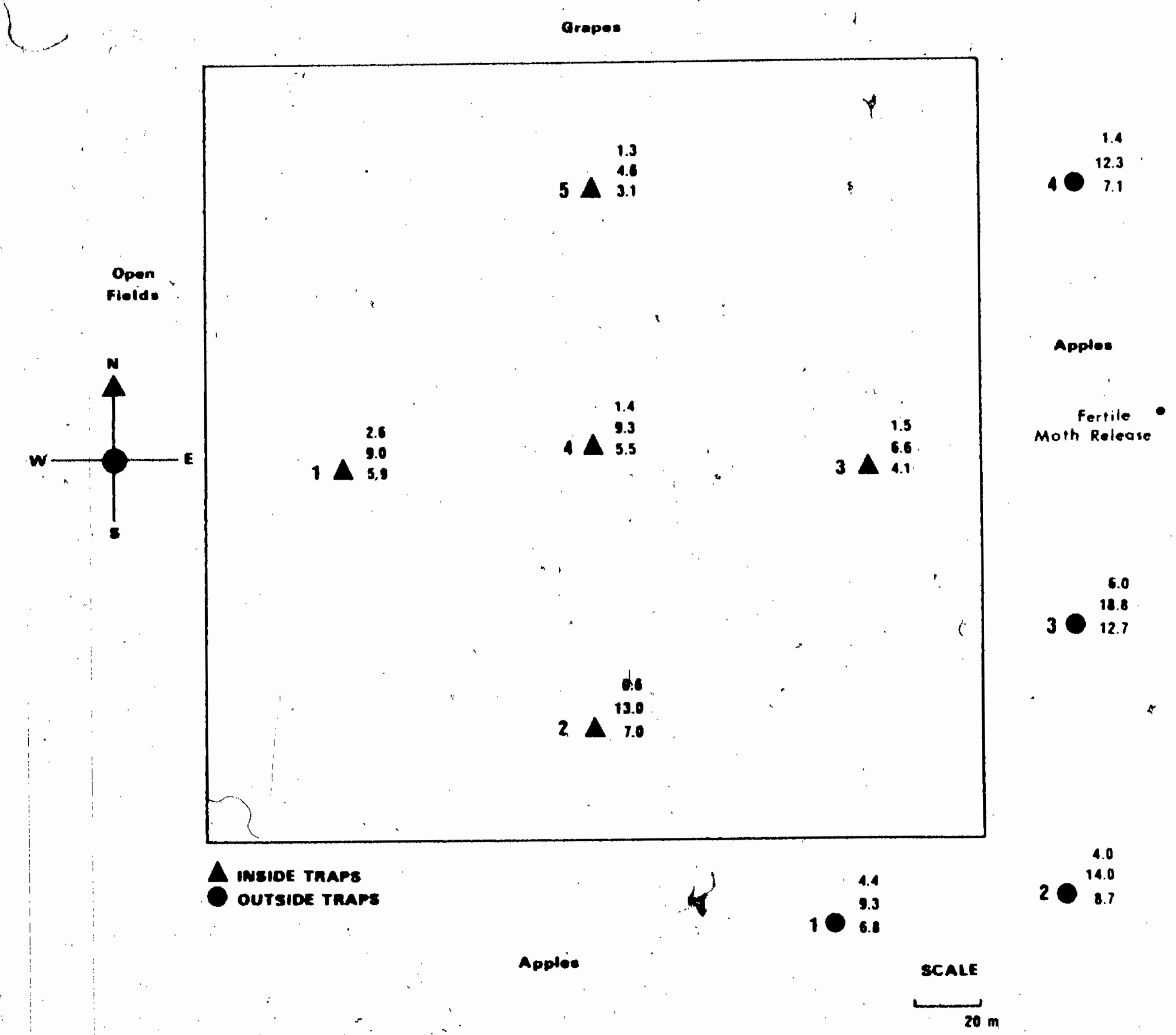


Table VI. Number of virgin, marked[a] males recaptured in traps located varying distances from a release station 100 m. outside the monitored C.D.A. Substation orchard, July 23rd to August 12th, 1974

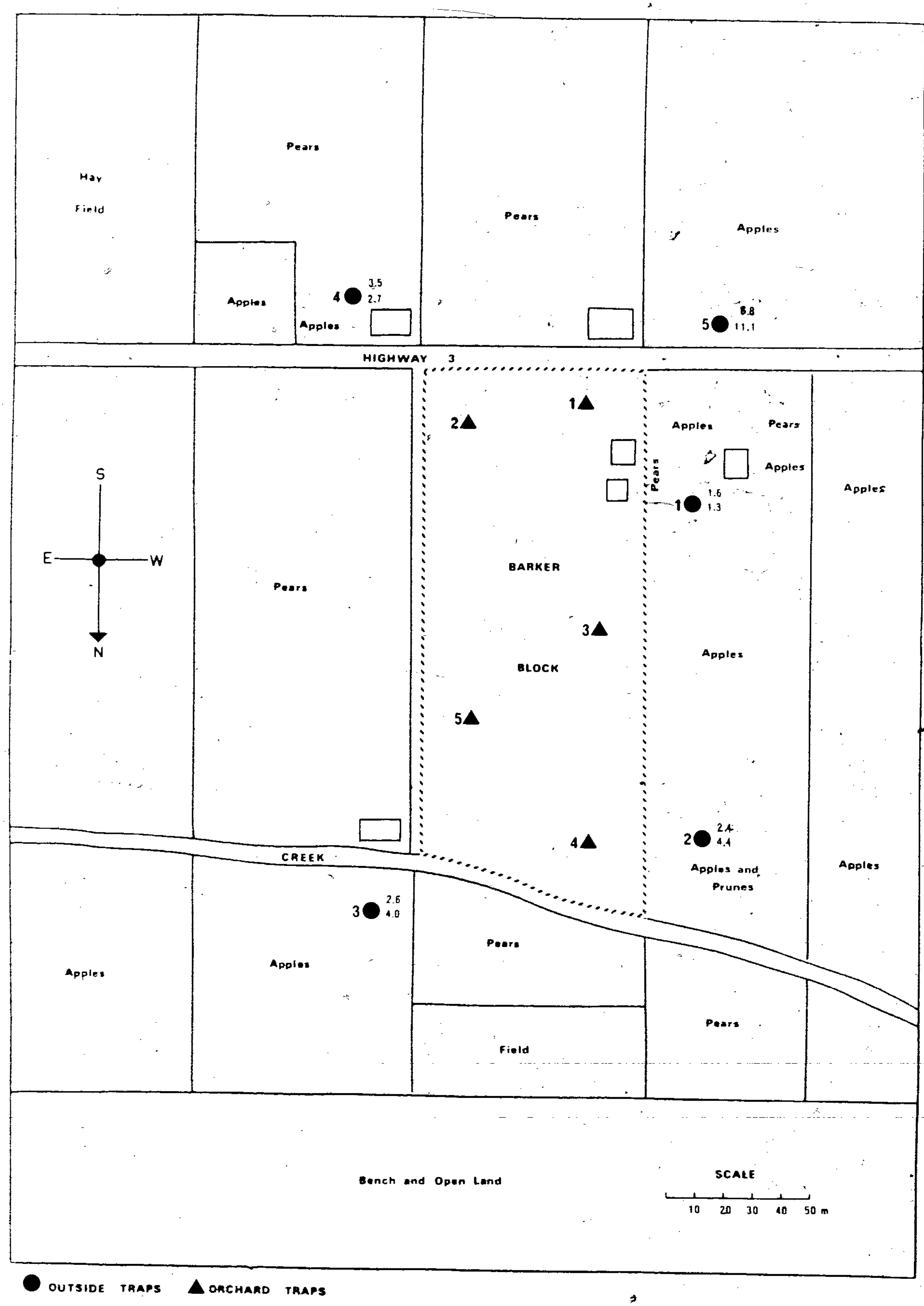
Trap Number	Distance From Release Station (m)	Number Males Recaptured on Recording Dates				
		July 23	July 29	Aug. 6	Aug. 12	Total
outside						
1	180	60	95	7	0	162
2	140	73	90	9	0	172
3	60	72	56	17	0	145
4	60	12	29	10	1	51
Total		217	270	43	1	530
inside						
1	260	6	23	3	0	32
2	200	11	26	2	0	39
3	100	7	49	7	2	65
4	180	12	14	16	1	43
5	200	5	53	3	0	61
Total		41	165	31	3	240

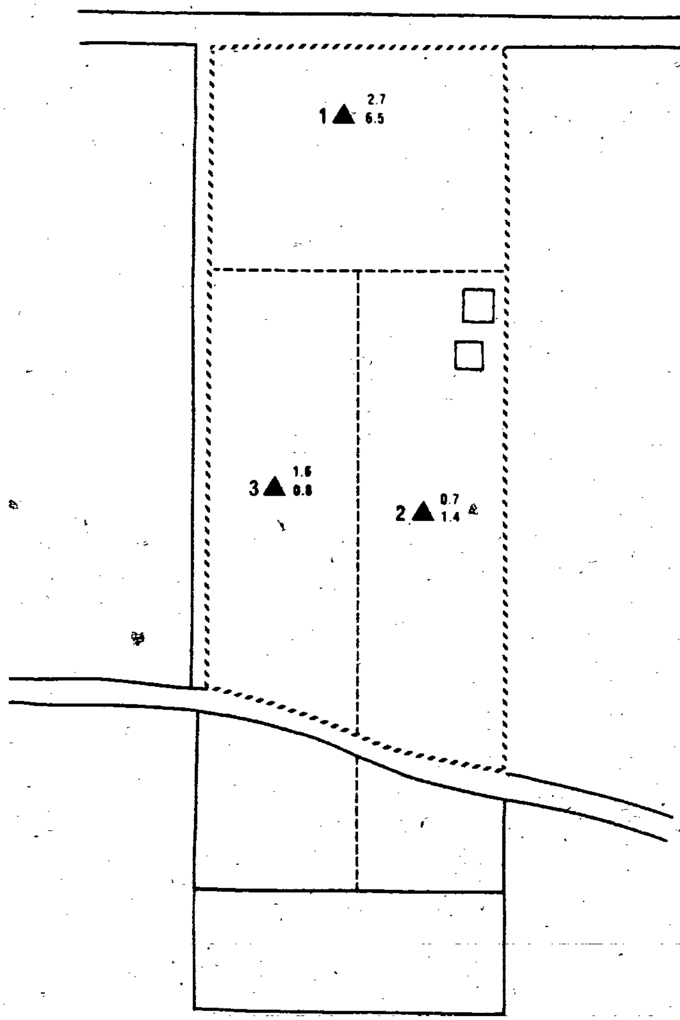
[a] Marked by dust application of Day-Glo® fluorescent pigments.

Fig. 11. Diagrammatic representation of the Barker orchard area, Keremeos, showing the location of outside traps for 1973-74 and the inside traps for 1973. Numbers beside outside trap locations refer to mean weekly catches for 1973 (upper figure) and 1974, respectively

Fig. 12. Location of inside traps for the Barker orchard, 1974. Numbers in each quadrant (dotted line) refer to the mean weekly catch in 1973 (upper figure) and 1974, respectively

BARKER AREA - KEROMEOS B.C.




1
2.7
6.5
3
1.6
0.8
2
0.7
1.4

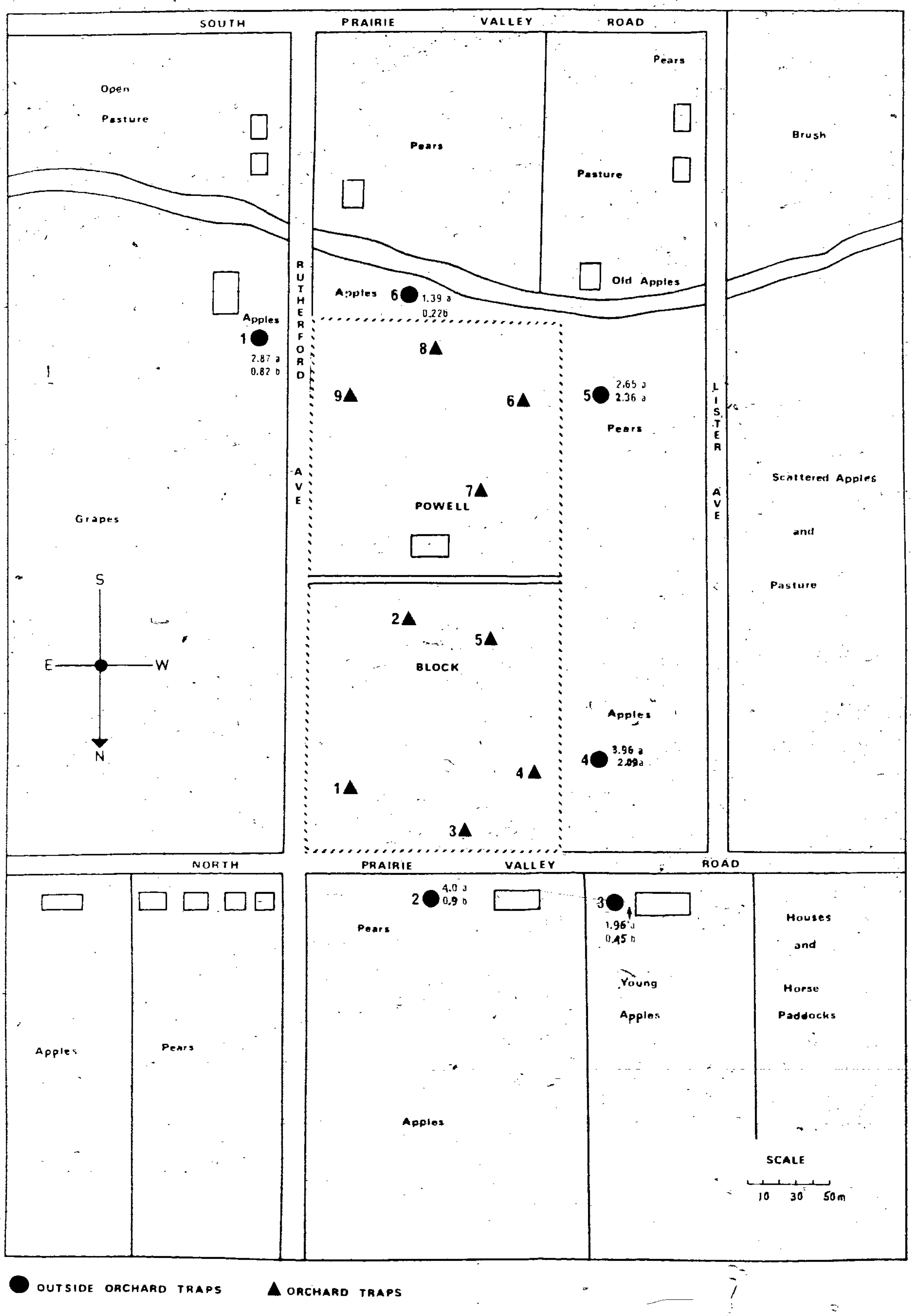
located near outside trap 5, approximately 100 m. from area 1 (Fig. 11). The influence of these sources heavily infested during 1974 was more pronounced particularly during August and September as the trap in area 1 (trap 1, Fig. 12) consistently captured males exceeding 2/trap, even though 2 cover sprays had already been applied. It is evident that outside traps 4 and 5 identified an infested source which was verified as an unsprayed, abandoned pear and apple orchard. These traps probably reduced the influx of males from this source sufficiently so that catches in inside trap 1 reflected a potentially damaging population level late in the season.

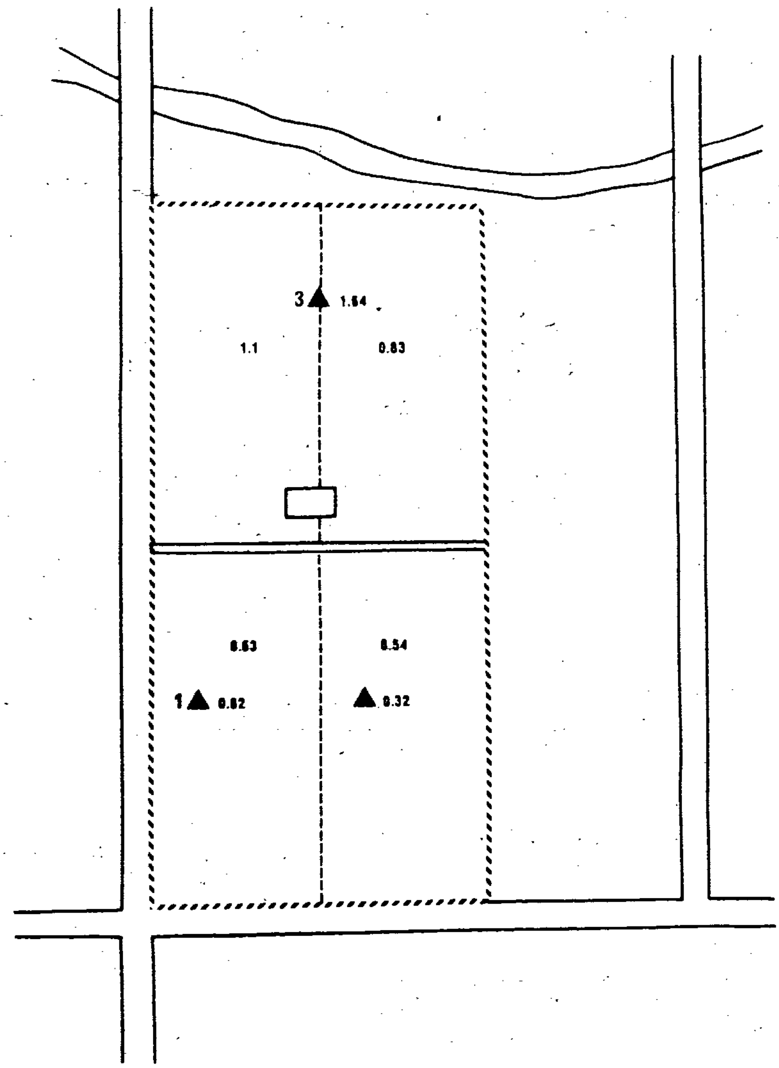
In the Powell orchard, captures within the orchard (Fig. 13) were also influenced by the influx of males from the outside (Table IV). In 1973, backyard and neglected trees with apples infested were found in areas near outside traps 1, 2, 3, and 6 (Fig. 13). The apple and pear block adjoining the west side of the Powell block received a full spray program during both years. Therefore, most of the males caught in traps 4 and 5 probably originated from the scattered trees located further west (Fig. 13). The significant reduction in catches during 1974 in outside traps 1, 2, 3, and 6 (Fig. 13) resulted from more careful spraying of these neglected trees. For example, a group of dwarf Red Delicious trees in the area of outside trap 1 had a spring and summer codling moth spray applied during 1974, primarily because the grower checked the trap in 1973, and because traps in his orchard during 1973 indicated a potentially damaging codling moth level. As no cover sprays were applied in the Powell orchard in 1974, the slight increase in male

Fig. 13. Diagrammatic representation of the Powell orchard area, Summerland, showing the location of outside traps for 1973-74 and inside traps for 1973. Numbers beside trap locations refer to mean weekly catches for 1973 (upper figure) and 1974, respectively. Means followed by the same letter not significant, t-test, $P < 0.05$

Fig. 14. Location of inside traps for the Powell orchard, 1974. Numbers beside trap locations refer to mean weekly catches for 1974. Numbers in each quadrant refer to mean weekly catches in 1973

POWELL AREA - SUMMERLAND B.C.





3
1.64
1.1
0.83
0.63
0.54
1
0.62
0.32

catch (Fig. 14) probably reflected an actual increase in population density within the orchard rather than influx of males.

Since the Emery orchard was isolated from the influx of adults, the trap captures could be more easily related to the damage distribution in the orchard (Figs. 15 & 16). Codling moth populations were modified by pesticides but certain inadequacies in spraying occurred because the orchard borders a campsite and bird sanctuary. Sprays must be applied so they will present the least hazard to Canada goose nesting and offspring.

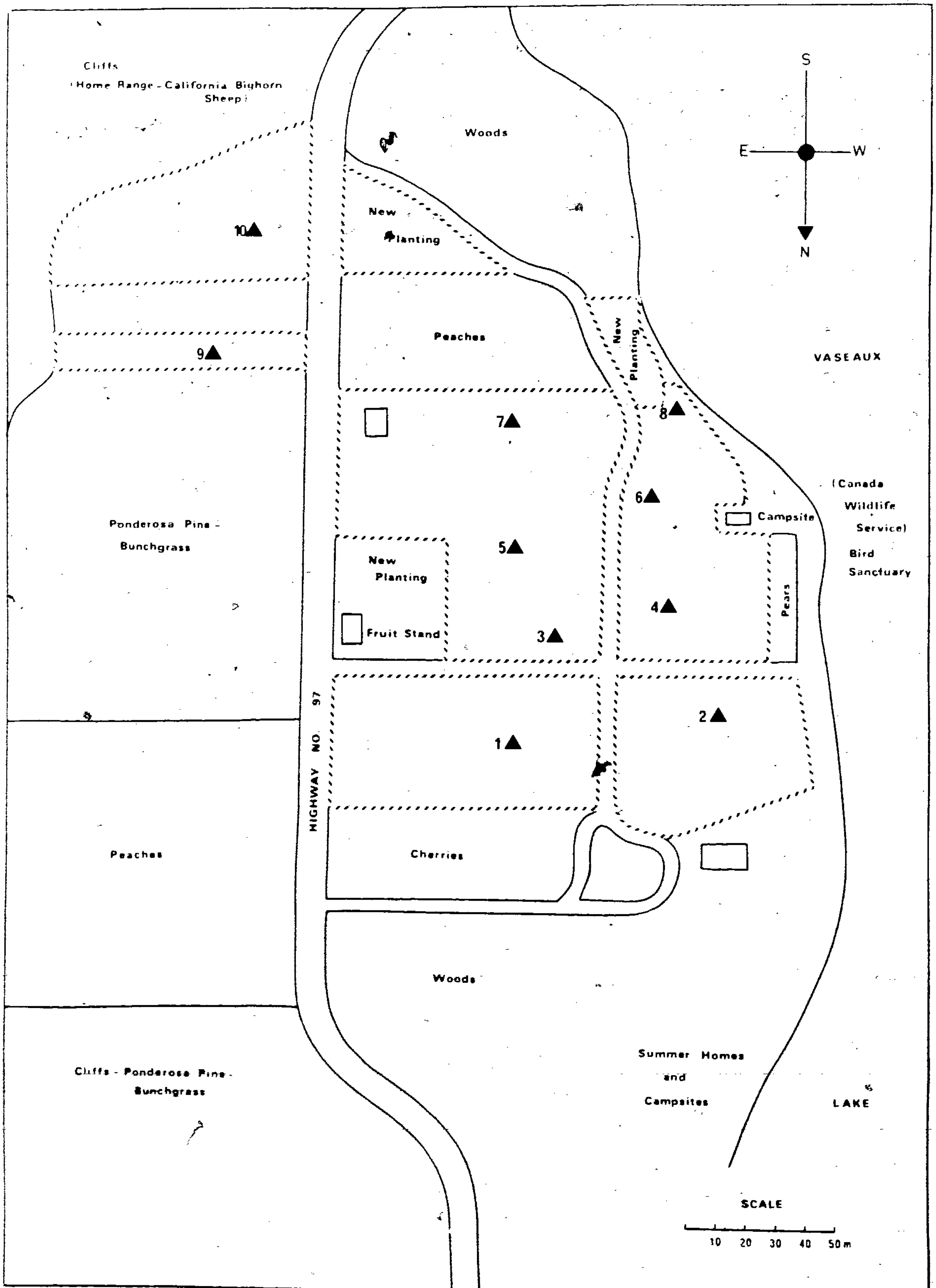
This orchard was not included in the study until after the spring generation codling moth spray had been applied in 1973. At least 5 factors contributed to a codling moth problem in the orchard:

1) incomplete control occurred because considerations for wildlife prompted too early spraying. This was indicated by high catches during July and August;
2) the summer generation spray was applied 10 days later than recommended. As a result of the damage occurred during this period;
3) two pear trees and an apple tree beside a fruit stand were left unsprayed during 1973;
4) trees in the campsite were not sprayed during the summer generation in 1973; and
5) a potentially damaging population late in the season indicated by trap catches, was not chemically controlled because regular

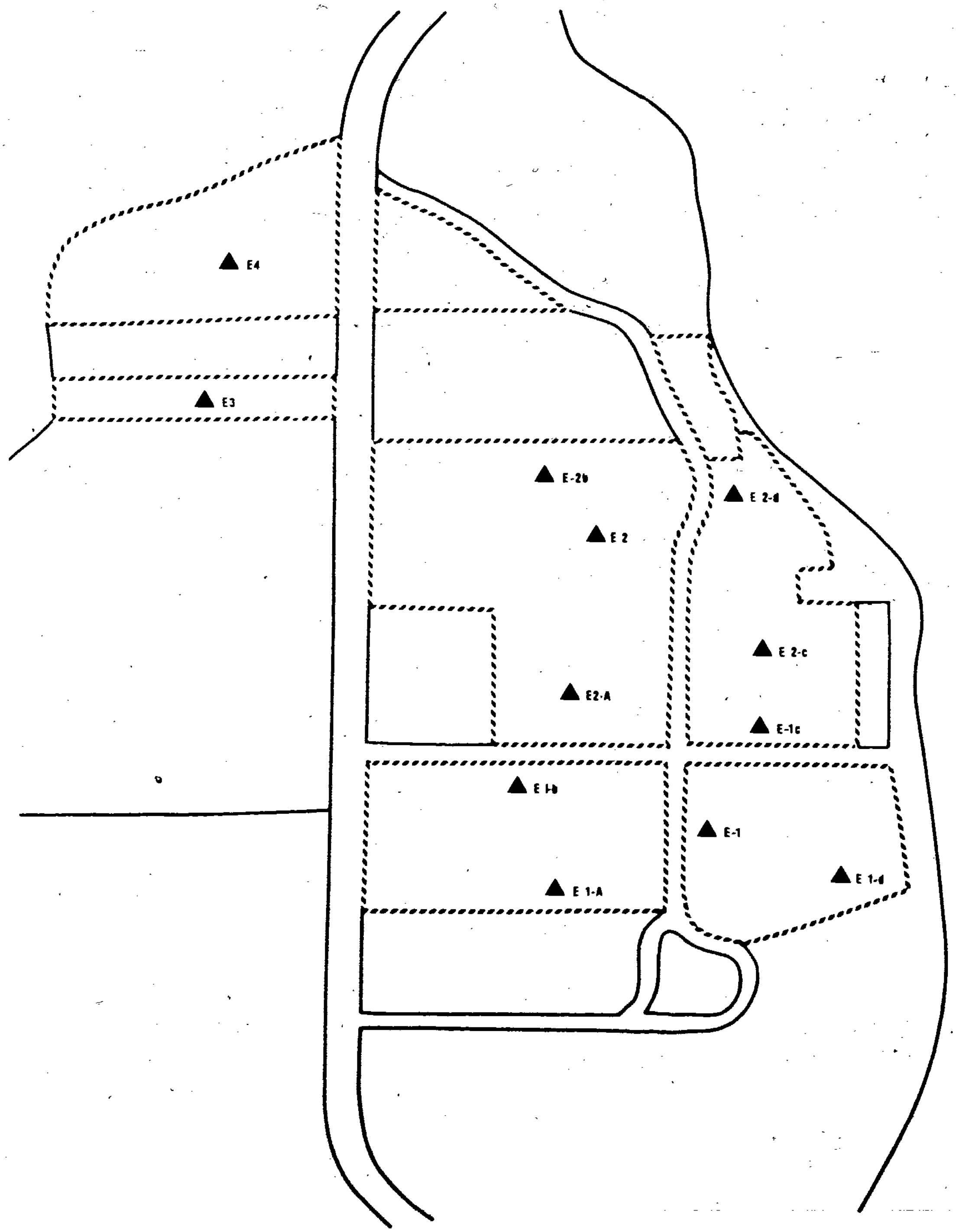
Fig. 15. Location of traps for the Emery orchard, Vaseaux Lake, 1973

Fig. 16. Location of traps for the Emery orchard, 1974. Traps serviced 1 or 5 acres during each sampling period. (i.e., E1+E1A,E1B,E1C,E1D and E2,E3,E4 or E1,E3,E4 and E2, E2A,E2B,E2C,E2D)

EMERY AREA - VASEAUX LAKE, OLIVER B.C.



▲ ORCHARD TRAPS


E4
E3
E-2b
E 2
E 2-d
E 2-c
E2-A
E-1c
E 1-b
E-1
E 1-A
E 1-d

visual checks of the orchard showed that the amount of late-season damage was not increasing enough to warrant a spray.

The numbers of summer generation and late season males captured (Table VII) were significantly correlated with the damage in each area (N = 10, r calculated = 0.9182, $r_{0.01}$ = 0.8343).[6] Therefore, the female population within each area also correlated with males captured. In area 2, late season captures were influenced by males emerging from the unsprayed apple and pear trees by the fruit stand (Table VII). In 323 pears dissected near harvest (1,371 collected), exit holes left by the spring and summer generation larvae totalled 56 and 184, respectively. The number of live larvae found was 508, with 80% of these larvae in instars 1-3. Based on the number of multiple-injured fruit in the sample, females did not move appreciable distances from the pear trees which was further supported by the low late season infestation recorded in area 2 (0.02%).

The results in the Emery orchard suggest that male captures could be directly related to damage levels occurring within areas of an orchard. Male and female dispersal in other orchards and the difficulties in obtaining adequate harvest samples to determine damage distribution prevented attempts to establish more precise relationships between specific areas in the other study orchards.

In the orchards studied, catches in pheromone-baited traps were shown to be influenced by males coming in from infested areas. Females

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[6] Value of the correlation coefficient for P < 0.01 from Fisher and Yates (1963) for 6 degrees of freedom.

Table VII. Comparison of the number of males trapped and ensuing damage during the summer generation and late in the season in 5 areas of the Emery orchard, Vaseaux Lake, Oliver, B.C., 1973

Orchard Area	Pesticide Treatment[d]	Trap/Tree Ratio[a]	Summer Generation Males Captured July 9 - Sept. 4	Percent Summer Generation Damage[b]	Late Season Males Captured Sept. 4 - Oct. 1	Percent Late Season Damage[c]
1	2 sprays, no trees left unsprayed	1/115	32	0.35	33	0.23
2	2 sprays, no trees left unsprayed except 3 trees at fruit stand	1/72	79	0.18	54	0.02
3	2 sprays, campsite trees not sprayed summer generation	1/54	60	0.33	39	0.25
4[e]	2 sprays, trees near house partially sprayed	1/48	133	0.79	82	0.42
5[f]	2 sprays, no trees left unsprayed	1/70	61	0.19	18	0.01

[a] Method proposed by Reidl and Croft (1974) for standardizing trap monitoring areas.

[b] Damaged fruit with summer generation larval exits, 5th and 4th instar larvae still present in fruit.

[c] Damaged fruit containing instars 1 to 3 and fruit with fresh tunnelling but no larvae found in the fruit.

[d] Two sprays were 1 early spring generation spray and 1 late summer generation spray.

[e] Also trees near fruit stand left unsprayed.

[f] Area separated from main orchard block by main highway (c.a. 25 m.).

were also shown to disperse from areas infested with codling moth. The influx of males and females influences interpretation of captures, causing both excessive and low estimates of the potential damage which could occur within an orchard. Therefore, unless an orchard is isolated, influx of adults must be taken into consideration. I conclude that, although the outside traps prevented some influx of males, in most of the orchards extensive influx of males still occurred. Catches in traps placed outside orchards identified infested sources. In South African orchards, Myburgh et al. (1974) reported that outside traps pinpointed areas infested with codling moth.

Future research must take into account the number of infested apples and pears occurring in orchards during the previous year's harvest so that estimates of the adult populations and the potential numbers of dispersing insects in adjoining areas can be made. Increasing the numbers of traps outside an orchard could further reduce influx of males, but results from a sterile male release made at the Nuyens orchard, Okanagan Centre, suggests that influx would not necessarily be greatly reduced or eliminated. In this experiment, 1,200 sterile males (30 Krad, internally marked) were released from 4 stations located in a 4-acre block. Traps were deployed at a density of 8/acre. While 75.5% of the males recaptured were recovered in these traps, 24.5% of those recaptured were in traps deployed at 1/acre in the remaining 8 acres of orchard. The ability to directly measure influx of adults would enable captures within an orchard to be related more meaningfully to the damage expected.

The Effects of Monitoring Area and Population Density on Pheromone Trap Efficiency

Two important factors affect trap efficiency: (1) the extent of the monitoring area for a trap, and (2) competition from native females for males during each sample period.

In 1973, trap densities were kept at approximately 1/0.4 hectares. In 1974, in some orchards, a density of 1 trap/hectare was used based on preliminary data from South Africa (H. F. Madsen, personal communication).[2] Riedl and Croft (1974) showed that the trap/tree ratios of 1/25 to 1/150 trees (with an average of 65 trees/hectare) were within the monitoring range of a single trap, and that a slow increase in catches occurred from 70 to 250 trees/trap. A single trap was found to effectively monitor 1.8 hectares when the codling moth density was high enough to cause damage in South African orchards (Myburgh et al. 1974). Therefore, the trap densities utilized during this study did not exceed the monitoring range of a trap by the criteria obtained thus far.

It is difficult to estimate the degree to which increasing the monitoring range of traps in some of the orchards in 1974 influenced catches. For recommending application of sprays, changes in the monitoring range was not considered to reduce catches. However, for making accurate damage predictions, variable trap densities can be compensated for by multiplying the mean number of infested fruit/tree for each individual trap station by the number of trees serviced by the respective trap (Riedl and Croft 1974).

A method proposed by Wolf, Kishaba and Toba (1971) could be adapted to determine the trapping area and performance of traps at various densities from release and recapture data. The influence of female population density on trap efficiency can be tested by artificially creating female populations (Howell 1974). Riedl and Croft (1974) found the total infestation at harvest increased gradually up to a cumulative mean catch of approximately 100 males/trap but above this point mean catch did not increase much while the total infestation increased rapidly. But this point corresponded to harvest infestation exceeding 20% or well above an economic threshold level. Howell (1974) concluded that practical numerical estimates based on catches in sex attractant traps are possible for low populations only. His experiments, however, utilized female-baited traps which are not as effective as synthetic pheromone-baited traps (Madsen and Vakenti 1972; Culver and Barnes 1973).

Further research is necessary to determine the monitoring area of a single trap and the performance of traps deployed at various densities under B.C. conditions. This should enable trap density and placement schemes to be established so that traps will be efficient in capturing males up to and exceeding economic threshold population levels. At present, captures in traps deployed at 1/0.4 hectares inside orchards indicate codling moth population levels requiring chemical control.

POPULATION MONITORING AS A PEST MANAGEMENT TOOL

Sprays Applied When a Minimum Population Level Indicated by Captures

One goal of pest management is to reduce pesticide input. For the codling moth this can be accomplished by eliminating sprays based on a pre-determined calendar and by spraying only when population estimates based on catches in pheromone traps exceed a minimum level. In this way, the number of sprays applied in the study orchards (Table VIII) was reduced by 43.1% compared to a calendar spray program (B.C. Dept. Agric. 1973, 1974).

Catches for the Kidston orchard (Fig. 17) indicated high codling moth populations in neighbouring orchards and potentially damaging populations within the orchard during both years. Since the spraying level was exceeded frequently, a full, 3-spray program was recommended and applied in both years (May 29th, June 27th, and August 8th in 1973, and June 19th, August 6th, and August 28th in 1974). In 1974, cool spring weather delayed development of the spring generation, and above-normal temperatures in August and September caused extended codling moth activity. As a result, damage at harvest approached 1% even though 3 sprays were applied (Table VIII).

The Fitzgerald orchard (Fig. 18) had a low population within the orchard, and higher populations in neighbouring orchards. In 1973, no codling moth sprays were applied and the harvest damage was very low (Table VIII). In 1974, the catches showed a potentially damaging level on

Table VIII. Number of cover sprays applied and harvest damage obtained with a pilot population monitoring program for codling moth as compared with a 3-spray calendar program routinely followed in the Okanagan Valley, B.C.

Orchard Location	Year	# Sprays Applied With Monitoring Program	% Reduction in Sprays From Calendar Spray Program	Percent Harvest Damage with Population Monitoring Program[a]							% of Total Crop Sampled
				McIntosh	Tud.	Spartan	Red Del.	G.Del.	Wins.	Average[b]	
Kidston,	1973	3	0	0.06	0.03	–	0.23	–	–	0.149	8.46
Vernon	1974	3	0	0.10	0.90	–	0.80	–	–	0.39	5.31
Fitzgerald,	1973	0	100	0.00	–	0.03	0.10	–	–	0.07	4.15
Kelowna	1974	0	100	–	–	0.10	0.70	–	–	0.74	3.70
Powell,	1973	1	66.6	–	–	0.02	0.11	–	–	0.05	4.50
Summerland	1974	0	100	–	–	0.10	0.10	–	–	0.09	6.65
Workman,	1973	2	33.3	0.62	–	0.24	1.25	0.15	–	0.39	74.21
Naramata	1974	2	33.3	0.80	–	4.40	1.90	1.80	–	1.90	60.56
Emery,	1973	2	33.3	–	–	0.86	1.24	1.05	0.90	1.05	14.93
Vaseaux Lake	1974	2	33.3	–	–	0.70	0.90	0.30	–	0.75	10.88
Barker,	1973	3	0	–	–	0.00	0.16	0.03	–	0.13	20.58
Keremeos	1974	2.5	16.7	–	–	0.04	0.60	0.22	–	0.38	25.96
	Total	20.5	43.1								

[a] Apple varieties not present or sampled represented by –.

[b] Average percent harvest damage calculated from:

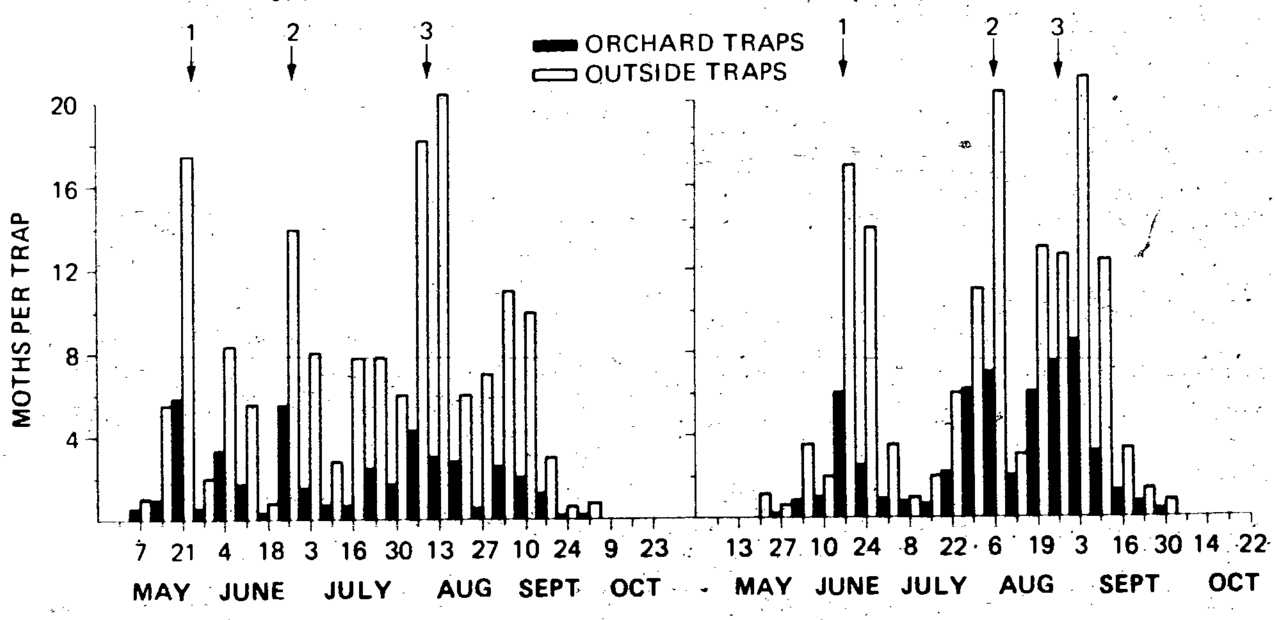
$$\frac{\text{Number damaged fruit in all varieties}}{\text{Total number fruit harvested}} \times 100.$$

[c] .5 sprays refers to 1/2 of the orchard sprayed.

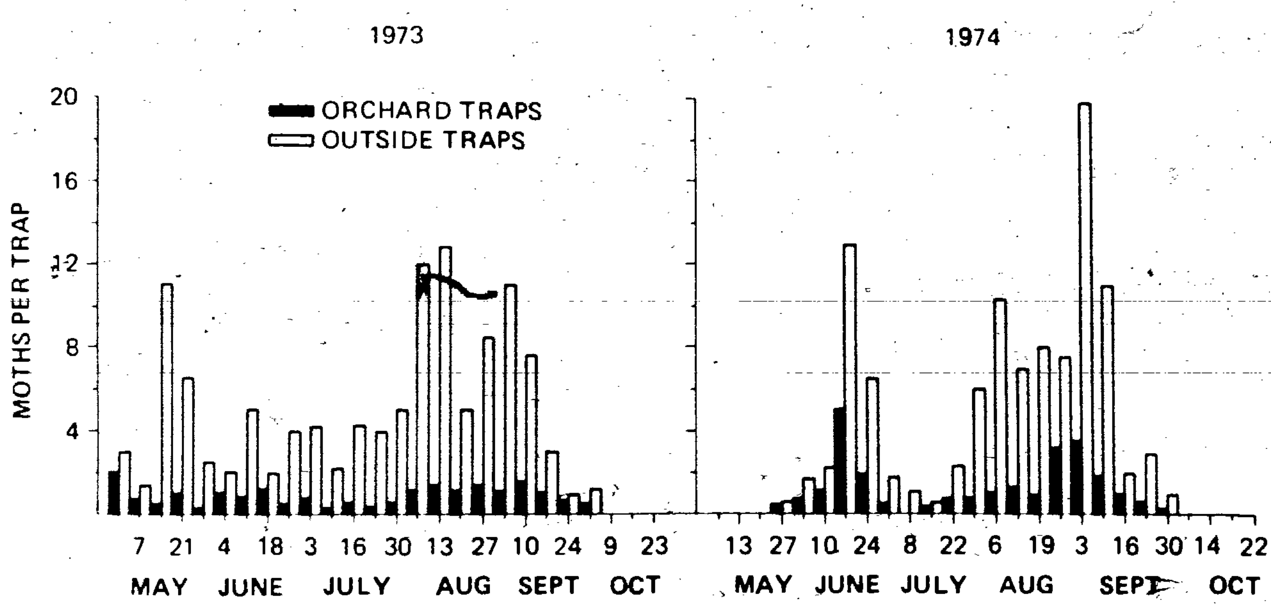
Fig. 17. Catches in traps baited with synthetic pheromone for the Kidston orchard, Vernon, 1973 and 1974 (arrows indicate spray application dates)

Fig. 18. Catches in traps baited with synthetic pheromone for the Fitzgerald orchard, Kelowna, 1973 and 1974

CODLING MOTH SEX ATTRACTANT TRAP CAPTURES
KIDSTON ORCHARD VERNON B.C.



CODLING MOTH SEX ATTRACTANT TRAP CAPTURES
FITZGERALD ORCHARD KELOWNA B.C.



June 17th and 24th, and again on August 26th and September 3rd (Fig. 18). Although damage was expected, the grower chose not to apply sprays during 1974. The infestation at harvest was 0.7% in the major variety, Red Delicious.

The Powell orchard (Fig. 19) had low populations indicated in both 1973 and 1974. In 1973, males captured did not exceed the spraying level but the grower chose to spray during the summer. In 1974, the treatment level was exceeded once but no codling moth sprays were recommended. At harvest infestation of 0.1% justified this decision (Table VIII).

The catches within the Workman orchard (Fig. 20) indicated a moderate codling moth population level in 1973, but higher in 1974. During the spring generation in 1973, the spraying level was not exceeded but a spray was applied on June 1st because an adjoining orchard showed high codling moth numbers and there was evidence that an infestation was developing along one border. However, the control obtained was evidently inadequate and the damage during the spring generation was found distributed throughout the orchard. Since most of the damage occurred in old, large Spartan and McIntosh on the other side of the Workman block, poor spray application could have accounted for this damage. Another spray was applied on August 8th, and the harvest damage averaged 0.38% although catches indicated another population level requiring spraying in late August (Fig. 20). A spray was not applied because residues would have been too high at harvest.

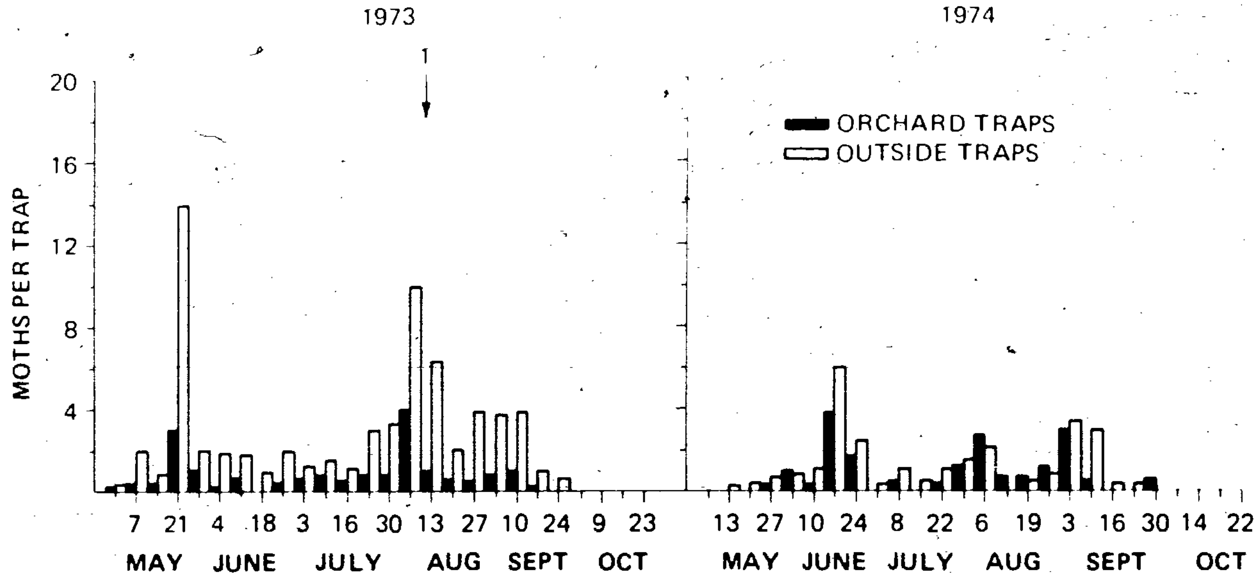
In 1974, the Workman orchard catches indicated damaging population levels especially during August and early September. Two sprays were

Fig. 19. Catches in traps baited with synthetic pheromone for the Powell orchard, Summerland, 1973 and 1974 (arrows indicate spray application dates)

Fig. 20. Catches in traps baited with synthetic pheromone for the Workman orchard, Naramata, 1973 and 1974 (arrows indicate spray application dates)

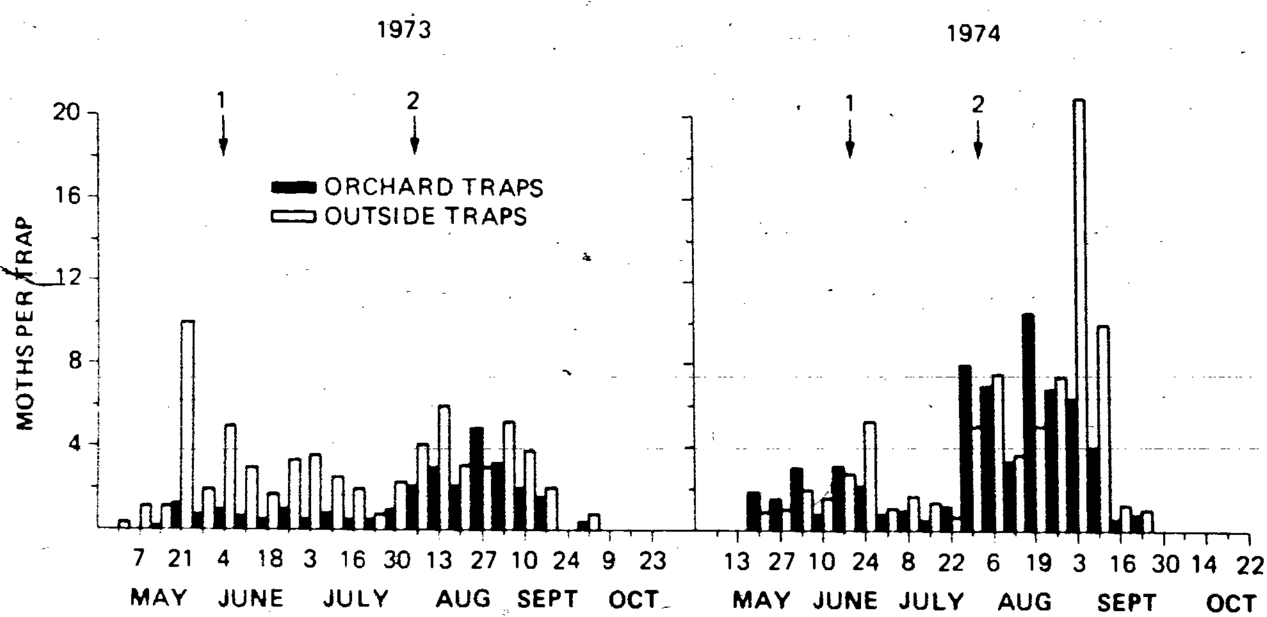
1

CODLING MOTH SEX ATTRACTANT TRAP CAPTURES
POWELL ORCHARD SUMMERLAND B.C.



2

CODLING MOTH SEX ATTRACTANT TRAP CAPTURES
WORKMAN ORCHARD NARAMATA B.C.



applied (June 20th and July 29th), and although a third was indicated by the catches, it was not applied because of the difficulties encountered in applying a spray in a high density planting near harvest. As a result, the harvest infestation was above 1% in 3 of the 4 varieties (Table VIII). Dissection of apples showed that most of the larvae found were in instars 1 to 3, indicating that much of the damage occurred shortly before harvest.

The trap captures in the Emery orchard (Fig. 21) indicated damaging population levels throughout July, August and early September in 1973 but only 1 summer generation spray was applied on July 29th. Many of the males caught during the late season were shown previously to have come from unsprayed pear trees and poorly sprayed trees in other sections of the orchard. Although the spraying level was exceeded and little insecticide residue remained on the trees after the July 29th spray, an additional spray was not recommended because few fresh attacks on the fruit were observed. The pear trees were sprayed during 1974 and the late-season flight was substantially reduced (Fig. 21). The number of males captured reflected the low late-season damage.

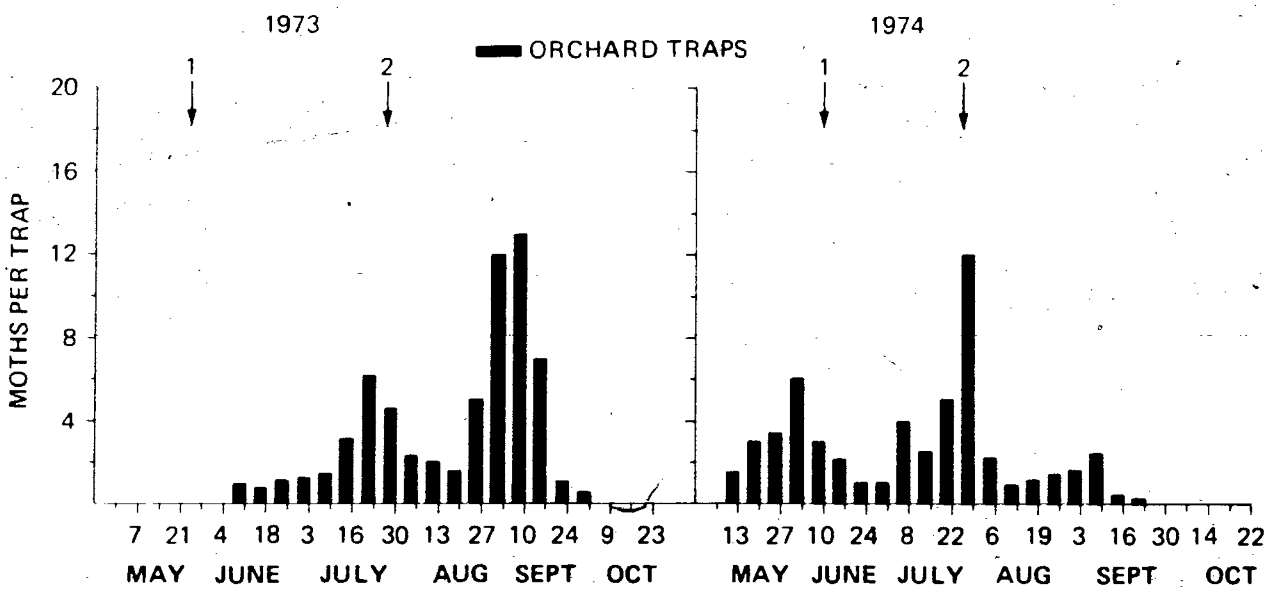
In 1974, the captures indicated potentially damaging population levels during both generations and 2 sprays were applied (June 15th and July 25th). There was <1% injured fruit (Table VIII) and most of these apples were from trees in the campsite and near a house where adequate spray coverage was difficult.

The Barker orchard (Fig. 22) had potentially damaging populations and infested sources in neighbouring orchards. Three sprays were applied

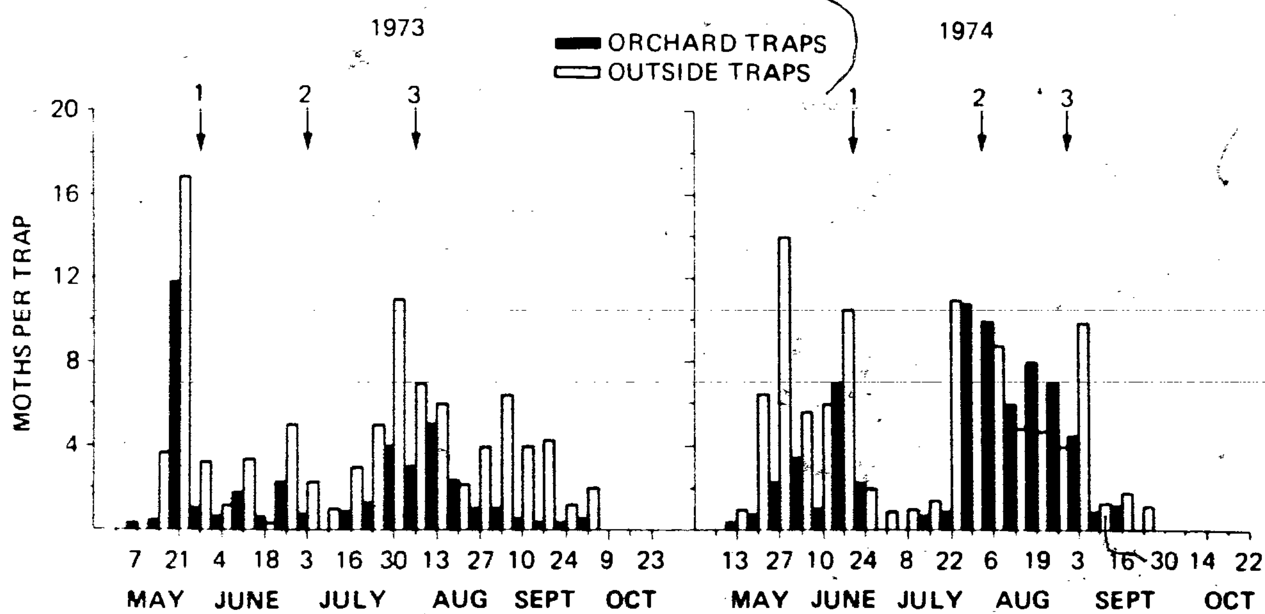
Fig. 21. Catches in traps baited with synthetic pheromone for the Emery orchard, Vaseaux Lake, 1973 and 1974 (traps not installed in the Emery orchard until June 4, 1973; arrows indicate spray application dates)

Fig. 22. Catches in traps baited with synthetic pheromone for the Barker orchard, Keremeos, 1973 and 1974 (arrows indicate spray application dates)

CODLING MOTH SEX ATTRACTANT TRAP CAPTURES
EMERY ORCHARD VASEAUX LAKE B.C.



CODLING MOTH SEX ATTRACTANT TRAP CAPTURES
BARKER ORCHARD KEREMEOS B.C.



in 1973 (May 25th, July 2nd, and August 2nd) and the harvest damage was well below acceptable levels. In 1974, a similar pattern in catches was recorded but with high numbers captured during August and early September. Two sprays were applied to the entire orchard (June 30th and July 31st), and a third spray was applied to only one block of large Red Delicious trees (August 29th). The trap in this block captured high numbers of males while the number of males captured in the other orchard traps were below 2/trap. The results at harvest showed that little damage occurred in the blocks which did not receive the third spray. Most of the damage caused by the summer generation was found in the Red Delicious block.

In most of the study orchards, sprays were applied if the average number of males captured exceeded 2/trap during 2 consecutive weeks. The spraying level was shown to be of practical use in eliminating calendar spraying in the 6 commercial orchards during 1973 and 1974. Little or no damage would be expected to occur if the average number of males captured/trap was below the spraying level unless influx of females occurred.

Spring Generation Trap Catches and Damage Caused by the Spring Generation

In those orchards where the codling moth populations were not influenced by sprays, the captures would be used to try and establish relationships with actual numbers of injured apples. Since sprays were applied in most of the orchards, a number of assumptions were used to estimate the number of apples which would have been injured if the populations were not controlled. These are as follows:

1) the total number of fruit harvested was calculated by multiplying the number of bins harvested by an average of 2,500 apples/bin (based on 100 apples/box and 25 boxes/bin);
2) the percent of the crop sampled in each orchard (Table 8) re-reflected the total number of apples injured by codling moth larvae;
3) the number of apples available for the spring generation was the same as the number harvested during that season. This minimized difficulties in determining crop sizes before and after thinning during the spring generation;
4) the potential number of larvae overwintering in an orchard was equal to the number of summer generation larvae exits found in fruit during the previous year's harvest (Proverbs 1971);
5) no mortality was assigned to mature larvae searching for and establishing overwintering sites because in the low populations in commercial orchards little competition for cocooning sites would be expected (Geier and Hillman 1971);
6) mature larvae from both the spring and summer generations contribute to the number of overwintering larvae (Geier and Hillman 1971). Proverbs (1971) did not include the estimated 15% of the spring generation larvae which entered diapause under Okanagan Valley conditions when estimating the overwintering population;
7) a 50:50 sex ratio in larvae establishing overwintering sites was assumed in these orchards although differential mortalities

could have occurred during pesticide applications, and fluctuating sex ratios could be influenced by population density (Hagley 1974; MacLellan 1972);

8) an overwintering mortality of 20% caused by the parasite, *Ascogaster quadridentata* Wesmail., bird predation and cold winter temperatures was assumed (Proverbs 1971);

9) pupal mortality prior to the emergence of spring generation moths was not included as it is probably low (Ferro and Harwood 1974);

10) the emergence ratio of adults during the spring generation was considered as 50:50 in both years although fluctuating sex ratios between years has been reported (Hagley 1974; MacLellan 1972);

11) reports on female codling moth fecundity during the spring generation vary (Ferro and Harwood 1974). An average of 50 eggs/female was used, a value previously used in computing codling moth life systems (Clark et al. 1967). The mortalities of codling moth eggs and 1st-instar larvae were assigned by assuming that each female produces either 5, 10 or 20 injured fruit (this represents 90, 80 and 60% mortalities in these stages).

The number of apples expected to be injured during the spring generation was estimated using the following formula:

$$\text{Estimated number of apples injured spring generation} = dx \qquad [3]$$

Where d is the number of females expected to emerge during the spring generation calculated by using Equation [1] (p. 21) and x is 5, 10 or 20 injured fruit/female.

In Table IX, the population estimates and the number of apples injured during the spring generation are given for the orchards. Linear regressions were used to determine if relationships could be established between the number of actual or calculated injured fruit and the population estimates obtained with traps. The population estimates tested were as follows:

1) the number of times a spraying level of an average of 2 males/trap/week was exceeded during the spring generation;
2) the number of times an average of 2 males/trap/during 2 consecutive weeks was exceeded during the spring generation;
3) the total number of males captured in the orchard traps during the flight of the spring generation divided by the number of hectares in each orchard to obtain the total males captured/hectare (the length of the spring flight was averaged from Figs. 17-22); and
4) the total number of males captured in the orchard traps during a 3-week period before the 1st codling moth spray would be applied in commercial orchards according to B.C. Dept. Agric. recommendations (B.C. Dept. Agric. 1973, 1974). This figure was converted to males captured/hectare.

The two population estimates based on a spraying level being exceeded did not reflect the total number of apples (actual or calculated) damaged in these orchards ($r = 0.16$ for estimate 1 and $r = 0.27$ for estimate 2). The number of males captured/hectare during the spring

Table IX. Population estimates and the estimated number of apples damaged during the spring generation in study orchards without sprays applied during 1973 and 1974

# Times Spraying Level Exceeded		Total Males Captured/ Hectare, Spring Generation	Accumulated Males/Hectare by Average Spray Date, Spring Generation	Estimated Number of Apples Damaged with Population Increases[a]		
1 week	2 weeks[c]			(5 F/♀)	(10 F/♀)	(20 F/♀)
4	1	31.1	11.1	361	721	1,441
3	2	19.2	12.1	41	81	161
2	1	9.1	4.5	1 (180)[b]	1	1
3	2	11.7	9.0	1(1,100)[b]	1	1
2	1	15.9	11.8	1 (1)[b]	1	1
3	2	6.5	4.3	1 (76)[b]	1	1
1	1	11.1	4.7	1,026	2,051	4,101
4	2	23.8	17.3	801	1,601	3,201
8	6	39.3	36.6	1,011	2,021	4,041
3	1	27.0	19.3	1,191	2,381	4,761
5	3	13.3	11.1	191	381	761
4	3	38.3	13.0	6,411(4,052)[b]	12,821	25,641

[a] Each female emerging produces 5, 10 or 20 injured fruit.

[b] Numbers in parentheses refer to the number of apples actually injured by the spring generation in orchards with no spring generation sprays applied.

[c] Consecutive weeks.

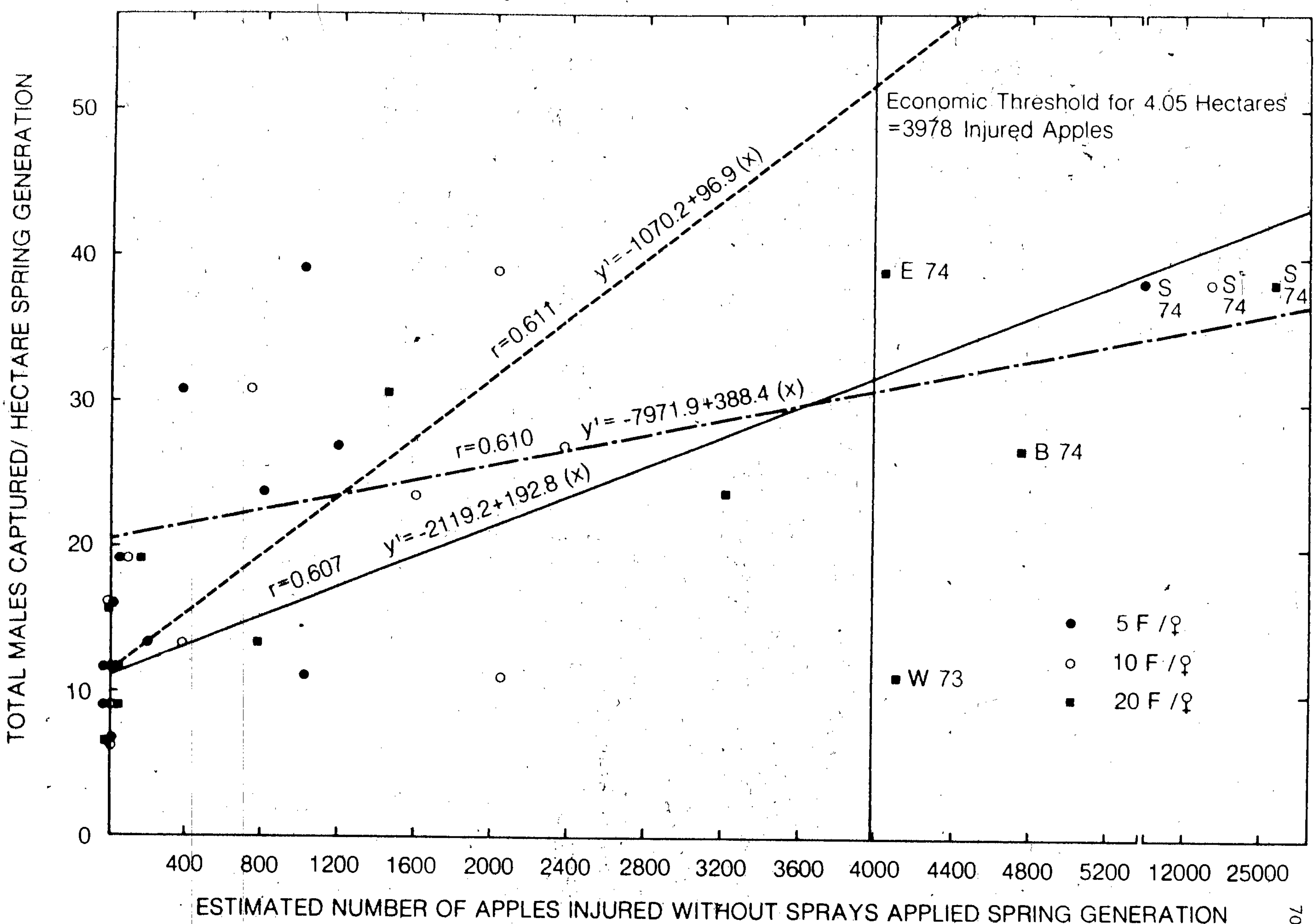
generation was correlated with the number of apples injured by the spring generation (Fig. 23). These relationships, though, are limited on practical terms for predicting the number of injured apples because:

1) more information is needed from commercial orchards where insecticides are not applied during the spring generation. This would allow the use of actual infestation levels rather than calculating estimated damage (Table IX); and
2) this population estimate depends on obtaining the total number of males captured for the spring generation before damage predictions could be generated. Damage would occur before these data were available.

Significant correlations were not obtained (r = 0.18) using the number of males captured before the spring generation codling moth spray would normally be applied in commercial orchards (i.e., 4 weeks after the first males are captured). Riedl and Croft (1974) suggested withholding sprays until trapping results indicated that the infestation level approached the economic threshold. They observed little fruit damage after 4 weeks but damage increased rapidly after 6 weeks of trap catches. This approach would limit pesticide pressure on early season populations and allow damage correlations to be based on previously-taken figures (Riedl and Croft 1974).

To examine whether insecticide pressure could have been further reduced or eliminated during the spring generation, preliminary economic thresholds for codling moth damage were formulated. The economic

Fig. 23. Relationships between the total males captured/ hectare during the spring generation and the estimated number of injured apples without sprays applied in the commercial orchards, 1973-74. Damage was estimated by using 3 theoretical population increases; 1 ♀ produces 5, 10 or 20 injured fruit. Orchards in which the estimated damage would have exceeded the economic threshold are marked: E = Emery, S = Substation, B = Barker, and W = Workman. Value of correlation coefficient for $P < 0.05$ for 8 D.F. is 0.6319 and for $P < 0.1$ it is 0.5494 (Fisher and Yates 1963)


TOTAL MALES CAPTURED/ HECTARE SPRING GENERATION
0
10
20
30
40
50
400
800
1200
1600
2000
2400
2800
3200
3600
4000
4400
4800
5200
12000
25000
ESTIMATED NUMBER OF APPLES INJURED WITHOUT SPRAYS APPLIED SPRING GENERATION
Economic Threshold for 4.05 Hectares
=3978 Injured Apples
r=0.611
y' = -1070.2+96.9 (x)
r=0.610
y' = -7971.9+388.4 (x)
r=0.607
y' = -2119.2+192.8 (x)
E 74
B 74
W 73
S 74
S 74
S 74
5 F /♀
10 F /♀
20 F /♀

threshold for *L. pomonella* damage was established at 3,978 apples injured by the spring generation. This figure corresponds to the point at which the total costs of a control action (i.e., 1 application of Guthion) are returned by reducing this damage. The formula poposed by Southwood and Norton (1973) was used:

$$C\ (a) \leq Y\ [s(a)]\ .\ P - Y\ (s)\ .\ P \qquad [4]$$

Where $C\ (a)$ refers to the total costs of a control action, a, or $136.40 for applying Guthion on 4.05 ha. (Appendix 1, 4.05 ha. is the average acreage of the orchards studied; $Y\ (s)\ .\ P$ refers to the dollar loss if no control action is taken with Y the total number of apples harvested, P is the price received per unit of crop[7] and s is the level of pest damage; and $Y\ [s\ (a)]\ .\ P$ refers to the dollar gain when a pest control action, a, is taken (an efficacy of 99.9% for a Guthion spray was arbitrarily selected).

A figure of 3,978 apples damaged by the spring generation represented yield losses varying from 0.44 to 1.75%. Therefore, the number of apples injured rather than the % damage was used as the economic threshold so that actual dollar losses or gains could be calculated when sprays were or were not applied. Table X shows that the economic threshold varies with the acreage on which the pest population is to be controlled.

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[7] A price of $0.127/pound was used as this is an average value guaranteed by the B.C. Income Insurance Act (B.C. Dept. Agric. 1974b). Dollar losses were calculated based on codling moth causing only losses in yield and no dollar return from injured apples. For converting the crop to lbs., a conversion of 3.5 apples/lb. was used.

Table X. Economic thresholds for codling moth damage based on the costs of treating a pre-determined acreage once converted to the number of injured apples required before control costs are returned by spraying

Orchard Size (ha.)	Costs of 1 Control Action, $C(a)$ ($)	Economic Threshold Damage Level (Number of apples)	Theoretical Population Level Causing Damage[a] Number	Number
0.4	13.64	399	40	40
1.2	40.92	1,194	119	119
2.0	68.20	1,989	199	199
4.0	136.40	3,978	398	398
6.1	224.60	6,551	655	655
8.1	272.80	7,956	796	796
20.2	682.00	19,892	1,989	1,989
40.5	1,364.00	39,784	3,978	3,978
202.4	6,820.00	198,920	19,892	19,892

[a]Assuming that 1 female produces 10 injured fruit during the spring generation.

The actual dollar return from the control action(s) given in Table XI were calculated as follows:

1) if no control actions were applied, the dollar return was calculated by subtracting the loss in yield from the costs of 1 control action; and
2) if control(s) were applied, it was calculated by:

$$C\ (a) - [(a - b) \cdot P] \qquad [5]$$

Where *a* is the number of apples damaged if controls were not applied and *b* is the observed damage determined at harvest. (Efficacy of the control action is not, therefore, arbitrarily set at 99.9% as in equation [4].)

In the orchards where no controls were applied, the damage exceeded the economic threshold in only the Substation orchard in 1974. In the orchards where 1 or 2 sprays were applied, the control costs were not returned by reducing the potential damage which would have occurred without spray applications (Table XI). However, if the efficacy of a spray was greater, one was justified in the Barker (1973), Workman (1973), and Emery (1974) orchards if the highest theoretical population increase (1 ♀ produces 20 larvae) occurred. The second spray applied in the Barker orchard during 1973 was not economically justified (Table XI).

If the damage potential/female exists in the area of 10 injured fruit during the spring generation under Okanagan Valley conditions, commercial growers could absorb loss of fruit by the spring generation on

Table XI. Financial return with controls applied against the estimated potential number of injured fruit occurring during the spring generation (- dollar return indicates control action used unnecessarily and + indicates control action used was satisfactory)

Orchard	Year	# Sprays Applied	Estimated # Injured Fruit Without Sprays: Theoretical (5F)	Population (10F)	Increase[a] (20F)	Observed # Injured Fruit at Harvest	Dollar Return with Control Action Applied: Theoretical (5F)	Population (10F)	Increase[a] (20F)
Kidston	1973	2	360	720	1,440	225	-268.37	-255.83	-231.14
	1974	1	40	80	160	403	-[b]	-[b]	-[b]
Powell	1973	0	0	0	0	0	+136.40	+136.40	+136.40[c]
	1974	0	0	0	0	75	+133.83	+133.83	+133.83[c]
Fitzgerald	1973	0	0	0	0	179	+130.26	+130.26	+130.26[c]
	1974	0	0	0	0	1,099	+98.72	+98.72	+98.72[c]
Workman	1973	1	1,025	2,025	4,100	479	-119.96	-84.82	-15.68
	1974	1	800	1,600	3,200	941	-[b]	-113.76	-58.95
Emery	1974	1	1,010	2,020	4,040	773	-128.28	-93.64	-24.40
Barker	1973	2	1,190	2,380	4,760	162	-237.55	-196.75	-21.24
	1974	1	190	380	760	465	-[b]	-[b]	-126.29
Substation	1974	0	6,410	12,820	25,640	4,051	-70.64	-70.64	-70.64[d]

[a] Females emerging from overwintered larvae produce 5, 10 or 20 injured fruit in the absence of sprays.

[b] Errors in harvest damage samples or influx of females could account for the actual damage exceeding the estimated damage.

[c] Since no sprays applied, the costs of 1 spray are saved and the only losses result from injured fruit.

[d] The actual injury figure was used for calculating the dollar return.

economic terms. Further increases in damage could be limited during the summer generation with a well-timed, effective control action. This hypothesis would depend on growers following preventative spraying prior to adopting a population monitoring program.

By establishing an economic threshold for codling moth damage, it was shown that pesticide pressure during the spring generation could have been limited further than it was during the study. The spraying level used in this study was a safe one. As more population dynamics data are generated from unsprayed commercial orchards, the spraying level could be modified to give economic damage predictions for both the spring generation and for later in the season.

Summer Generation Trap Catches and Damage Caused by the Summer Generation

Certain assumptions were again made so that captures could be related to the total damage occurring if sprays were not applied during the summer generation. In those orchards where no sprays were applied, the observed rather than the calculated injury level was used. Other assumptions, as follows, were necessary since measuring and predicting the population increase per generation and between generations is difficult since it varies between generations, and is influenced by many variables, particularly, weather (Proverbs 1971) and because specific mortality data were not available for the Okanagan Valley:

1) it was assumed that all of the larvae injuring and subsequently leaving the fruit during the spring would successfully develop into adults of the summer generation;

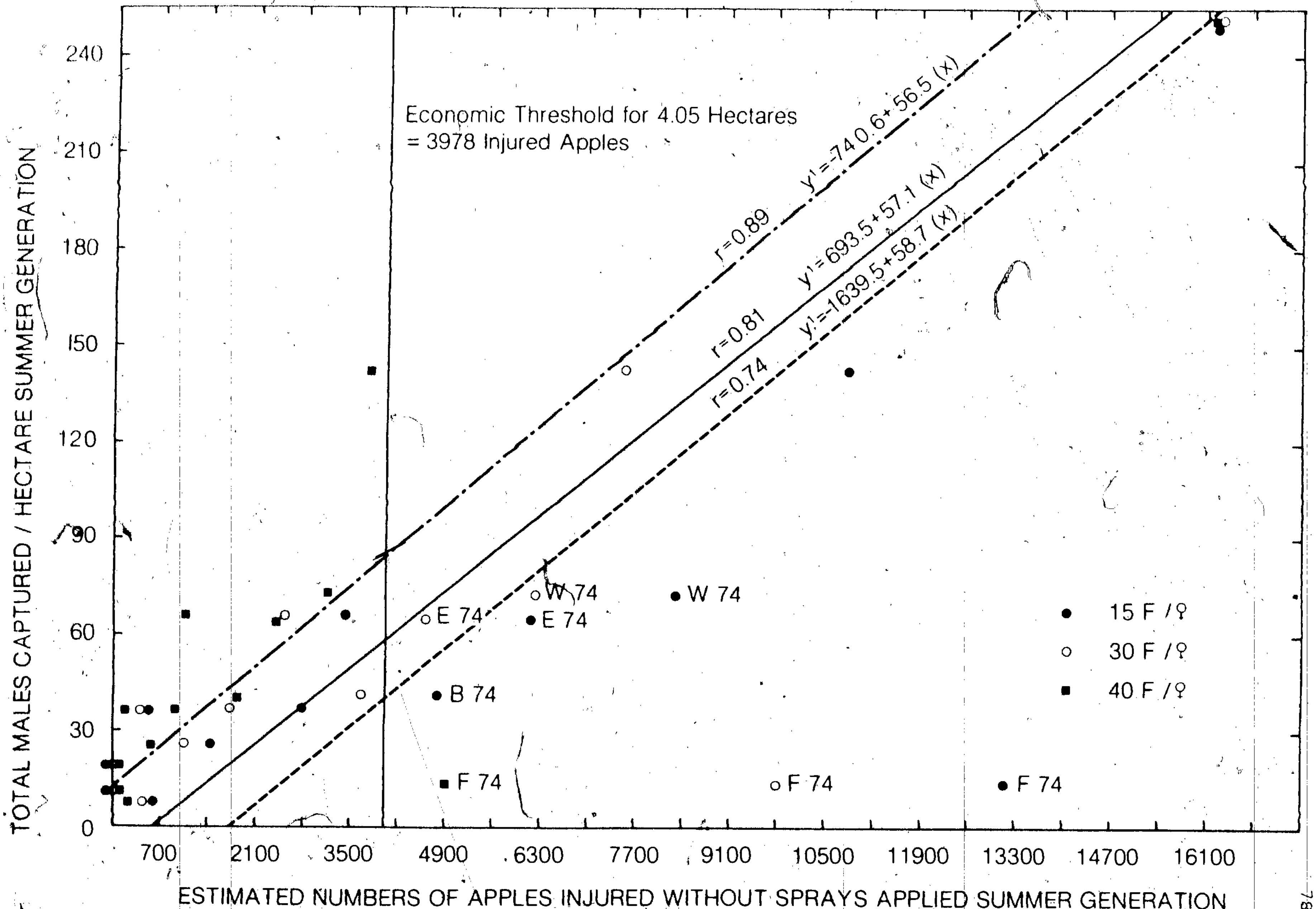
2) summer females, with a fecundity of 50 eggs/ , were assumed to produce 15, 30 or 40 larvae capable of injuring fruit. This represented 70, 40 or 20% mortalities in eggs and newly-hatched larvae; and

3) other assumptions used to calculate damage caused by the summer generation are detailed in the previous section related to calculating spring generation damage.

The number of apples expected to be injured by the summer generation was calculated for each orchard using Equation [3] (p. 65), where *d* becomes the number of females expected to emerge during the summer generation (Equation [2], p. 23), and x is 15, 30 or 40 injured fruit/female.

The population estimates tested were the number of times the 2 spraying levels were exceeded and the total number of males captured/hectare during the summer generation (length of the summer generation was averaged from Figs. 17-22). The number of times the 2 spraying levels were exceeded were not correlated with the number of injured fruit caused by the summer generation without sprays applied (r values of 0.39 for 1-week sample and 0.35 for 2 weeks' sample). The total number of males captured/hectare was significantly correlated with the number of injured fruit caused by the summer generation (Fig. 24). As with total spring catches, total summer catches are of little practical value for predicting

Fig. 24. Relationships between the total males captured/hectare and the estimated number of apples injured without sprays applied during the summer generation, 1973-74. Damage was estimated in those orchards where sprays were needed by using 3 rates of population increase, 1 ♀ produces 15, 30 or 40 injured fruit in the absence of sprays. Orchards in which the damage would have exceeded the economic threshold are marked: E = Emery, S = Substation, B = Barker, and W = Workman. Value of correlation coefficient for $P < 0.01$ for 9 D.F. is 0.7348 and for $P < 0.001$ it is 0.8471.



Economic Threshold for 4.05 Hectares
= 3978 Injured Apples
y' = -740.6 + 56.5 (x)
r = 0.89
y' = 693.5 + 57.1 (x)
r = 0.81
y' = -1639.5 + 58.7 (x)
r = 0.74
W 74
E 74
B 74
F 74
15 F / ♀
30 F / ♀
40 F / ♀
TOTAL MALES CAPTURED / HECTARE SUMMER GENERATION
0
30
60
90
120
150
180
210
240
700
2100
3500
4900
6300
7700
9100
10500
11900
13300
14700
16100
ESTIMATED NUMBERS OF APPLES INJURED WITHOUT SPRAYS APPLIED SUMMER GENERATION

potential damage because damage would occur before enough data were collected from traps.

To examine whether the sprays applied during the summer generation were economically justified, the potential damage expected to be caused by females produced from the spring generation was compared to the economic threshold (Table XII). A figure of 3,978 apples represented the economic threshold for summer generation damage in these commercial orchards. The dollar return from any control action applied was calculated as for the spring generation (Equation [5], p. 73).

A summer generation codling moth spray was not recommended in the Powell orchard during 1973, but the grower elected to apply a spray on August 10th. Since no females were expected to emerge, the grower did not recover any of the control costs (Table XII). Although no summer control actions were recommended in the Fitzgerald orchard during 1974, the 5,607 injured apples found at harvest would have justified a control action (late season damage included in the total).

With the potential population increase arbitrarily set at 1 ♀ producing 15 injured fruit, none of the recommended sprays were economically justified because this population increase would not have resulted in enough injured apples to pay for each spray (Table XII). However, since the rate of population increase between the generations is unpredictable and could be high, upper limits were used to safeguard against underestimating the number of apples injured. Proverbs (1971) found the increase per generation varied from 2- to 28- fold with an average increase of 6- fold in experiments with caged adults. He also noted that the

Table XII. Financial return with controls applied against the estimated potential number of injured fruit occurring during the summer generation (- dollar return indicates control action used unnecessarily and + indicates control action used was satisfactory)

Orchard	Year	# Sprays Applied	Estimated # Injured Fruit Without Sprays			Observed # Injured Fruit at Harvest	Dollar Return with Control Action Applied		
			Theoretical (15F)	Population (30F)	Increase[a] (40F)		Theoretical (15F)	Population (30F)	Increase[a] (40F)
Kidston	1973	1	210	420	560	252	_[b]	-130.64	-125.84
	1974	2	1,290	2,580	3,440	699	-252.04	-208.30	-178.82
Powell	1973	1	0	0	0	0	-136.40	-136.40	-136.40
	1974	0	225	450	600	121	+132.26	+132.26	+132.26[c]
Fitzgerald	1973	0	0	0	0	193	+129.78	+129.78	+129.78[c]
	1974	0	4,920	9,840	13,120	2,881	+37.62	+37.62	+37.62[c]
Workman	1973	1	900	1,800	2,400	953	_[b]	-107.36	-86.79
	1974	1	3,135	6,270	8,360	2,267	-106.65	+0.84	+72.50
Emery	1973	1	3,780	7,560	10,800	1,816	-91.17	+16.31	+171.62
	1974	1	2,340	4,680	6,240	699	-79.10	+1.13	+54.61
Barker	1973	1	555	1,110	1,480	196	-124.09	-105.06	-92.38
	1974	1.5	1,830	3,660	4,880	515	-159.52	-96.78	-54.94

[a] Females from the spring generation produce 15, 30 or 40 injured fruit in the absence of sprays.

[b] Errors in harvest damage samples or influx of females could account for the actual damage exceeding the estimated damage.

[c] Since no sprays applied, the costs of 1 spray are saved and the only losses result from injured fruit.

increase in the larval numbers during the summer generation in the Okanagan Valley is three or more times that of the spring generation. Higher theoretical population increases (1 ♀ produces 30 or 40 injured fruit) would have resulted in enough injured apples to pay for one spray in the Workman (1974), Emery (1973 and 1974), and Barker (1974) orchards (Table XII).

Since it is difficult to estimate the damage occurring during the late season because it could be caused by late emerging females from the spring generation or females produced by the summer generation, the economics of the spray applied to half of the Barker orchard in 1974 are unknown. Further research on population dynamics of late season adults is needed because high catches were recorded in some orchards but the number of apples injured before harvest (Table XIII) was not as high as expected. Controlling the number of apples injured late in the season would not have paid the costs of a spray in the orchards listed in Table XIII. An additional summer spray was justified in the Workman orchard in 1974 because a total of 3,504 apples were found at harvest (Tables XII and XIII). A further spray would not have been economic in the Emery orchard because many of the apples were injured before the summer spray was applied. Enough damage did not occur during the rest of the season to pay for the costs of another spray (Tables XII and XIII).

It is difficult to project the number of apples injured by the summer generation when control(s) are not applied against the spring generation. Certain population parameters can be arbitrarily selected to give a theoretical population increase during the spring generation.

Table XIII. Financial return obtained by controlling damage caused by late season moths, 1973-74

Orchard	Year	Total Number Apples Damaged Late Season[a]	Return With 1 Control Action/$
Kidston	1974	295	-126.29
Fitzgerald	1974	2,726	-42.94
Workman	1973	713	-111.96
	1974	1,237	-93.99
Emery	1973	1,043	-100.64
	1974	295	-126.29
Barker	1973	23	-135.61

[a] Apples at harvest with instars 1-3 present.

This allows a spring generation population to be established (or the number of injured apples) based on the number of females emerging from larvae overwintering during the previous season. A theoretical summer generation population can be calculated using various rates of between generation increase in moth numbers. However, attempts to relate catches during the spring generation with the number of apples injured by the summer generation are difficult because the data are lacking for *L. pomonella* populations in unsprayed commercial orchards. Additional research is needed so that realistic estimates can be made of population increases expected during a generation and between generations in varying weather conditions and locations in the Okanagan Valley. The sprays needed in this study prohibited establishing realistic predictions of summer damage by catches during the spring generation.

Projecting summer damage using theoretical per generation and between generation population increases indicates that precise damage correlations for the summer generation may not be required on a practical level, particularly, if sprays are not applied during the spring generation. In Table XIV the number of apples injured by the summer generation was estimated by using a 2.5-fold increase during the spring generation and a 3.5-, 7.0- or 9.8-fold between generation increase (increases equivalent to 1 ♀ producing 5 injured fruit during the spring generation and 1 ♀ during the summer generation producing 15, 30 or 40 injured fruit). In 9 of 12 orchards, the damage approached or exceeded the economic threshold of 3,978 apples (Table XIV). Similarities in the amount of damage caused by the summer generation were obtained with the

Table XIV. Estimated number of fruit injured by the summer generation with no seasonal sprays applied (assuming a 2.5-fold increase during the spring generation and a 3.5-, 7.0- or 9.8-fold increase [F.I.] between the generations)

Orchard	Year	Estimated Number Injured Fruit Spring Generation (2.5-F.I.)	Estimated Number Injured Fruit Summer Generation		
			(3.5-F.I.)	(7.0-F.I.)	(9.8-F.I.)
Kidston	1973	360	1,260	2,520	3,528
	1974	403[b]	1,411	2,821	3,949
Powell	1973	0[a]	0	0	0
	1974	75[a]	263	525	735
Fitzgerald	1973	179[a]	627	1,253	1,754
	1974	1,099[a]	3,847	7,693	10,770
Workman	1973	1,025	3,588	7,175	10,045
	1974	941	3,294	6,587	9,222
Emery	1974	1,010	3,535	7,070	9,898
Barker	1973	1,190	4,165	8,330	11,662
	1974	465[b]	1,628	3,255	4,557
Substation	1974	4,051[b]	14,179	28,357	39,699

[a] Actual spring damage used because sprays not applied.

[b] Actual spring damage used because the calculated damage at a 2.5-fold per generation increase was lower.

per generation increase for the spring generation set at 5-fold, because Clark et al. (1967) showed that the greater the relative size of the spring generation, the lower was the rate of increase between generations.

Damage correlations estimating the amount of spring generation damage from spring generation catches (Fig. 23) could be used along with predictions of between generation increases to project infestation levels caused by the summer generation. Spray decisions would be made on an economic threshold basis. Alternatively, since summer generation catches were correlated with the estimated summer damage (Fig. 24), the potential overwintering population could be estimated. A simulation model could be built similar to the one developed by Geier and Hillman (1971), in which the spring generation damage was accurately estimated from the number of overwintering larvae successfully established. Summer catches could be used to determine the number of overwintering larvae instead of searching vegetation and debris under trees, the tree trunk at and below ground level, crotch, base of main limbs and crown of sample trees for cocooning sites. This is limited on a practical basis because sampling at low populations would be too time consuming. Detailed sampling of fruit at harvest for larval exits is possible but limited for use in a commercial monitoring program for *L. pomonella*. As more data are obtained from unsprayed commercial orchards, catches during the spring generation may prove useful in directly predicting damage caused by the summer generation.

Forecasting Spray Timing With Catches

Timing insecticide applications for maximum effect against the target organism means predicting the period of greatest codling moth egg hatch. Accurate prediction is difficult because moths emerge over a long period during both generations. Therefore, eggs are deposited and hatch under a considerable variation in climatic conditions.

A number of methods have been reported for determining the first egg hatch. Glenn (1922) used day-degree summations, based on a developmental threshold of 10°C. However, Hagley (1972a) showed that although egg development occurred at 10°C., no larvae emerged and all eggs died after 48 days. His results showed that the development threshold was 11° ± 1°C. Later studies (Hagley 1973) showed that the greatest larval emergence occurred 6-10 days after the first emergence of larvae during the spring. Hagley (1973) observed that the first female moths which emerge are frequently of low fecundity and lay few eggs, although weather conditions are suitable in the spring. Since the date of the first female emergence can be determined from emergence cages, the start of egg hatching can be calculated. Accuracy, though, is limited by climatic factors affecting female oviposition behaviour (Hagley 1973; Putman 1963; Madsen 1967; Batiste et al. 1973).

Periods of greatest egg deposition could be determined by systematic collecting and examination of fruit and leaf clusters throughout the orchard (Hagley 1972b; Batiste et al. 1973). This method is limited because a minimum of 150-200 individual clusters must be examined for reliable estimates when the egg population is low (Hagley 1972b).

Batiste et al. (1973) found only 20 eggs in total of 4,460 fruit and leaf clusters collected in untreated areas of an orchard with infestations at harvest averaging 53%.

The occurrence of first egg hatch has been related to the emergence and activity of males in the spring (Hagley 1973; Riedl and Croft 1973). Hagley (1973) found that 144- and 137-degree days were required for egg hatch after the first catches in pheromone-baited traps during 1971 and 1972 in Ontario. Riedl and Croft (1973) reported that accumulating 50 heat units for preoviposition and 158 heat units for egg development after the first catches accurately estimated the first egg hatch in Michigan orchards.

Sprays for the spring generation are currently recommended 10-14 days after petal fall (B.C. Dept. Agric. 1974). In 1973, sprays were applied 24-38 days after petal fall and peak emergence occurred 13-36 days after petal fall. As a general rule, sprays were applied after the catches indicated a peak emergence of adults after petal fall. Cool spring weather delayed the peak emergence during 1974 as compared with 1973. Accumulated degree-days for May 1973 and 1974 were 257.21 and 136.23, respectively. Figures were calculated from maximum and minimum daily temperatures (Ives 1973) for the Substation orchard, Kelowna. Additional hygrothermograph records could not be obtained for the various orchard locations used during 1973 and 1974. The degree-day accumulation during May 1974 indicated that the spring generation spray should have been applied later than the B.C. Dept. Agric. (1974) recommended date. Many growers who followed the standard program required a second spray for the spring generation.

Another method of timing developed by Batiste et al. (1973) was used to determine the first egg hatch in the Emery orchard in 1974. This consisted of confining adults reared in the laboratory in cages in the orchard from the first catches of males to when eggs in the cage began to hatch. The adults were replaced weekly. Although, an estimated 733 apples were injured by the spring generation, the spray applied June 15th was effective considering the damage potential from 1973 (Table XII).

Timing of summer generation sprays is made easier because weather conditions are favourable for oviposition. Growers were advised to apply a summer spray after catches exceeded an average of 2 males/trap. There were a few exceptions when less than optimum weather conditions for oviposition followed this date. More data are necessary to determine the period of greatest egg hatch during the summer generation.

Further research is needed on predicting the period of maximum egg hatch during the spring generation. Degree-day accumulations after the first catches and oviposition cages should prove useful in developing a timing model for commercial orchards.

Summary and Conclusion--Pheromone Traps as Pest Management Tools

For most commercial orchard populations, damage projections (< 5% damage) for low moth densities are vital for determining optimum control strategies (Madsen and Vakenti 1973; Riedl and Croft 1974; Madsen et al. 1974). More research is necessary in unsprayed Okanagan Valley commercial orchards before reliable predictions of damage by catches can be made as with Riedl and Croft's (1974) model for populations causing harvest damage greater than 2% in semi-abandoned Michigan orchards.

More data are needed so that catches can be adjusted when influenced by the factors summarized in a relationship proposed by Riedl and Croft (1973):

Catch = f (AD, D, CO, TTR, TE) + Influx

AD refers to the number of days the weather conditions are suitable for male response to traps. Catches in different areas and years as influenced by weather conditions could be standardized by using degree-day accumulations instead of weekly sample periods (Riedl and Croft 1974). However, degree-days do not adequately reflect differences during the daily flight period. The density of males during any trapping period, *D,* influences the magnitude of catches. In the sampling procedures used in the study, *TE* (trap efficiency as influenced by synthetic pheromone formulations and trap designs) and *TTR* (trap/tree ratio or trap/area ratio) were standardized as much as possible, although modifications were made when improvements were necessary. *CO* (trap efficiency dependent on female density and sex ratio) influenced catches in orchards where population densities approached the economic threshold. *Influx* of males was shown to influence catches. Both influx of females and males were shown to influence spray decisions. Deploying traps outside of the study orchards reduced the influx of males so that spray decisions could be made.

A spraying level was tested based on catches exceeding an average of 2 males/trap during 2 consecutive weeks. The number of sprays applied was substantially reduced. However, projecting potential injury levels and establishing an economic threshold for injury during both generations showed that other sprays were unnecessary because the costs of the spray were not returned. Although, the spraying level would indicate *L. pomonella* populations that would exceed the economic threshold (shown in Appendix 3), further population dynamics studies in unsprayed commercial orchards would allow more precise damage predictions to be developed. These studies are extremely important since damage predictions in commercial orchards are subject to a wide range of cultural and pesticide practices not found in semi- or abandoned orchards. Population increases and mortality factors and percents would likely differ. With more accurate assessments of fecundity and mortalities influencing within and between generation increases, catches could be used reliably to predict infestation levels.

Catches during the spring and summer generations were related to the number of apples injured by the respective generations. As more data are obtained from unsprayed orchards, these relationships could be used to estimate the damage potential during succeeding generations. Economically sound spray decisions could then be made.

APPLICATION OF POPULATION MONITORING IN AN APPLE PEST MANAGEMENT SYSTEM

Reduced Codling Moth Spray Schedules and Influences on Secondary Apple Pests

Insecticides are usually applied to reduce temporarily populations of one or more pest species. Other components of an ecosystem are affected, e.g., changes in the status of secondary pests and resurgence of treated populations (Madsen and Morgan 1970; Newsom 1974). Broad-spectrum chemicals used for *L. pomonella* have been considered to control other pests at the same time (Madsen 1968; Proverbs 1971).

In a commercial orchard left unsprayed for *L. pomonella* for 6 years, natural enemies were unable to bring injurious populations of the fruittree leafroller, *Archips argyrospilus* (Walker), the eye-spotted budmoth, *Spilonata ocellana* (D. & S.) and the white apple leafhopper, *Typhlocyba pomaria* McAtee under control (Madsen 1971). In two commercial orchards under programs of sterile *L. pomonella* release, Proverbs (1971) observed that *A. argyrospilus* populations increased rapidly but *S. ocellana* and *T. pomaria* populations did not. Sprays for these pests were not required after three years of moth release.

In the monitored orchards, sprays were omitted for relatively short periods, therefore the effects of spray elimination on secondary pests were inconclusive. Some trends developed in the Fitzgerald orchard, in which *L. pomonella* sprays were not applied from 1972-74. *T. pomaria* populations did not increase (Madsen, Peters and Vakenti 1975).

Populations of *S. ocellana* gradually increased until damage was noted at harvest.

Leafrollers, *A. argyrospilus* and *Archips rosanus* (L.) caused damage in all of the orchards, although samples in 1974 before petal fall indicated that populations did not require treatment (Madsen et al. 1975). More research is needed to establish the variations in the time and length of egg hatch of these two species under varying climatic conditions so that late applications or reductions in *L. pomonella* control during the spring generation do not enhance leafroller population increases.

It was difficult to determine if biological controls were influenced by reducing the number of sprays applied for *L. pomonella* control. As an example, 3 sprays were applied for codling moth control in the Kidston orchard during both years but no miticides were needed during both years. At the Fitzgerald orchard where no sprays were applied for *L. pomonella* control, a miticide in both years was needed for the apple rust mite, *Aculus schlechtendali* (Nalepa), in spite of the fact that the predatory mite, *Typhlodromus occidentalis* (Nesbitt) was present in high numbers. Conflicting results were obtained with *Aphis pomi* DeGeer populations, as high numbers developed in orchards with both reduced and full *L. pomonella* spray programs.

Integration of a 'Key-Pest' Monitoring System into a Pest Management Program on Apples

The estimated return to the growers involved in this study is detailed in Table XV . The expenditures of the program were calculated

Table XV. Revenue gained under a pilot population monitoring program as compared with a 3-spray calendar program for *L. pomonella* control in six commercial orchards during 1973 and 1974 (acreage totalled 124 acres)

Orchard	Year	Expenditures Under Monitoring Program ($)	Expenditures Under Calendar Spray Program ($)	Revenue Using Monitoring Program ($)
Kidston	1973	425.54	414.69	-10.85
	1974	463.57	415.41	-48.16
Fitzgerald	1973	13.25	418.20	+404.95
	1974	232.95	424.84	+191.89
Powell	1973	136.40	414.34	+277.94
	1974	6.71	413.10	+406.39
Emery	1973	430.38	416.67	-13.71
	1974	332.33	413.18	+80.25
Workman	1973	346.39	418.76	+72.37
	1974	446.25	419.83	-26.42
Barker	1973	422.25	414.96	-7.29
	1974	375.66	413.66	+38.00
Totals		3,631.68	4,997.64	+1,365.96
Less Total Costs of Monitoring Program (7.48/acre)				-927.50
Net Return				+438.44

by adding the total costs for applying sprays (Appendix 1) and the dollar loss in yield at current prices. The cost/acre for an *L. pomonella* monitoring program operated by a commercial company (Appendix 2) was also added. This figure was used instead of the costs involved in running a research program on widely separated commercial orchards. The expenditures of calendar spraying were calculated by adding the total costs of applying 3 sprays and dollar losses in yield at current prices (assuming 3 sprays would still give a loss in yield of 0.05%). Omitted in the calculations were the charges to growers levied by packinghouses for sorting and grading damaged fruit since in most cases, insect-damaged applies represent less than 20% of the apples culled by the packinghouse. Most apples are culled on the basis of size, shape, colour, bruising, punctures and sun scald.

While some of the growers involved in the program lost revenue (Table XV), adoption of complete pest management could reduce spray costs further and thereby support the viability of a pest management program (Madsen, Vakenti, and Peters 1975). In those orchards which lost revenue, population monitoring indicated codling moth populations requiring 3 sprays based on the treatment level used in this study. While it is proposed that spring generation spraying may not be necessary in many commercial orchards, considerable work is necessary to verify this hypothesis and the simple model developed in this study.

Besides providing the opportunity to reduce spray costs, the population monitoring program confirms the need for insecticides in preventing excessive damage. The dependence, though, on preventative spray programs will lessen with the adoption of population monitoring. Other factors such as increasing insecticide costs, pest resistance, environmental concerns and potential lack of replacement insecticides, make the implementation of such programs a necessity in maintaining the grower's ability to respond to damaging insect populations.

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APPENDIX 1

COSTS OF CODLING MOTH INSECTICIDE SPRAYS

The costs of spraying one acre of apples in a standard planting were calculated using the methods of M. D. Proverbs (personal communication)[1] and Maisonneuve and Shortreed (1972) for equipment costs. Guthion was used as it is most commonly applied for *L. pomonella* control. The total cost/acre was calculated in two ways:

1) using both fixed and variable costs, this figure was used for calculating the economic threshold for *L. pomonella* damage on 10 acres of commercial orchard; and
2) using only variable costs because fixed costs associated with equipment operation are not normally considered by growers to be part of the total costs of applying sprays.

<u>Variable and Fixed Costs of Spray</u>

1. *Total cost/hour; tractor + driver for applying 1 spray* $8.75

   Calculated by:

a)	Cost of depreciation (10%/yr for 10 yr), interest (8%), $1,500/yr repairs, housing for tractor costing $5,000	
b)	Cost of above items/hr assuming 600 hrs use/yr = $1,500/600	$2.50
c)	Cost of fuel, oil, grease/hr of tractor use is approximately	$1.25
d)	Wages for owner or hired labour/hr	$5.00
	Total	$8.75

2.	*Total cost/hour for sprayer*		$11.25
	Calculated by:		
	a) Cost of depreciation, interest, repairs, housing $900/yr for 2-sided, air blast costing $4,500		
	b) Cost of above items/hr assuming 80 hours $11.25/hr use/yr (average of 11 sprays & 17 acres) = $900/80		
3.	*Total costs for equipment operation/hr*		$20.00
4.	*Total costs/acre for equipment operation for 1 spray*		$ 8.40
	Calculated by:		
	a) Time to spray one acre (2 mph in 20'x20' planting and allowing time for filling, mixing spray, and turning is approximately 25 minutes		
	b) Cost to spray one acre = 25/60 x $20.00	$8.40	
5.	*Total cost/acre for insecticide*		$ 5.24
	a) Cost of insecticide/acre based on 1.25 lb applied/acre at a 1974 price of $4.19/lb for Guthion	$5.24	
6.	*Total costs/acre for applying 1 spray Guthion*		$13.64

Variable Costs of Spray

1.	*Total costs/acre for equipment operation for 1 spray*		$ 2.63
	Calculated by:		
	a) Total cost for equipment operation/hr using only costs of fuel, oil, grease and wages	$6.25	
	b) Cost to spray one acre = 25/60 x $6.25	$2.63	
2.	*Total cost/acre for insecticide*		$ 5.24
3.	*Total costs/acre for applying 1 spray Guthion*		$ 7.87

If the variable costs are used for calculating the costs of applying one spray of Guthion/acre, the economic threshold for codling moth damage becomes 2,286 apples on 10 acres of commercial orchard. With both variable and fixed costs, it is 3,978 apples on 10 acres.

APPENDIX 2

COSTS OF CODLING MOTH POPULATION MONITORING PROGRAM

For calculating the costs of operating a monitoring program in commerical orchards, a hypothetical company is proposed. It has 5,000 acres of apples under contract in a discrete geographical area, e.g., in the Kelowna, B.C. area. Company costs in offering the monitoring service were estimated at $7.48/acre. The calculations were based on 1974 prices.

<u>Estimated Company Costs</u>

1. *Total costs of sampling materials for 5,000 acres* — $7,660.00

   Calculated by:

   a) Costs of traps for season on 5,000 acres (assuming 1 Zoecon ICP trap lasts one season and bottom surface changed 3 times during 24 weeks; trap density of 1/hectare; costing $0.65/trap + $0.26/replaceable bottom surface) — $2,860.00

   b) Costs of pheromone supplies on 5,000 acres (using Zoecon CM formulation changed every month for 2,000 traps at a cost of $0.40/bait receptacle) — $4,800.00

   Total — $7,660.00

2. *Total manpower costs for servicing traps and making decisions for 5,000 acres* — $24,000.00

   Calculated by:

   a) Two managers employed for 6 months at $1,000/month — $12,000.00

   b) Five assistants for servicing traps and relaying catch data to office. Hired for 4 months at $3.00/hr. — $10,000.00

c)	Two office workers for recording data. Hired for 4 months at $3.00/hr.	$2,000.00	
	Total	$24,000.00	

3. *Total Office and Transportation costs for 5,000 acres* — $5,750.00

Calculated by:

a)	Office rent including utilities for 6 months	$1,000.00	
b)	Office equipment-rentals on typewriters, calculators, telephone, etc.	$350.00	
c)	Stationery supplies	$500.00	
d)	Computer terminal & telephone hook-up	$800.00	
e)	Transportation costs--3 vehicles rented for $250.00/month with 4,000 miles free and insurance and servicing included for 4 months	$3,000.00	
f)	Gas, oil, etc.	$300.00	
g)	Postal and newsletter costs	$300.00	
	Total	$5,750.00	

4. *Total operating costs for 5,000 acres* — $37,410.00

5. *Total operating costs/acre* — $7.48

APPENDIX 3

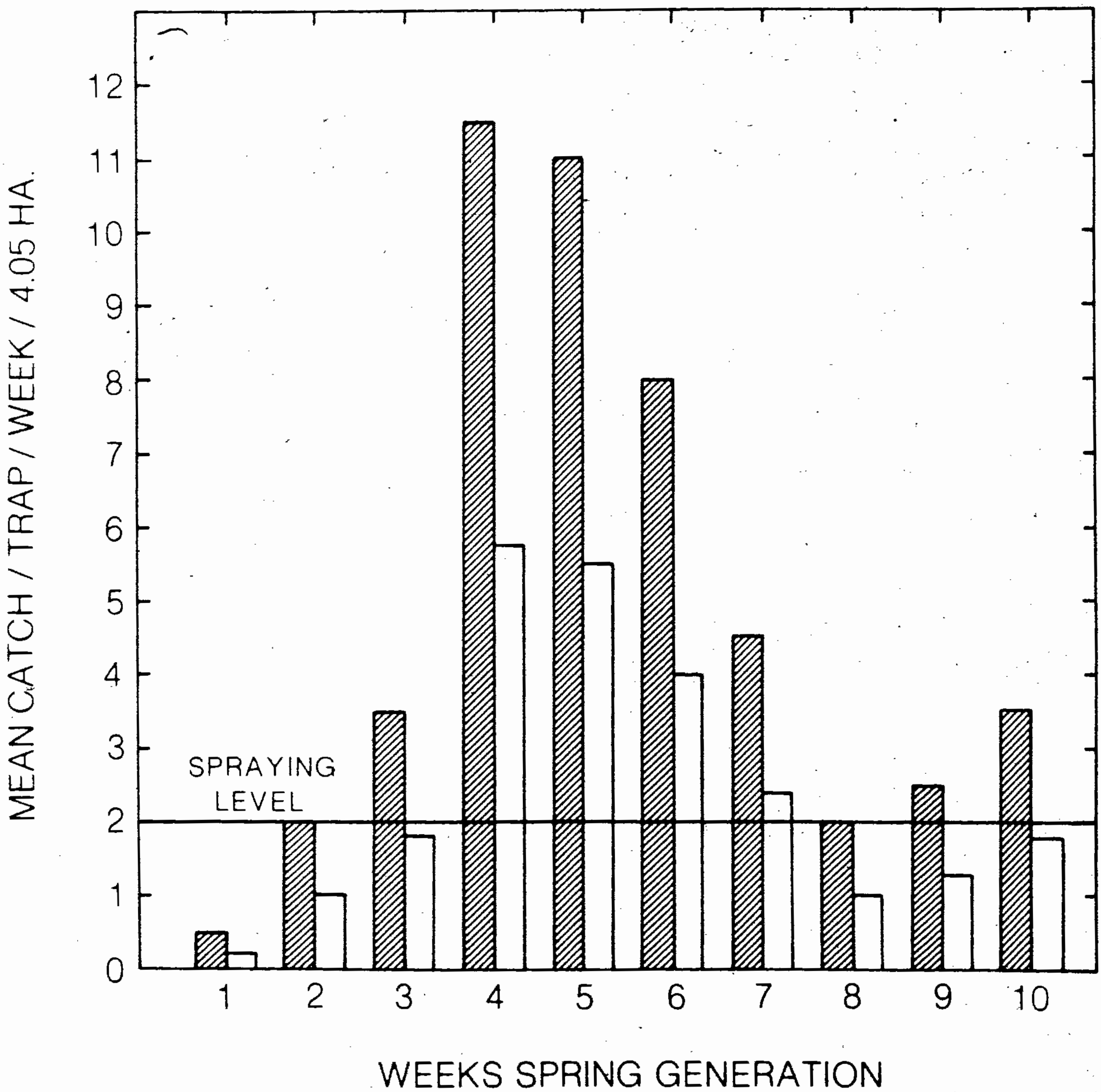
SPRAYING LEVEL

On theoretical terms, the spraying level used in this study indicates economic threshold populations. In Table 16, the estimated percentage capture rate/week during the spring generation was determined from 3 years of catches in pheromone-baited traps. In each example, the orchard area is 10 acres, the economic threshold 3,978 apples, and a capture rate of 50% of the emerging males is assumed. In the first population (Fig. 25, solid bars), in which an injury-potential of 10 fruit/♀ is assumed, 398 ♀♀ and 398 ♂♂ would have to emerge during the spring generation to cause economic damage. This population would be detected by the third week. In the second population (Fig. 25, clear bars), in which an injury potential of 20 injured fruit/♀ is assumed, a minimum emergent population of 199 ♀♀ and 199 ♂♂ would be necessary. The economic threshold population would be detected by the fourth week.

Table XVI. Relative percent captures of male codling moths during each week of the spring generation flight (N = 23 records of captures from 6 locations and 3 years, 1972-74)

Week Number	Total Males Captured (N = 23)	% of Total Captured Each Week
1	34	0.82
2	151	3.65
3	316	7.63
4	971	23.44
5	921	22.24
6	681	16.44
7	395	9.54
8	168	4.06
9	216	5.21
10	289	6.98

Fig. 25. Theoretical detection of economic threshold populations for determining the need for chemical sprays. Population 1 (solid bars) consists of 398 ♀♀ and 398 ♂♂ emerging during the spring generation and population 2 (clear bars) is 199 ♀♀ and 199 ♂♂ emerging during the spring generation


MEAN CATCH / TRAP / WEEK / 4.05 HA.
0
1
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11
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SPRAYING
LEVEL
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2
3
4
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6
7
8
9
10
WEEKS SPRING GENERATION

APPENDIX 4

FEMALE FECUNDITY AND MORTALITY OF STAGES

In calculating theoretical per generation and between generation increases, data on *L. pomonella* fecundity (Table XVII) and percentage mortality of stages (Table XVIII) were compiled from Geier (1963), Clark et al. (1967), and Ferro and Harwood (1974). Most of the values listed in Table XVIII were from abandoned or unsprayed orchards.

Table XVII. *L. pomonella* fecundity in various geographical locations.

Region	Generation or Year	Estimated or Observed Mean Egg Production/♀
Arkansas	Spring	8
	Summer	52
Bathurst, N.S.W. Australia	Spring	22
	Summer	26
Sinkiang, China	Spring	33
	Summer	43
Snake River, Washington	1973	42
	1974	37
N.S.W., Australia	1963	44
New Zealand	1967-68	44.9
	1968-69	90.0
	1969-70	47.0
Yakima, Washington	Laboratory Colony	76.0
Washington	Spring	64.0
	Summer	83.0
Central Europe	Unspecified	20-80
Switzerland	Unspecified	66
France	Unspecified	50
Illinois	Unspecified	31-42

Table XVIII. Percentage mortalities of *L. pomonella* stages in various geographical locations

Region	% Mortality Eggs	% Mortality 1st Instars	% Larval Mortality in Apple	% Mortality 5th Instar Larvae After Leaving Apple	% Mortality Pupae	% Overwintering Mortality
Snake River, Washington	25-50	62 72	35	5.3-27.5	2.8-5.0	50-75
Michigan	53-75 46-80					
Ontario	12-62	18				
Nova Scotia	14.4	69		94		51.0
Nova Scotia	70[a]			80		60
United States	32-43 19-23			21 32		24.2
Washington		66				
Quebec						79.4
California						52.0
Okanagan Valley, British Columbia						20.0 50.0
New Zealand				57.0		

[a] Percentage mortality of eggs and 1st-instar larvae.

CURRICULUM VITAE

Jerry M. VAKENTI

PERSONAL INFORMATION:

Birthdate: December 30, 1948. Married. Canadian Citizen.

EDUCATION:

1966 Graduated from Port Coquitlam Senior Secondary, Port Coquitlam, British Columbia.

1972 B.Sc. (Biology), Simon Fraser University, Burnaby, British Columbia.

1972- M.Sc. (Biology) in progress, Simon Fraser University, Burnaby, British Columbia.

SOCIETIES:

Entomological Society of British Columbia.

Entomological Society of Canada.

WORK EXPERIENCE:

1971 Research Assistant, Agriculture Canada, Summerland, B.C. April to November 1971. Responsible for conducting experiments with sex pheromones of the codling moth and fruittree leafroller, ecological studies of the white apple leafhopper, and evaluation of integrated control insecticide plots. Supervisor: Dr. H. F. Madsen.

1972 Research Assistant, Agriculture Canada, Summerland, B.C. April to November 1972. Assisted Dr. H. F. Madsen in developing a codling moth population monitoring program utilizing the synthetic pheromone. Evaluated pheromones for 2 species of tortricid moths (*Archips argyrospilus* and *A. rosanus*). Supervised one student assistant and several rodent control personnel from the B.C. Dept. of Agriculture.

1973 Research Assistant, Agriculture Canada, Summerland, B.C. April to November 1973. Assisted Dr. H. F. Madsen in developing an

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Report to Western Co-operative Pest and Disease Management Conference, Portland, Oregon, January 1973 (Abstracts).

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Vakenti, J. M. and H. F. Madsen. Codling moth: Optimizing control strategies in Okanagan Valley commercial orchards in British Columbia (in preparation for J. Econ. Entomol.).

experimental pest management program on apples. Conducted research on "male-disruption," "trapping-out," and population monitoring of the codling moth utilizing synthetic sex pheromone. Supervised 2 student assistants and several rodent control personnel from the B.C. Dept. of Agriculture.

1973 Teaching Assistant in Introductory Biology, Simon Fraser University, Spring 1973. Tutorial instruction and laboratory demonstration under an audio-visual system.

1973-1974 Research Assistant, S.F.U., November 1973 to April 1974. Assisted Drs. D. L. Pierson and J. H. Borden in researching the possibility of promoting herbicide action with the addition of various plant growth hormones.

1974 Research Assistant, Agriculture Canada, Summerland, B.C. April to November 1974. Directed apple-pest management program during 1-year absence of Dr. H. F. Madsen. Involved planning, population sampling, and making decisions on pesticide applications based on damage predictions. Continued research on alternative methods of codling moth control utilizing pheromones in "male-disruption" and "trapping-out" techniques, and on codling moth mating behaviour.

1975 Project Assistant, S.F.U. Mountain pine beetle research program, May to September 1975. With N. A. Alexander and Dr. J. H. Borden. Preparation of a case history study of a mountain pine beetle outbreak on Tree Farm Licence #9, Crown Zellerbach Co., Kelowna, B.C. Involved determination of pest impact on short- and long-range forest management plans, and impact of management procedures on the pest population. Also involved interviewing of personnel in Crown Zellerbach Co. Ltd., B.C. Forest Service, Canadian Forestry Service, B.C. Dept. Lands, Forests and Water Resources, B.C. Dept. Fisheries and Wildlife, B.C. Dept. of Agriculture and local environment organizations.

1976 Insecticide Evaluation Officer, Agriculture Canada, Control Products Section, Ottawa, Ontario. January 1976.

PUBLICATIONS:

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Papers Presented to Scientific Meetings

Vakenti, J. M. and H. F. Madsen. Summary of codling moth population monitoring experiments in Okanagan Valley commercial orchards, 1971-1974. Presented to Joint Meeting Ent. Soc. B.C. and Washington State Ent. Soc., Penticton, B.C., April 1974.

Vakenti, J. M., H. F. Madsen, and M. D. Proverbs. Codling moth population monitoring, male-disruption, trapping-out, and sterile moth release program. Presented to W-109 Regional Codling Moth Project Meeting, Univ. of Calif., Berkeley, November 1973.

AWARDS:

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