

AN ABSTRACT OF THE THESIS OF

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Title: The Potential of Endemic Natural Enemies to Suppress Pear Psylla, *Cacopsylla pyricola* Förster, in the Hood River Valley, Oregon

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This thesis addressed the potential of endemic predaceous and parasitic arthropods of the Hood River Valley, Oregon to suppress the pear psylla, *Cacopsylla pyricola* Förster. Natural enemies adequately suppressed psylla in three of seven unsprayed orchards of differing vegetational settings, orchard age, and size. Relatively few psylla natural enemies dispersed to unsprayed pear mini-orchards, despite abundant populations on surrounding noncultivated vegetation. Pear psylla natural enemies were more abundant on arboreal rather than herbaceous non-pear hosts. Selective programs of pear pest control based on diflubenzuron were moderately successful in controlling the pear psylla, with natural enemies aiding in suppression in six of fourteen commercial trials of selective programs. In both unsprayed and commercial pear orchards, late-season psylla densities appeared to be best suppressed when levels of natural enemies were high during early-season. Classification analysis confirmed that orchard site, chemical regime, type (mini- or commercial), and season affected proportions of natural enemies and their pear psylla prey. Complexes of natural enemies and pear psylla immatures from commercial orchards where biological control was successfully demonstrated were taxonomically similar. Effective natural enemy complexes in commercial orchards were characterized by earwigs, lacewing larvae, and moderate proportions of pear psylla immatures during early season and *Deraeocoris brevis*, earwigs,

and lacewings during mid-season. *Plagiognathous guttatipes* (Uhler) or *Diaphnocoris provancheri* (Burque) dominated effective natural enemy seasonal complexes at each of two mini-orchards.

The functional response to pear psylla eggs was measured for five predaceous mirids. Functional response parameters differed among species and their life-stages, but all destroyed large numbers of psylla eggs.

Further experimental directions for the implementation of pear psylla biological control are proposed. General investigative strategies include: (1) augment natural enemies on non-pear vegetation adjacent to the target orchard, and (2) modify the orchard habitat to both encourage natural enemy colonization and allow permanent complexes of natural enemies to develop. Specific tactics include: plant hedgerows of filbert or willow, cultivate snakeflies, introduce *Anthocoris nemoralis*, adjust early season psylla densities with suitable timing and kind of delayed dormant sprays, using a more effective selective psyllacide, and reduce winter pruning to allow development of natural enemies which overwinter in the egg stage.

The Potential of Endemic Natural Enemies to Suppress Pear Psylla, *Cacopsylla pyricola*
Förster, in the Hood River Valley, Oregon

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THE POTENTIAL OF ENDEMIC NATURAL ENEMIES TO SUPPRESS PEAR PSYLLA, *CACOPSYLLA PYRICOLA* FÖRSTER, IN THE HOOD RIVER VALLEY, OREGON

I. INTRODUCTION

The pear psylla, *Cacopsylla pyricola* Förster, is a pest of considerable economic importance in commercial pear orchards of the Pacific Northwest (Burts 1970, Westigard and Zwick 1972, Wilde and Watson 1963) and California (Bethell and Barnett 1978). Pear psylla nymphs produce honeydew which russets the fruit and lowers its commercial value. Large psylla populations disrupt photosynthesis, cause leaf-drop, and lead to loss of tree vigor (Madsen et al. 1963). Pear psylla can also vector tree diseases such pear decline (Burts 1970) or fireblight (Wilde et al. 1971). This insect is highly dispersive, possesses a high intrinsic rate of natural increase, and has been historically difficult to control (Westigard and Zwick 1972).

Current management strategies for the pear psylla depend mostly upon broad-spectrum insecticides applied according to both seasonal schedules (Fisher et al. 1990) and psylla threshold levels (Burts 1988, Brunner 1981, Westigard et al. 1979). Presently, only a few registered materials are available to effectively suppress populations below economic threshold levels. Pear psylla has developed resistance to many pesticides from several different chemical classes (Westigard and Zwick 1972, Follet et al. 1985) including synthetic pyrethroids (Croft et al. 1989), and shows the potential to develop resistance to currently effective compounds (Van de Baan 1988). Therefore, development of an alternative strategy for pear psylla control is imperative.

Biological control of the pear psylla has most often resulted from endemic natural enemies which colonize orchards from the adjacent vegetation at certain times of the season and in sufficient numbers (Fauvel and Atger 1981, Gut et al. 1982, Herard 1986, Grbic et al. 1988). Control programs featuring chemicals which selectively control major pear pests without eliminating populations of beneficial insects are being implemented in southern Oregon (Westigard et al. 1986), France (Fauvel and Atger 1981), Holland (Van der Blom et al. 1989), and England (Solomon et al. 1989). In the Hood River Valley, the fauna of pear psylla natural enemies and their abundance on non-pear plant hosts has not been thoroughly

documented. Trials featuring both natural enemies and selective chemicals to control the pear psylla have not been evaluated.

The overall goal of this study was to compare and evaluate the potential of endemic natural enemies to control pear psylla in the Hood River Valley. Two studies (Ch. II, Ch. III) were conducted to describe the potential of endemic natural enemies to suppress pear psylla in unsprayed pear orchards of the Hood River Valley as influenced by their abundance on non-pear plant hosts, and to assess their role in selective pest control programs in commercial pear orchards. Successful cases of biological control were identified in both unsprayed and commercial orchards by correlating seasonal dynamics of predaceous arthropods with that of their pear psylla prey. Subsequently, classification techniques were used to compare complexes of natural enemies and their pear psylla prey among Hood River orchards of differing chemical regime, location, age, size, and degree of demonstrated biological control (Ch. IV). Given the large number of species which can prey on pear psylla (Fauvel and Atger 1981, Grbic et al. 1988, Gut et. al 1988), these experimental approaches are both practical and holistic. To compare the ability of particular species to consume pear psylla, functional response experiments measured handling times, search rates, and maximum number of pear psylla eggs attacked per day of five predaceous mirids (Ch. V). Finally, additional tactics to further investigate the implimentation of pear psylla biological control in the Hood River Valley were addressed (Ch. VI).

II. PREDACEOUS AND PARASITIC ARTHROPODS ON PEAR AND NON-PEAR VEGETATION IN THE HOOD RIVER VALLEY AND THEIR RELATIONSHIP TO THE BIOLOGICAL CONTROL OF THE PEAR PSYLLA

Introduction

Recent publications have demonstrated that the vegetational setting strongly influences the development of the orchard arthropod community (Liss et al. 1982, Gut 1985, Gut et al. 1988, Rathman and Brunner 1990) as well as the potential for biological control (Gut et al. 1981, Gut et al. 1982). With regard to the latter, hedgerows of unsprayed young apple trees provide habitat for arthropod generalist predators (Whalon and Croft 1986). Plantings of alternate host-plants of the apple aphid in or near apple orchards may enhance the biological control of that pest (Carroll and Hoyt 1986). The importance of the vegetational setting to pear psylla suppression has been inferred by studies in southern Oregon (Gut et al. 1981, Gut et al. 1982, Gut et al. 1988).

Reports of pear psylla natural enemies in other geographic regions such as Yugoslavia (Grbic et al. 1988), Italy (Briolini et al. 1990), England (Solomon et al. 1989), California (Madsen et al. 1963, Nickel et al. 1965), British Columbia (Wilde and Watson 1963, McMullen and Jong 1967) eastern Washington (Burts 1970, Burts 1971), and southern Oregon (Westgard 1968) include predaceous and parasitic arthropods collected only on pear and provide little information on their occurrence on surrounding vegetation. The only previous study of pear psylla natural enemies in the Hood River Valley (Zwick and Fields 1977) is typical in this respect. In contrast, descriptions of species linked to psylla suppression often list geographic ranges and preferred host plants, but say little about their potential to biologically control the pear psylla (Kelton 1980, Kelton 1982). Only in France has the relationship of natural enemies of *Psylla pyri* L. to alternate prey on non-pear vegetation been fully described (Fauvel and Atger 1981, Herard 1986).

The primary objective of this study was to characterize psylla natural enemies by their diversity and abundance on local vegetation and their ability to immigrate to unsprayed pear and suppress pear psylla. Pear psylla natural enemies and their dominant non-pear hosts have not been thoroughly inventoried for the Hood River Valley. By experimental design,

orchards differed in vegetational setting. By necessity, they also differed in age, size, and time since pesticide applications. The level of biological control was assessed at each site so that the organization of effective and ineffective natural enemy assemblages could be compared in a subsequent analysis (Ch. IV). Because arthropod community organization is a consequence of member life-histories, which include attributes such as trophic level and seasonal behaviors (Liss et al. 1986), the seasonalities of key natural enemies were observed in this study, but are discussed later (Ch. IV).

Materials and Methods

Study sites

Because Hood River County pest regulations require that pear psylla be maintained below damage thresholds in commercial orchards, mini-orchards of small (two year old) trees were planted in 1987 to provide an unsprayed pear habitat for pear psylla and their natural enemies. The mini-orchards were unsprayed, but were substantially smaller and younger than a mature commercial block. To compare mini-orchards with orchards of commercial age and size, a mature pear block was left unsprayed at the Mid Columbia Agricultural Research and Extension Center (MCAREC) during 1988 and 1989. In addition, a commercial planting of four year old trees, the same age as the mini-orchards, was left unsprayed at the Valley Crest site during 1989.

Figure II.1 shows the locations of all study sites. Study sites were located among areas of different vegetational settings. MCAREC is located on the southern edge of the town of Hood River at an elevation of 140 m near the Hood River Gorge. Tracts of mature ponderosa pine/oak/Douglas fir (*Pinus ponderosa*, *Quercus garyana*, *Pseudotsuga menziesii*) are common, but orchards dominate the landscape (Figure II.2). McCarty Orchards are located on the western side of the valley (elevation 240 m) where orchards do not dominate the landscape as extensively as in the central valley and larger stands of mature ponderosa pine and oak are present (Figure II.3). Gale Orchards are located at a slightly higher elevation (200 m) in the central pear growing region where only small pockets of non-pear vegetation, typically wild cherry (*Prunus* spp.), willows (*Salix* spp.), red alder (*Alnus rubra*), native filbert (*Corylus* spp.), and Scotch broom (*Cytisus scoparius*) grow along roadways (Figure II.4). Valley Crest Orchards are located 2 miles south of Parkdale at an elevation of 610 m at the southern edge of the fruit-growing district. Large tracts of mature Douglas fir/ponderosa pine are co-dominated by grand fir (*Abies grandis*) and, with lesser frequency, silver fir (*Abies amabilis*) (Figure II.5). Devil's club (*Oplonanax horridum*) and sword fern (*Polystichum munitum*) dominate the understory.

Three of the four mini-orchards consisted of 30 'Swiss Bartlett' trees purchased as second-leaf trees in 1987. In 1988, the trees were planted in three rows of 10 trees each.

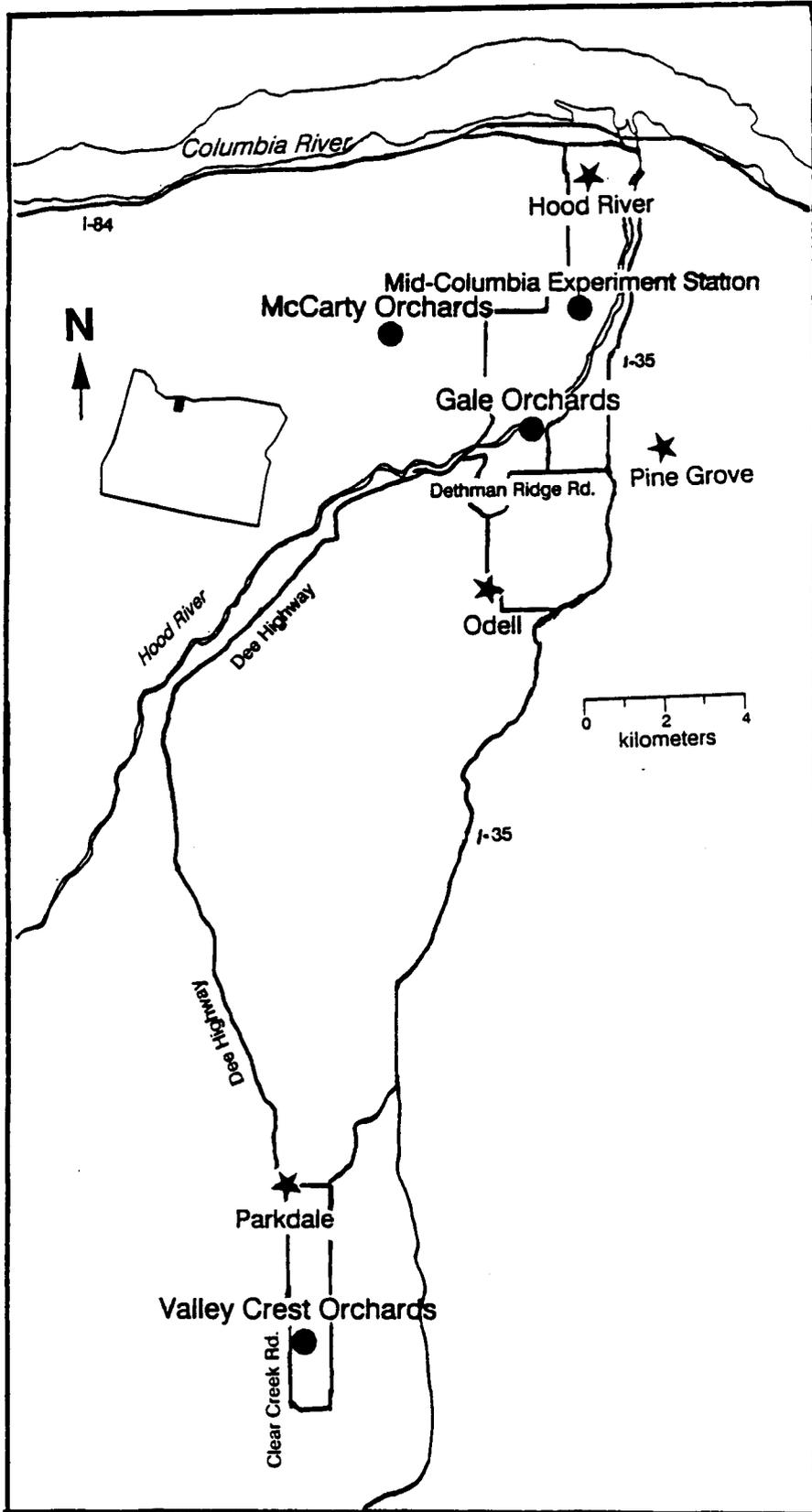


Figure II.1. Locations of unsprayed orchard study sites in the Hood River Valley, Oregon.

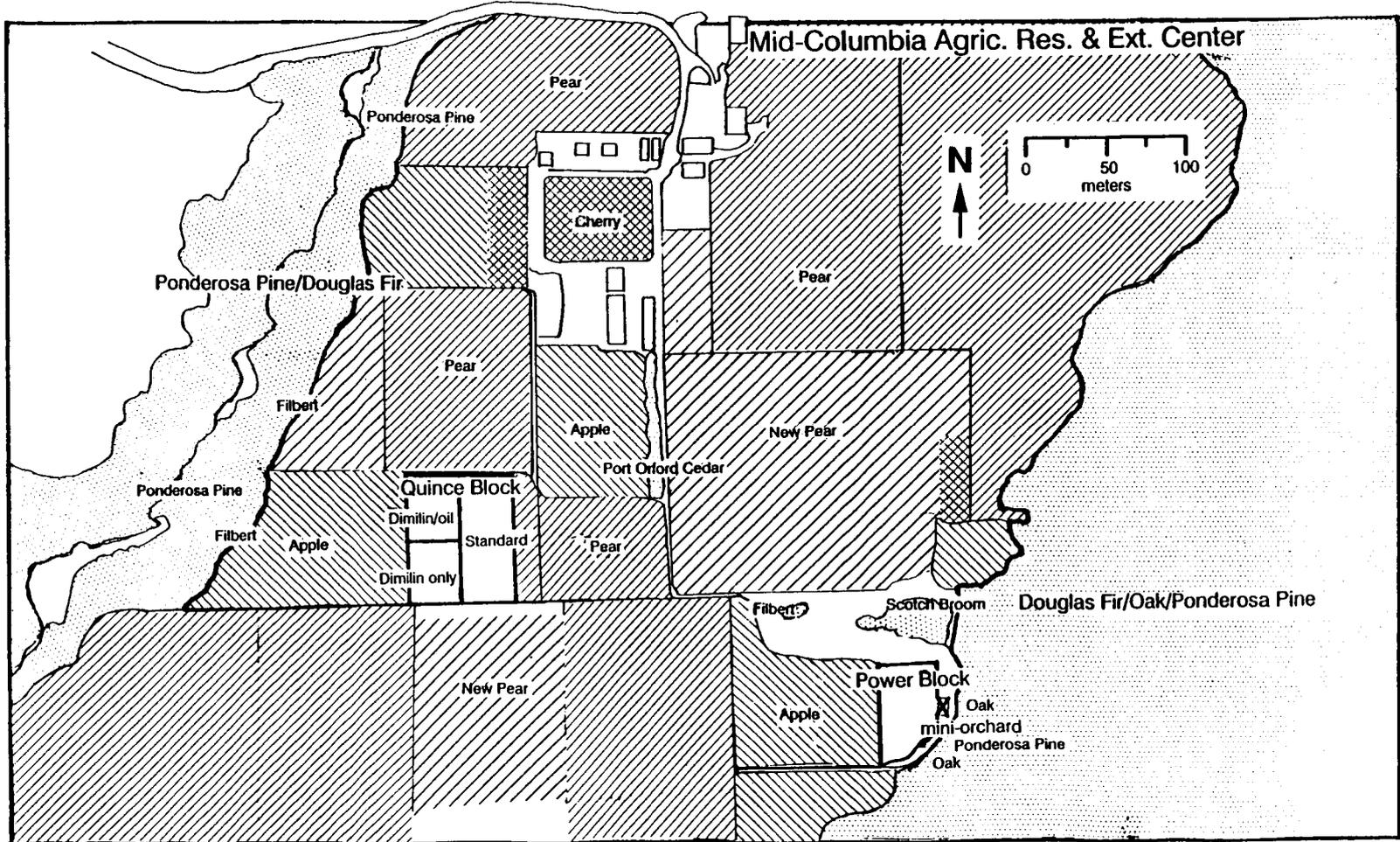


Figure II.2. Vegetational setting and orientation of MCAREC study sites.

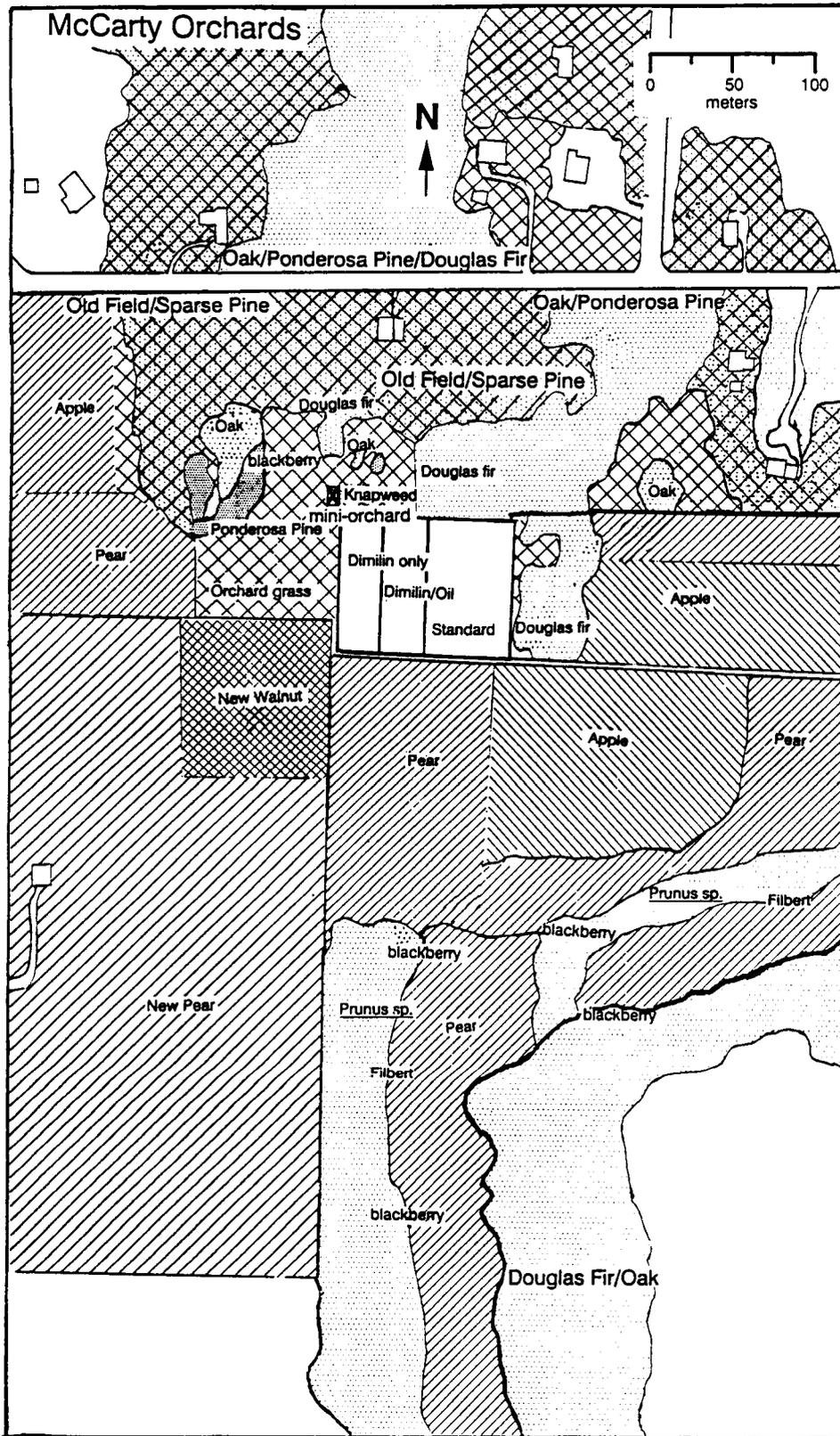


Figure II.3. Vegetational setting and orientation of McCarty study sites.

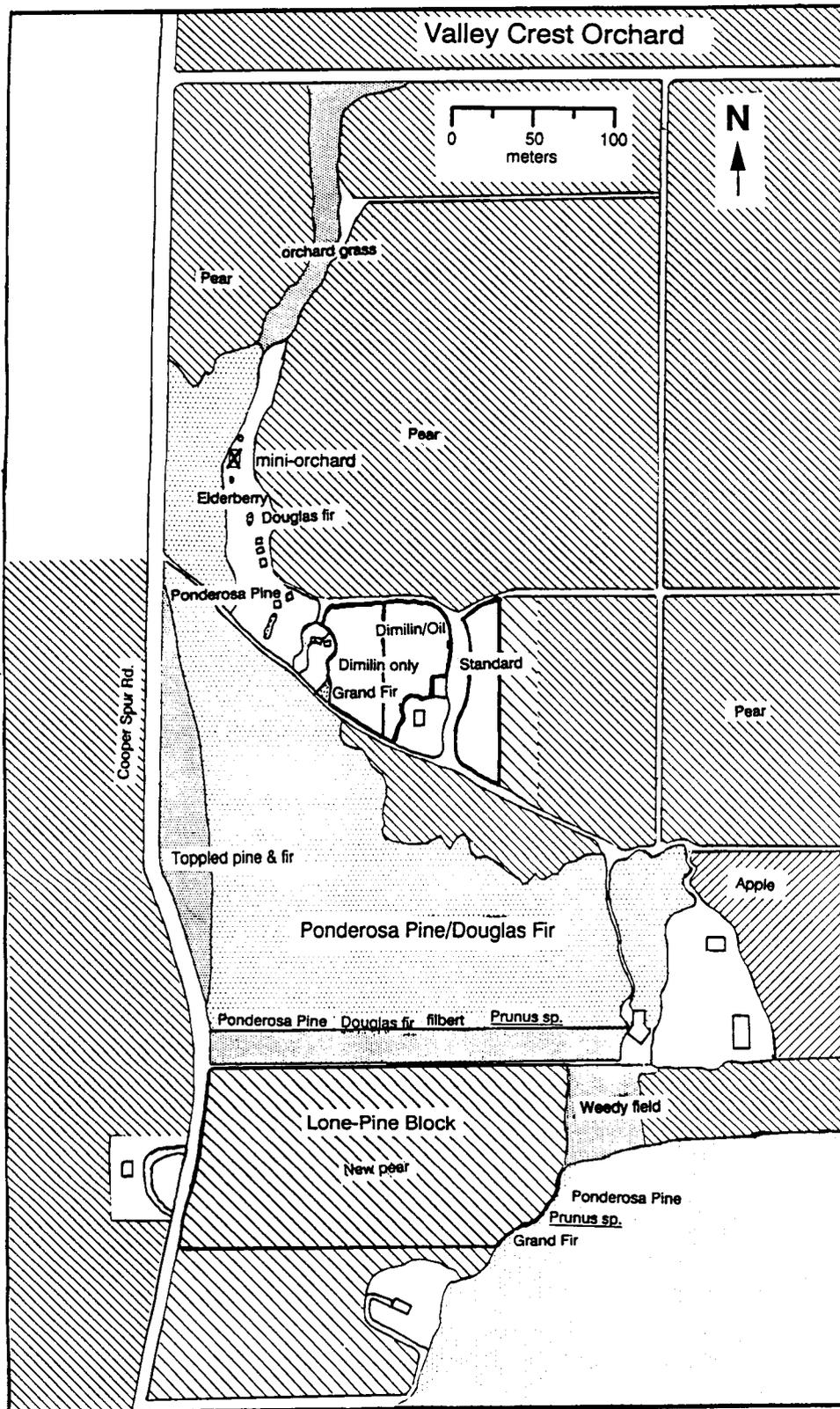


Figure II.4. Vegetational setting and orientation of Valley Crest study sites.

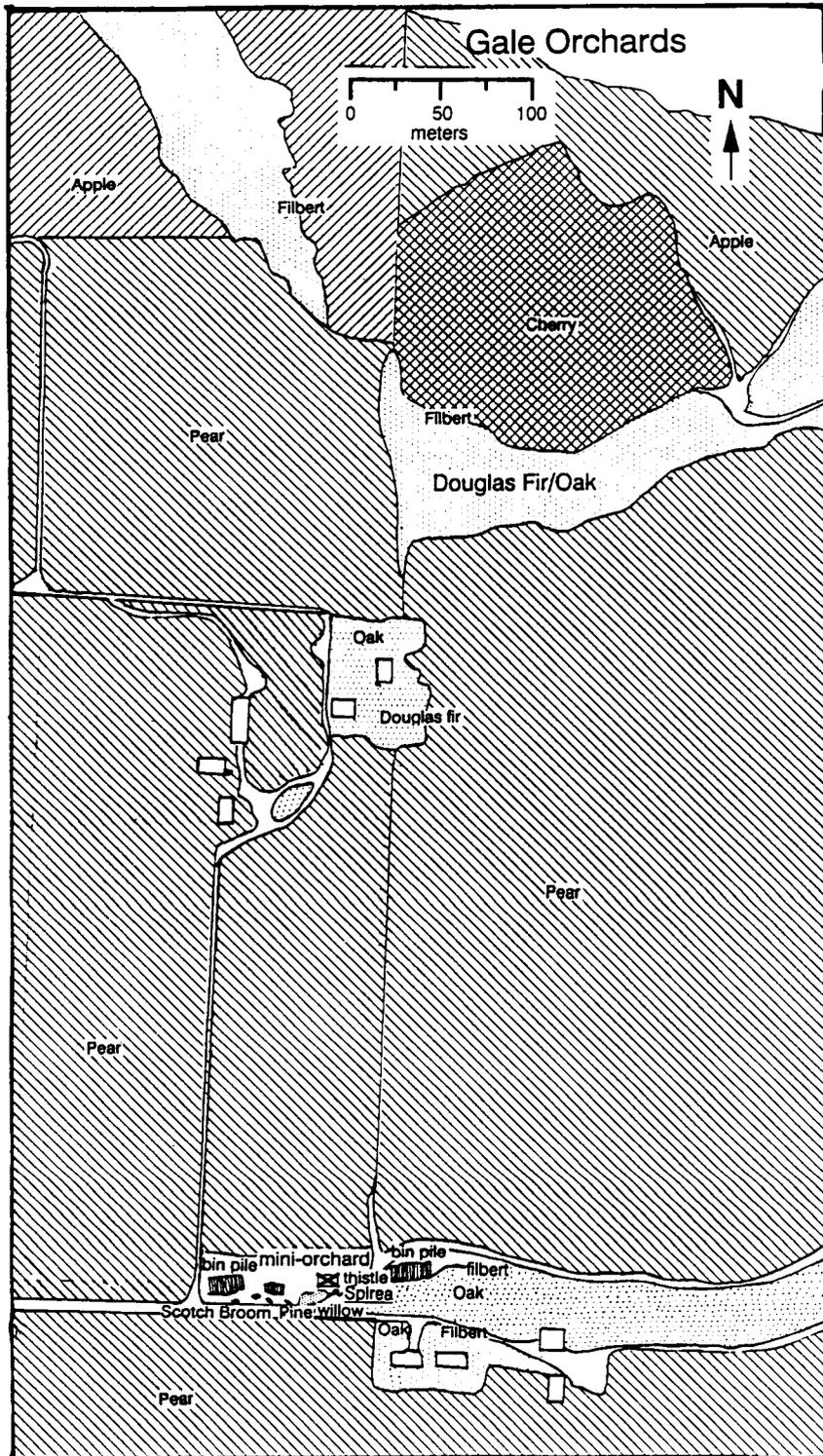


Figure II.5. Vegetational setting and orientation of Gale study sites.

Inter-row and inter-tree distances were 1 m and 0.7 m, respectively. Trees were regularly fertilized and hand-weeded. A fairly dense cover of orchard grass had established between rows by 1989, but inter-tree spaces were bare soil. During the 1987 and 1988 seasons, trees were drenched with 150 gal of water at least twice weekly and showed moderate growth. To increase growth rates, drip irrigation systems were installed at all but the Valley Crest site during spring 1989. Drenching was continued at the Valley Crest site, but the cooperating orchardist also allowed water from the neighboring commercial block to drain to the mini-orchard every 14 days.

The Power Block mini-orchard was located at the MCAREC, between the heavily vegetated Hood River Gorge and a 25 year-old unsprayed pear orchard, the mature Power Block. It consisted of 50 first-leaf 'Bartlett' trees planted in spring 1987. Trees were planted 0.7 m apart with 1.5 m between tree rows. No insecticides were applied from 1987 to 1989, but benomyl was applied during 1989 to prevent mildew infection. Benomyl reportedly has only a slight suppressive effect on beneficial arthropods. Croft (1990) examined 60 records of benomyl effecting predaceous arthropods and derived an average toxicity rating which corresponded to a 10-30% effect. This is substantially lower than values of 90-100% for most insecticides.

Except for the weekly benomyl applications at the Power Block mini-orchard during 1989, no pesticides were applied to the mini-orchards. The Gale mini-orchard was located 75 m and 25 m east and south of commercial pear blocks to avoid spray drift. The McCarty and Valley Crest mini-orchards were closer to frequently sprayed pear blocks but were covered with large plastic sheets during pesticide applications to neighboring blocks.

Power Block (0.17 ha) was planted in 1972 near the southeast corner of the MCAREC and contained 4 rows of 20 'Anjou' trees with a row of 20 'Bartlett' trees in the middle. Experimental chemicals had been applied to selected trees during summer of 1986 and 1987, but no chemicals were applied during 1988. A mildew infection was contracted during 1988, so weekly applications of benomyl were applied from late April until July, 1989. Power Block was not pruned during the three years of study, but was irrigated weekly during the summers. The trees remained vigorous during the 1989 growing season and

showed substantial watershoot growth (Booth, unpublished data). The block was bordered on the north by a deep gully dominated by on the sides by orchard grass and by herbaceous vegetation and immature deciduous trees in the center. To the west, an unsprayed row of mature pears of unidentified root-stock varieties buffered the block from spray drift. About 20 m to the east, Power Block was bordered by a forest community of ponderosa pine, Douglas fir, and oak, which extended along the southeast side.

Lone Pine Block (2.2 ha) at the Valley Crest site was planted with 'Anjou' and 'Red Bartlett' third leaf trees during 1988 on land cleared and fumigated during 1987. By 1989, most trees were at least 2 meters tall. Extensive tracts of mature mostly coniferous forest bordered the northern and southern edges.

The Operational Taxonomic Unit

In these studies (Chs. II, III, IV), natural enemies were classified into operational taxonomic units (OTU) according to taxonomic, developmental, and practical criteria. Different life stages exhibit different stages of seasonal development and predatory behavior. In addition, taxonomic characters of some species are not easily distinguished, especially among juvenile stages. For such groups, several species were often pooled to represent a single OTU. For example, hemerobiid and chrysopid larvae were recorded as lacewing larvae while adults of each family were recorded separately. Adults belonging to the two snakefly families were lumped into the general suborder Raphidioptera. The three most abundant spiders were identified to species, but all others were grouped as other spiders.

Sampling arthropods on pear

In the mini-orchards and at Lone Pine Block, arthropods were sampled every week to ten days from mid-April through August, 1989. During early season, immature psylla were counted on a developing bud collected from each of the 30 trees. After leaf expansion, two leaves were sampled from each of two terminal shoots/tree (120 leaves). One leaf from near the tip of the shoot and one from the lower third of the shoot was picked. Psylla eggs and nymphs, parasitized psylla (mummies), and apterous aphids were counted in the laboratory with the aid of a stereomicroscope. Mites were subsequently removed from one half of the leaves with a brushing machine and counted under a stereomicroscope.

Adult psylla and predaceous arthropods were sampled in the mini-orchards with a modified limb-tap technique (after Burts and Retan 1973). A large (1 m²) beating tray was modified with a cut from the center through the rim. The tray was placed around the trunk at waist height and the upper half of the tree was tapped six times to dislodge arthropods onto the tray. Ten to fifteen randomly selected trees were tapped per visit. Arthropods were replaced on the trees after counting. Observations were conducted during the cooler early morning hours (7 - 9 am), when arthropods were relatively inactive. Mean number of individuals/tray was calculated for each OTU.

At Lone Pine Block, sample trees were randomly selected among the central 16 trees in the east and west half of the block. Pear psylla immatures, mites, psylla mummies, and aphids were sampled with the same procedures as those used in the mini-orchard. During most of the season, two leaves on each of two terminals were sampled from 32 trees (128 leaves), but fewer trees were sampled on the first three sample dates (48, 48 and 80 leaves). Approximately 50 beating tray samples were taken at each visit to monitor adult psylla and predaceous arthropods. In addition, the number of vespid wasps observed per tree during a one minute observation period were recorded for 20 trees on September 6 and September 13.

The mature Power Block was sampled every ten days during 1988 and weekly during 1989. Every other tree was sampled during each sample period, and trees were alternated between samples. Like the young trees, leaves were sampled for immature arthropods by selecting an upper and a lower leaf from two terminals/tree. Psylla nymphs and eggs, mummies, and aphids were counted under a dissecting scope. Beating tray samples were taken from two limbs/tree on every other tree during a sampling period. Mites were monitored by collecting five leaves from a scaffold limb on every other tree. Mites were removed from leaves with a mite-brushing machine and were counted under a dissecting scope. In addition to those in regular leaf samples, pear psylla mummies were periodically collected from leaves sampled at eye level. Pear psylla mummies were placed in gelatin capsules, and reared to emergence under controlled conditions (e.g., 25° C, L:D 16:8).

Sampling arthropods on non-pear vegetation

The dominant non-pear vegetation at each site was sampled at four sites every 10 days to 2 weeks by the beating tray method. At most sites, accessible vegetation was scarce, so only two or three branches per plant were tapped per visit. Time constraints and requirements to disturb the sample branches as little as possible prevented large sample sizes and frequent sampling of all vegetation. Orchard ground cover and surrounding herbaceous vegetation were sampled less frequently with sweep nets. In particular, the knapweed field neighboring the McCarty mini-orchard was sampled twice monthly. As in the pear blocks, most arthropods were identified in the field and returned to the vegetation after counting.

Pear tree vigor

Terminal growth rate, as an indicator of tree vigor, was periodically measured on pear during these studies. Suppressed psylla development on nonvigorous pear trees has been noted by a number of researchers (Burts 1970, McMullen and Jong 1972, Westgard and Zwick 1972, Burts 1970). Because the mini-orchards were substantially younger, and were tended differently than mature commercial blocks, pear tree vigor could have confounded effects of natural enemies on pear psylla development. At each mini-orchard and at Power Block during 1989, the lengths of five terminals on each of ten trees were flagged and periodically measured during the season. The difference in terminal length at the next sampling period was divided by the number of days between sampling dates to give the growth rate in cm/day.

Temperature records

In these studies (Ch. II, Ch. III, Ch. IV), arthropod development was depicted along a seasonal scale of accumulated degree days. This allowed comparisons among orchards of differing location and year. Maximum and minimum daily temperatures for the Quince and McCarty blocks were recorded at MCAREC, which is a NOAA weather station. Temperatures at Valley Crest Orchards were monitored with a hygrothermograph in a standard weather shelter. Because the Valley Crest station was not established until April in 1987 and 1988, early-season temperatures at that site were estimated by linear regression of April degree days at MCAREC and Valley Crest (Table II.1). In 1989, the Valley Crest

station was not established until May, when temperature differences between the two sites may be substantially different than during earlier months. Degree days for February - March, 1989 at the Valley Crest site were estimated by linear regressions of the mean degree days from April 1987 and 1988 at MCAREC and Valley Crest (Table II.1).

Degree days were calculated from daily maximum and minimum temperatures according to the sine wave approximation (Baskerville and Emin 1969). Calculations were based on pear psylla lower and upper thresholds of 42° F and 90° F (Brunner, 1984) accumulated from a biofix corresponding to the first pear psylla egg found during each year. At MCAREC these dates were February 14, 18, and 19 for 1987, 1988, and 1989, respectively (Riedl, unpublished data). At Valley Crest, the first psylla egg was found on February 24 in 1988, the only year a comprehensive survey was conducted at that orchard. Biofix dates at Valley Crest for 1987 and 1989 were estimated as February 20 and February 25, according to the six day delay exhibited in 1988.

Fruit damage

In the mini-orchards, every pear was examined at harvest and the number of pears showing any russet or codling moth damage was recorded. Russeted fruit was also graded according to USDA standards. At the mature Power Block, fruit was sampled at both mid-season and harvest in 1989. In this block, pears were sampled according to a stratified random sampling design. At mid-season (June 28), two pears were removed from the top, middle interior, and lower exterior third of every alternate tree (sample size = 172 pears). At harvest, three pears were picked from each of these sites (sample size was 90 'Bartlett' and 400 'Anjou' pears).

Data analysis

Cases of successful and unsuccessful biological control were determined by a combination of criteria. Foremost, seasonal trends in abundance of pear psylla immatures were compared with those of all natural enemies. Because effects of temperature and pear tree vigor could not be precisely controlled, these factors were also taken into account. The degree of fruit russetting and downgrading at each site provided a final criterion.

Table II.1. Linear regression statistics of the degree days (lower and upper thresholds, 42°F, 90°F, respectively) from the first 15 days of April at MCAREC and Valley Crest for 1987, 1988, and their average. N, number of observations.

Year	Coefficient	Constant	N	r ²
1987	0.563	1.460	15	.377
1988	0.850	2.226	15	.363
Mean	0.641	2.450	15	.318

Results

Predaceous arthropods on unsprayed pear

Table II.2 lists species of pear psylla natural enemies collected on pear in the Hood River Valley 1987-1989 during these and other investigations (Booth unpublished data). Of the 45 species listed in Table II.2, 22 are documented natural enemies of pear psylla and all others except one are described as predaceous or semi-predaceous (Kelton 1980, Kelton 1985). The feeding habits of *Plagiognathous guttatipes* are not well documented (Knight 1917), but conspecifics are predaceous (Kelton 1982) and this species consumed large numbers of pear psylla eggs in the laboratory (Booth, unpublished data).

Seasonal abundance patterns of pear psylla immatures and their natural enemies

Figures II.6 and II.7 show seasonal patterns of natural enemy abundance in relation to pear psylla prey (eggs and nymphs) at the mini-orchards and commercial plantings, respectively. At all sites, peaks in natural enemy abundance always occurred during mid- or late season. In general, density of psylla immatures and abundance and diversity of natural enemies peaked consistently at about 1300 and 2400 accumulated degree days, which correspond roughly to late June and early August. Psylla egg densities best represent these seasonal trends, whereas the dynamics of psylla nymphs and predaceous arthropods were more variable. Seasonal patterns of natural enemies often resembled, but lagged behind, seasonal patterns of psylla abundance. At the McCarty mini-orchard, Power Block mini-orchard, and mature Power Block, seasonal fluctuations of natural enemies corresponded with fluctuations in psylla eggs rather than nymphs.

In addition, seasonal abundances of psylla natural enemies varied among sites (Figures II.6, II.7). Numbers were relatively low throughout the season at Gale mini-orchard, Valley Crest mini-orchard, and Lone Pine Block. At the McCarty mini-orchard, natural enemies were more abundant during early season, but numbers gradually declined during mid- and late season. The opposite trend occurred at the Power Block sites. The mature Power Block had the most arthropod generalist predators, especially during late season 1989.

Figure II.8 shows seasonal abundances of the nymphal and adult life-stage(s) of the dominant mirid generalist predators at Power Block during 1989. Voltinism, overwintering

Table II.2. Beneficial arthropods collected on pear in the Hood River Valley, 1987-89. Letters inside parentheses indicate lifestage collected (A, adults; J, juveniles. Asterisk indicates specimens tentatively identified awaiting confirmation.

Araneida	Neuroptera
Thomisidae (A,J)	Chrysopidae
Lycosidae	<i>Chrysopa nigricornis</i> Burmeister (A)
sp. 1 (A,J)	<i>Chrysoperla carnea</i> (Stephens) (A)
Salticidae	<i>Meleoma dolichartha</i> (Navas) (A)
<i>Metaphidippus</i> sp. 1 (A,J)	chrysopid spp. (J)
salticid sp. 2 (A,J)	Hemerobiidae
Clubionidae	<i>H. humulinus</i> L. (A)
sp. 1 (A,J)	<i>H. neadelphus</i> Gurney (A)
Dermaptera	<i>H. stigma</i> Stephens (A)
Forficulidae	<i>Micromus variolosus</i> Hagen (A)
<i>Forficula auricularia</i> L. (A,J)	<i>Hemerobius</i> sp.1 (A)
Hemiptera	<i>Hemerobius</i> spp. (J)
Nabidae	Raphidiodea
<i>Nabis alternatus</i> Parshly (A,J)	Raphidiidae
Anthocoridae	<i>Agulla</i> spp. (A)
<i>Anthocoris antevolens</i> White (A,J)	Inocelliidae
<i>Orius tricolor</i> (White) (A,J)	<i>Inocellia</i> spp. (A)
<i>O. minutus</i> (Linnaeus) (A,J)	Coleoptera
Miridae	Cantharidae
Mirinae	<i>Podabrus pruinosus</i> LeConte (A)
<i>Phytocoris fraterculus</i> Van Duzee (A)	<i>P. piniphilis</i> Dejean (A)
<i>P. jucundus</i> Van Duzee (A)	Coccinellidae
<i>P. dimitatus</i> Kirschbaum (A)	<i>Coccinella transfugatus</i> (Casey) (A)
<i>P. conspuricatus</i> grp. (A)	<i>Coccinella sempactata</i> L. (A)
<i>Phytocoris</i> spp. (J)	<i>Stethorus</i> sp. (A,J)
Orthotylinae	Diptera
<i>Heterotoma meriopterum</i> (Scopoli) (A,J)	Asilidae
<i>Paraproba nigrinervis</i> Van Duzee (A,J)	asilid spp. (A)
<i>Diaphnocoris provancheri</i> (Burque) (A,J)	Syrphidae
<i>Ceratocapsus pilosulus</i> Knight (A)	syrphid spp. (A)
Pilophorini	Hymenoptera
<i>Pilophorus perplexus</i> Douglas & Scott (A,J)	Vespidae
Phylinae	vespid spp. (A)
<i>Plagiognathous guttatipes</i> (Uhler) (A,J)	Encyrtidae
<i>P. fuscus</i> (Provancher) (A)	<i>Trechnites insidiosus</i> (Crawford) (A)
<i>P. chrysanthemi</i> (Wolff) (A)	<i>Prionomitus mitratus</i> (Dalm.) (A,J)*
Deraeocorinae	<i>Aphidencyrtus</i> spp. (A,J)*
<i>Deraeocoris brevis</i> (Uhler) (A,J)	Pteromalidae
<i>D. incertus</i> Knight (A,J)	<i>Pachyneuron</i> sp. (A,J)*
<i>D. fasciolus</i> Knight (A,J)	
<i>D. fusifrons</i> Knight (A)	
<i>D. rubroclarus</i> Knight (A)	
Dicyphinae	
<i>Campyloneura virgula</i> (Herrick-Schaeffer) (A,J)	

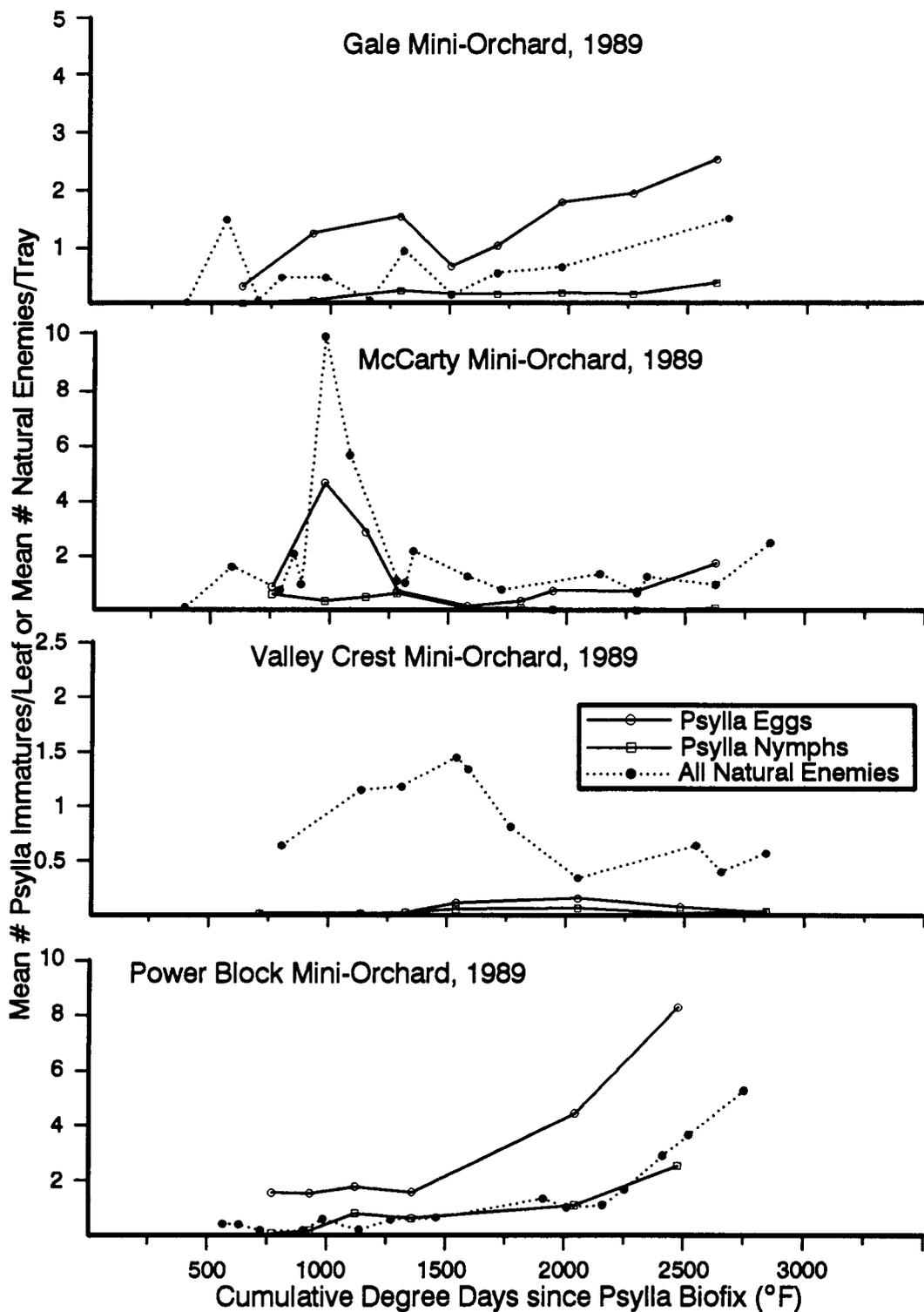


Figure II.6. Natural enemy/pear psylla seasonal dynamics at four unsprayed mini-orchards in the Hood River Valley.

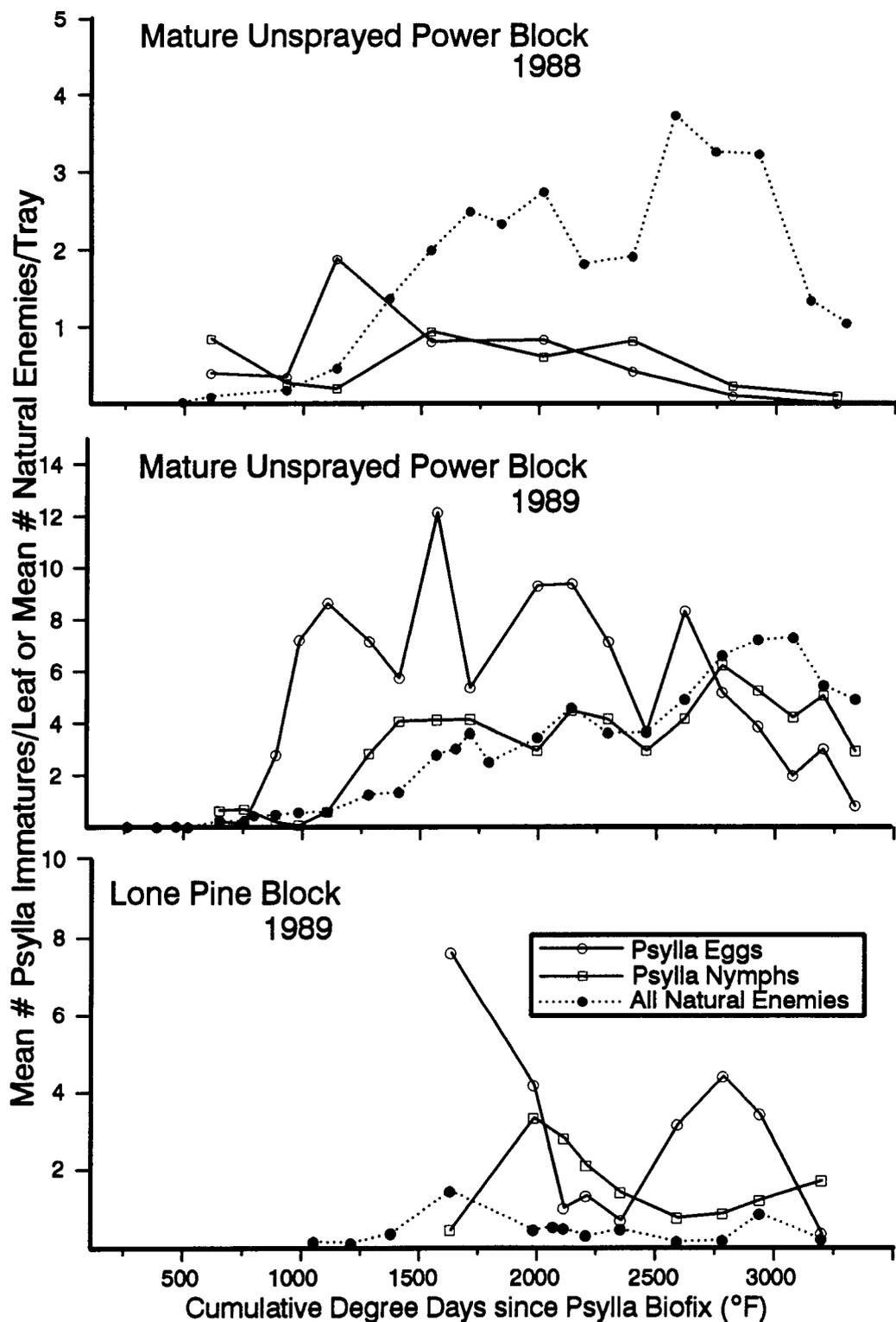


Figure II.7. Natural enemy/pear psylla seasonal dynamics at the mature unsprayed Power Block during 1988, 1989 and at the large commercial planting, Lone Pine Block during 1989.

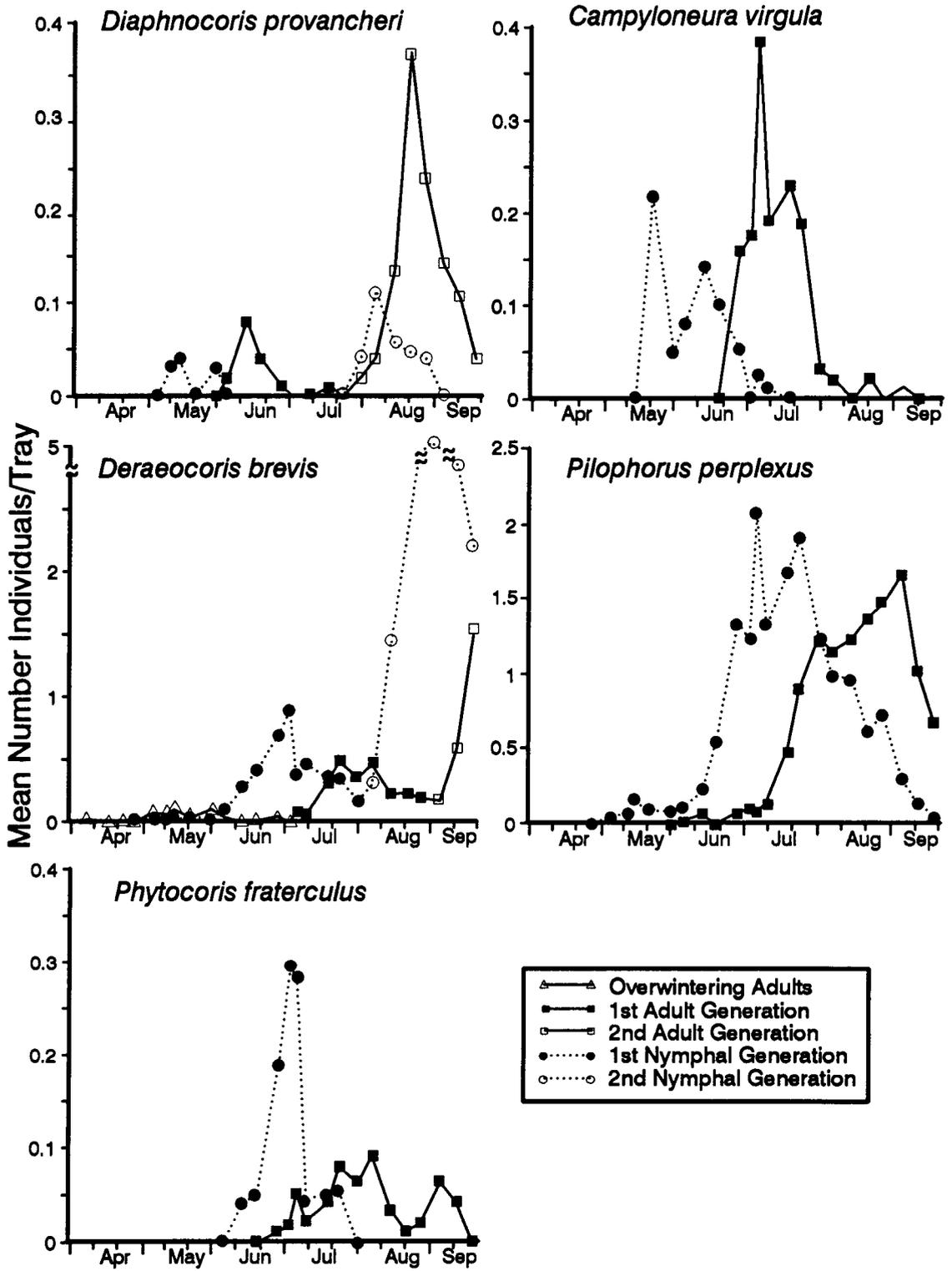


Figure II.8. Seasonality of five abundant predaceous mirids at the mature unsprayed Power Block, 1989.

life stage, and the magnitude and timing of abundance peaks varied considerably among species. Both *P. fraterculus* and *C. virgula* peaked in abundance during late June, whereas the other three species did not peak in abundance until mid- or late August.

Percent parasitism cannot be precisely calculated from these data. Parasitoid impact on host population dynamics is difficult to assess, especially when host mortality is life-stage specific (Van Driesche et al. 1990). Such is the case with *T. insidiosus*, which parasitizes mostly the fourth and fifth instars of *C. pyricola* (Unruh, unpublished data).

The initial peak in mummy density at most sites reflects a strong synchrony between *T. insidiosus* and pear psylla (Figure II.9). This peak was probably present, but not observed at Lone Pine Block because early season leaf samples were not taken. Parasitoids may have had a substantial impact on psylla population development at Lone Pine Block, where high late season mummy density was correlated with a substantial decline in nymphal psylla densities. Parasitoids apparently had less of an impact on psylla development at other sites.

The encyrtid *Trechnites insidiosus* accounted for 70% and 38% of the parasitoids which emerged from mummies collected at Power Block and Lone Pine Block, respectively (Table II.3). Seasonal differences in species composition of the parasitoid guild at Power Block are apparent, as *T. insidiosus* was less dominant during late season. Of the parasitoids reared from psylla, only *T. insidiosus* is a documented primary parasitoid of *C. pyricola* (Jensen 1957, Gutierrez 1965). The *Aphidencyrtus* sp. (det T. Unruh), and cynipid and pteromalid species are obligate secondary parasitoids (Gutierrez 1965). Results indicate that most primary parasitism was by *T. insidiosus*, but proportions were obscured by secondary parasitism. A large proportion of the mummies collected from both Power Block and Lone Pine block failed to emerge, with the proportion increasing as the season progressed.

Arthropod generalist predators on non-pear vegetation and immigration to unsprayed pear

Figures II.10 through II.13 show the abundance of selected predators on both pear and non-pear hosts at each site. Based on these abundance samples, most predaceous arthropods did not readily immigrate to unsprayed pear, regardless of site.

The most abundant generalist predators at the McCarty site, *P. guttatipes*, *D. provancheri*, and *D. brevis*, were sampled mostly on garry oak (Figure II.10). Lacewings,

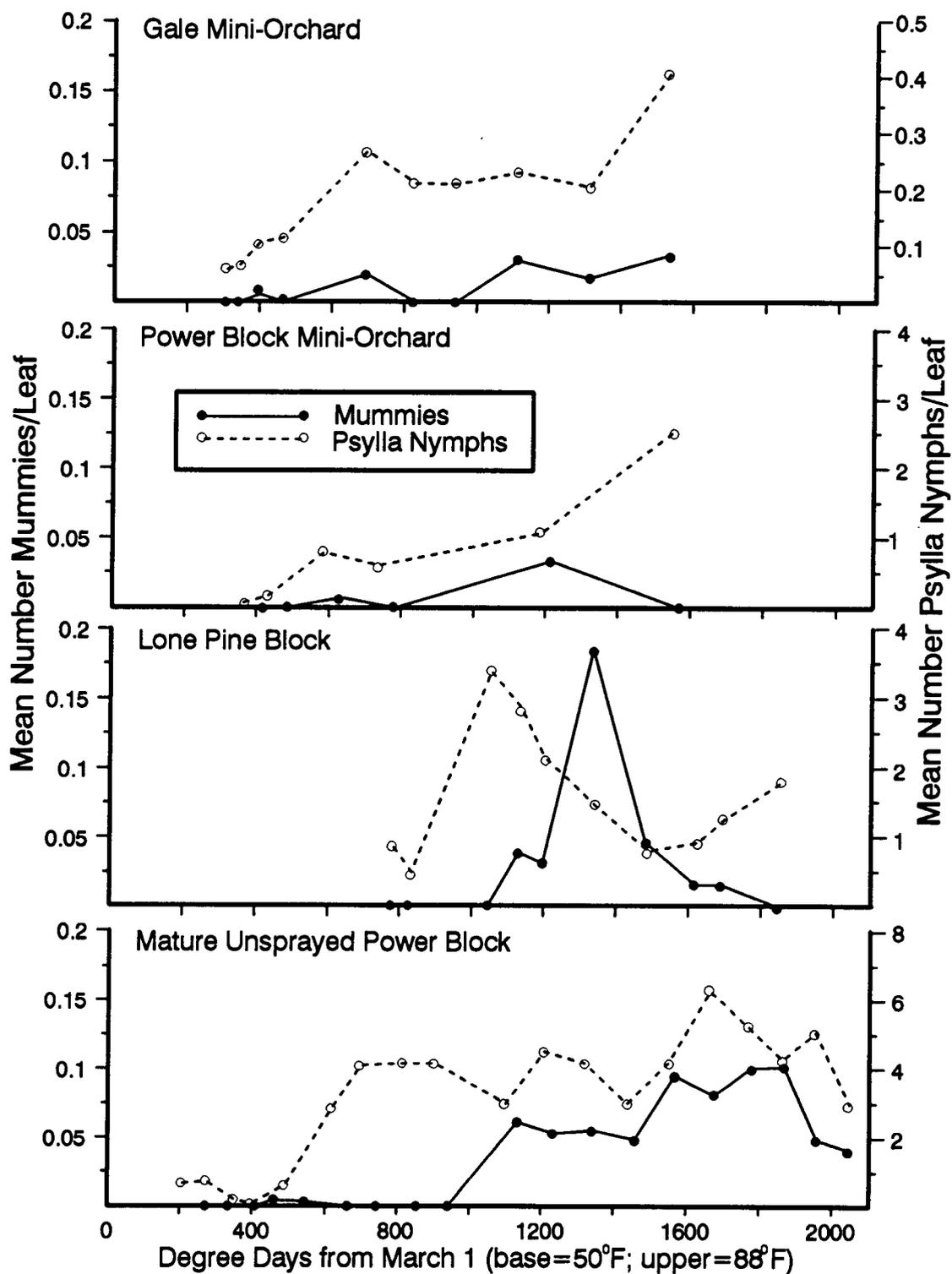


Figure II.9. Parasitoid/psylla seasonal dynamics at four unsprayed orchards in the Hood River Valley, 1989.

Table II.3. Percentage parasitoid emergence from parasitized psylla nymphs (mummies) at two unsprayed pear orchards in the Hood River Valley, 1989. N, number individuals collected.

Orchard	Date	N	<i>T. insidiosus</i>	Cynipid sp.	Pteromalid sp.	<i>Aphidencyrtus</i> sp.	unknown sp.	unemerged
Lone Pine Block	26 Jul	18	56	17	2	0	0	28
	11 Aug	25	20	4	0	0	0	76
	24 Aug	72	13	49	0	26	0	23
Power Block 1989	12 Jun	68	47	11	1	0	0	50
	19 Jun	75	51	3	0	0	16	31
	20 Jul	61	59	16	0	0	2	23
	24 Jul	31	29	19	0	0	6	42
	4 Aug	58	43	17	0	0	12	28
	16 Aug	23	52	35	0	0	0	13
	21 Aug	84	50	12	0	0	0	38
	28 Aug	52	25	8	12	0	0	56
	5 Sep	32	9	13	0	0	0	78
15 Sep	57	4	9	0	0	0	84	

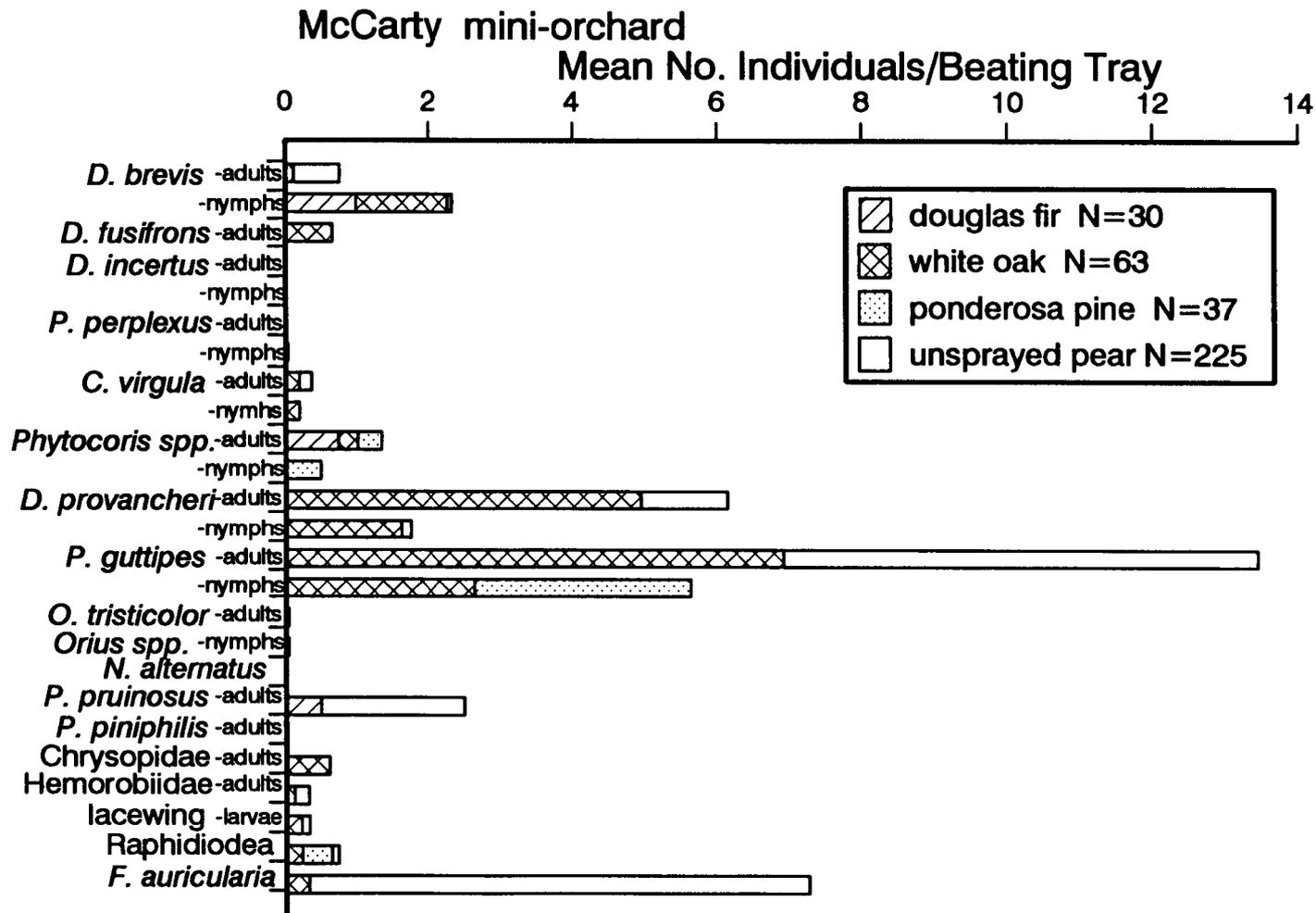


Figure II.10 Mean abundance of 25 natural enemies of the pear psylla sampled on the unsprayed pear mini-orchard and three adjacent non-pear hosts at the McCarty site, 1989. N, number of beating tray samples.

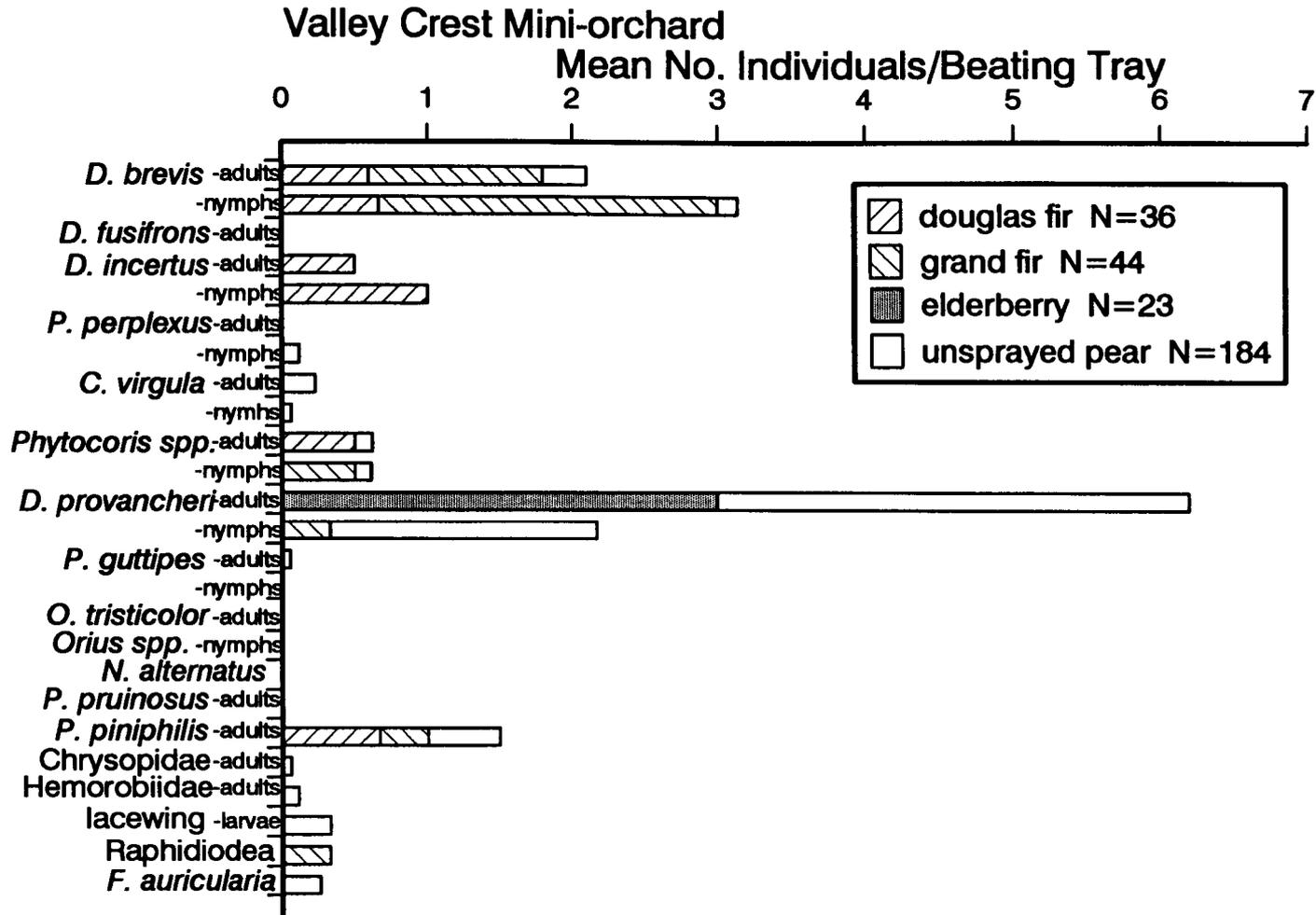


Figure II.11. Mean abundance of 25 natural enemies of the pear psylla sampled on the unsprayed pear mini-orchard and three adjacent non-pear hosts adjacent to the Valley Crest mini-orchard, 1989. N, number of beating tray samples.

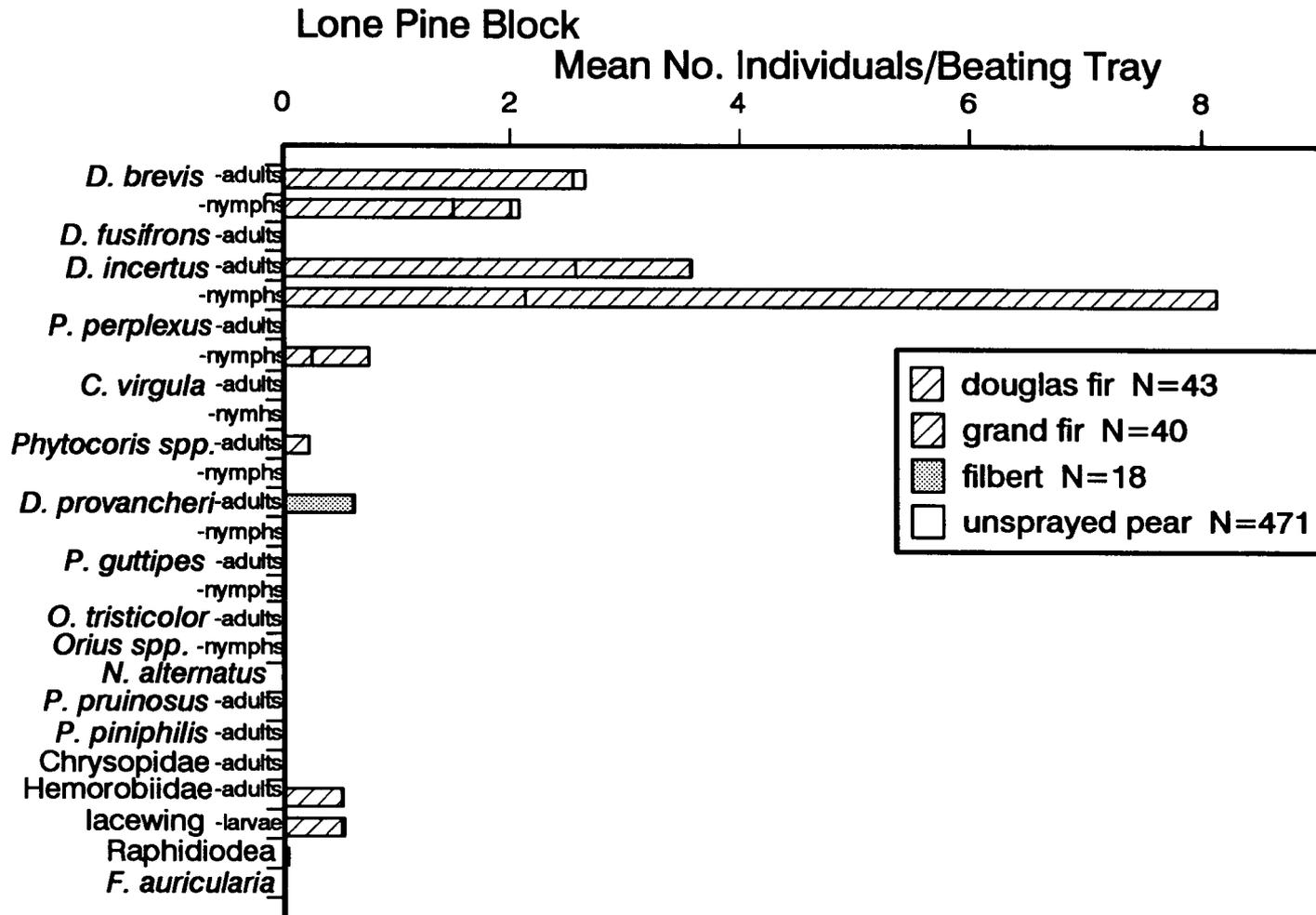


Figure II.12. Mean abundance of 25 natural enemies of the pear psylla sampled on young commercial pear planting, Lone Pine Block and three adjacent non-pear hosts at the Valley Crest site, 1989. N, number of beating tray samples.

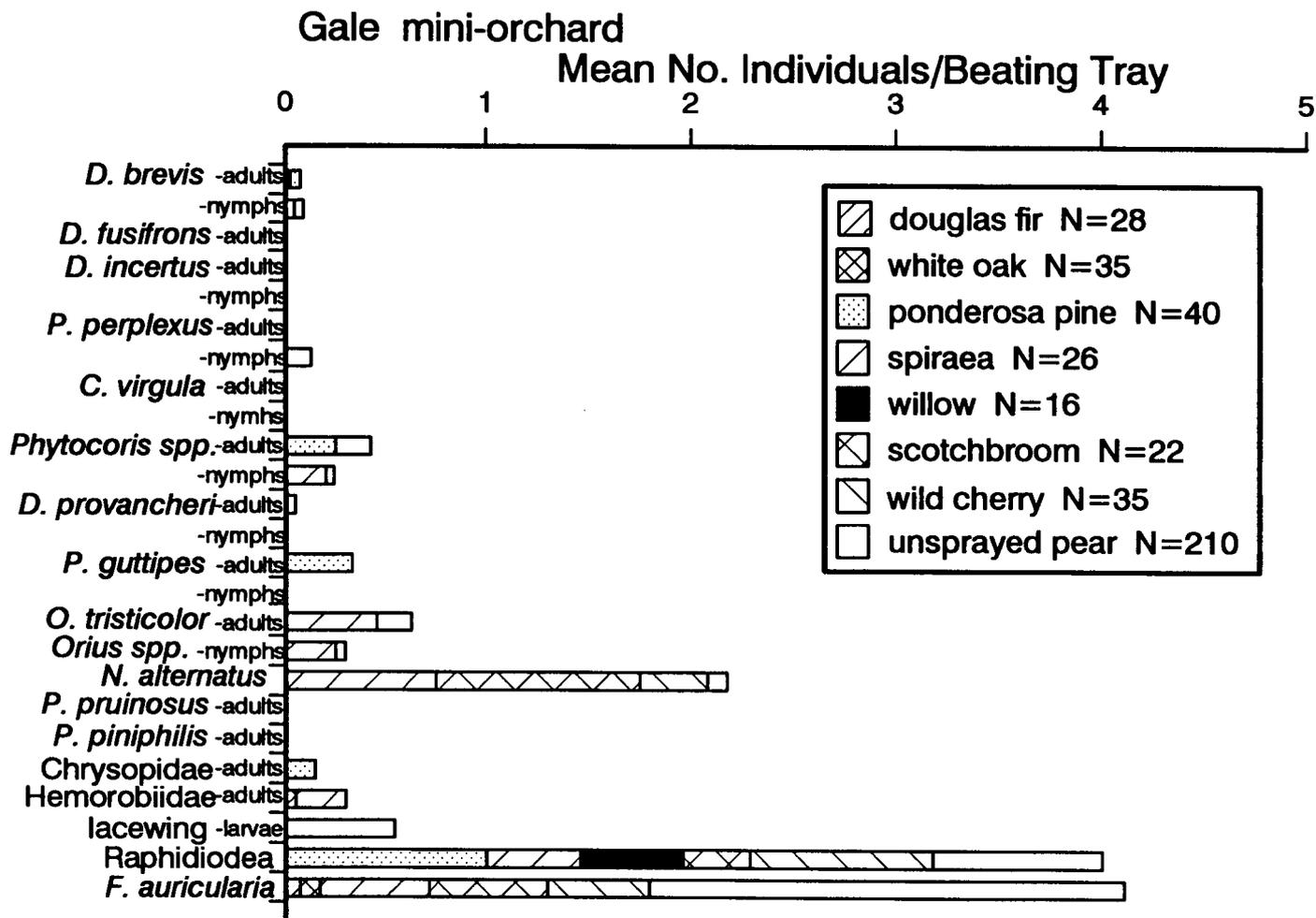


Figure II.13. Mean abundance of 25 natural enemies of the pear psylla sampled on the unsprayed mini-orchard and eight adjacent non-pear hosts at the Gale site, 1989. N, number of beating tray samples.

snakeflies, and *P. corticevivens* were sampled on ponderosa pine. Although adults of these species were also found in mini-orchard, *P. guttatipes* and the *Phytocoris fraterculus* apparently failed to reproduce there, as only adults were sampled. However, *D. provancheri* probably did reproduce in the mini-orchard, as seasonal patterns of adult and immature life stages resembled those observed in the mature Power Block (Figure II.8). Although small numbers of *P. pruinosis* adults were sampled at the McCarty site, the majority of them were found on the mini-orchard during early season.

Most psylla natural enemies at both Valley Crest sites were associated with Douglas fir and grand fir, although *D. provancheri* was found on both native filbert, and elderberry (Figures II.12, II.13). This species was found in the mini-orchard and on Douglas fir, where it apparently reproduced. Douglas fir and grand fir, hosted four species of predaceous mirids which were dominated by *D. incertus* and *D. brevis*. Accordingly, of these two species readily colonized Lone Pine Block despite ample representation in the surrounding vegetation (Figure II.12). Overlapping seasonalities of these two species at Lone Pine Block offered an opportunity to suppress psylla in sequence. *Deraeocoris incertus* was sampled in mid- and late- nymphal stages during early June while first generation *D. brevis* nymphs were still quite young. Nymphs of *D. incertus* were not sampled past early-July, indicating that this species was univoltine at Lone Pine Block. Nymphs of *D. brevis* matured quickly and adults were present by late July, followed by a second nymphal generation.

At the Gale site, both earwigs and snakeflies were found on a variety of non-pear hosts which included both trees and shrubs (Figure II.13). The third most abundant species, *N. alternatus*, was sampled on scotchbroom, spiraea, and wild cherry more often than pear. Other natural enemies were much less abundant.

Fruit damage

Percentage downgraded pears was unacceptable at all but the McCarty, Valley Crest, and Power Block mini-orchards, with the latter site showing a substantially higher percentage of #1s (Table II.4). At the mature Power Block, the percentage of downgraded fruit increased substantially after June. Damage was low at Lone Pine Block (Euwer personal communication). Codling moth infestation was zero at all sites.

Table II.4. Percent psylla russeted pears per USDA grade at five unsprayed mini-orchards and one mature unsprayed orchard in the Hood River Valley, 1989. Total downgraded are combined #2 and culls. N, sample size.

Orchard	Variety	Sample Date	Percent Russeted Pears				Total Downgraded
			N	#1	#2	Cull	
Gale - mini	'Bartlett'	24 Aug	40	7.5	5.0	2.5	7.5
McCarty - mini	'Bartlett'	24 Aug	81	3.0	0	0	0
Valley Crest - mini	'Bartlett'	7 Sep	47	2.0	0	0	0
Power Block - mini	'Bartlett'	29 Aug	28	28.6	0	0	0
Power Block - mature	'Bartlett'	28 Jun	60	20.0	8.0	8.0	16.0
	'Anjou'	28 Jun	240	9.5	5.5	3.0	8.5
	'Bartlett'	23 Aug	90	10.0	22.2	56.6	78.8
	'Anjou'	11 Sep	400	24.5	32.0	38.8	70.8

Mites and aphids on unsprayed pear

In this study, aphids and mites never reached high enough densities to suppress tree vigor and fruit quality. Their potential as alternate prey for arthropod generalist predators confounded the effects of natural enemies on pear psylla only at Lone Pine Block, where aphid densities rivaled those of the pear psylla during early season. According to criteria listed by Bethell and Barnett (1978), phytophagous mites remained at "very light" densities at all but the Gale mini-orchard (Table II.5). Both European red mites and pear rust mites reached light to moderate levels in this mini-orchard, but bronzing or loss of tree vigor was not observed. At the Valley Crest mini-orchard, pear rust mites increased dramatically during June, but declined just as sharply during July.

Aphid densities were low in the mini-orchards, especially during early season (Table II.7). At the mature Power Block, aphid densities remained low throughout 1988 and early 1989, but increased dramatically albeit briefly during mid-season 1989 (Table II.8). Aphid densities were highest at Lone Pine Block (Table II.8).

Although predatory mites (*Metaseilus* and *Typhlodromous* spp.) were present at most sites, (Table II.6) densities were too low to suppress phytophagous mites. Higher numbers were sampled in July at Gale and may have prevented a late season twospotted mite outbreak.

Pear tree growth rates

Pear tree growth rates were highest during early-season at all orchards, but usually slowed substantially by mid-July (Table II.8). An exception was the Gale mini-orchard, where growth rate levelled off after an early season flush but then remained high. Terminal growth rates were not measured at Lone Pine Block, but field notes indicated an early-season flush of growth, followed by substantially slower rates during August.

During 1988, the mature Power Block became heavily infected with mildew. In addition, the block, usually irrigated on a weekly schedule, was not watered for two weeks during mid-July. Unfortunately, terminal spurs were not measured during 1988, so the effect on psylla development can only be estimated. Leaves sampled for immature psylla were not abnormally hard until mid-July, but the growth of new foliage was especially low during early July.

Table II.5. Density of twospotted spider mites, (TSSM)¹, European red mites (ERM), pear rust mites (PRM), their phytoseiid predators (Pred.) and the predator/prey ratio² at five unsprayed orchards in the Hood River Valley, 1989. N, number of leaves sampled/date.

Orchard	Date	N	Mean number/10 leaves				
			TSSM	ERM	PRM	Pred.	Ratio
Gale	8 May	30	0	2.7	3.3	0	0
	13 May	90	0	0.4	15.4	0	0
	20 May	90	0	0.4	72.2	0	0
	31 May	120	0	7.3	38.3	0	0.3
	16 Jun	180	0	1.3	75.0	0.4	0.1
	27 Jun	90	0	1.6	77.8	1.1	1.8
	19 Jul	90	0.4	4.4	4.4	8.9	0.6
	16 Aug	90	0.9	0.4	18.9	0.9	0
McCarty	15 May	90	0	0	41.1	0	0
	22 May	117	0	0.3	--	0	0
	1 Jun	120	0	0	35.8	0	0
	14 Jun	90	0.4	0	24.4	0	0
	30 Jun	150	0	0	198.0	0	0
	12 Jul	150	0	0	2.0	0	0
	1 Aug	90	0	0	0	0	0
	15 Aug	90	0	0	0	0	0
Valley Crest	12 May	135	0	0	0	0	0
	7 Jun	90	0	0	160.0	0	0
	16 Jun	90	0	0	210.0	0	0
	27 Jun	90	0.4	0	1250.0	0	0
	21 Jul	90	0	0	51.1	0	0
	8 Aug	90	0	0	0	0	0
	24 Aug	90	0	0	0	0	0
Power Block - mini-	1 Jun	150	0	0	20.7	0	0
	11 Jun	75	0	0	22.7	0	0
	25 Jul	75	0.5	1.6	293.0	0	0
	18 Aug	75	0	0	1.3	2.1	0
Power Block	13 May	150	0	0.8	14.7	0.1	0.2
	31 May	150	0	0.3	0.7	0	0
	13 Jun	150	0	0	10.0	0	0
	29 Jun	150	0.3	0	32.7	0	0

¹ Spider mite complex was comprised mostly of the twospotted spider mite, *T. urticae* with some McDaniel mites, *T. mcdanieli*.

² Pred./(TSSM+ERM)

Table II.6. Mean density of aphid nymphs per ten leaves at four unsprayed mini-orchards in the Hood River Valley, 1989. N, number of leaves sampled/date.

Orchard	Date	N	Mean Number of Aphids/10 leaves
Gale	8 May	60	0
	13 May	120	0
	20 May	120	0
	31 May	180	0
	16 Jun	114	0
	27 Jun	120	0
	7 Jul	115	0.8
	19 Jul	180	0.2
	1 Aug	120	0
	16 Aug	110	0
	McCarty	15 May	104
22 May		174	0
1 Jun		174	0
8 Jun		174	0
14 Jun		116	0
30 Jun		114	0
11 Jul		114	0.1
17 Jul		116	0.1
1 Aug		116	0
15 Aug		112	0
Valley Crest		12 May	135
	7 Jun	120	0
	16 Jun	120	0
	27 Jun	120	0
	21 Jul	120	0.1
	8 Aug	120	0
	24 Aug	120	0
Power Block - mini-	23 May	100	0
	1 Jun	180	0
	11 Jun	90	
	23 Jun	100	0
	25 Jul	90	1.0
	18 Aug	90	0.1

Table II.7 Mean density of aphid nymphs per ten leaves at three unsprayed orchards in the Hood River Valley. N, number of leaves sampled/date.

Orchard/Year	Sample Date	N	Mean number aphids/10 leaves
Power Block 1988	5 May	400	0
	25 May	360	0.1
	11 Jun	300	0
	30 Jun	300	0
	22 Jul	300	0.2
	7 Aug	300	0.3
	26 Aug	300	0.5
	16 Sep	300	0.2
Power Block 1989	4 May	200	0
	10 May	200	0
	21 May	300	0
	30 May	450	0
	4 Jun	333	0
	12 Jun	300	0.2
	19 Jun	200	0
	26 Jun	200	0.5
	5 Jul	140	13.5
	17 Jul	200	14.0
	24 Jul	200	0.1
	31 Jul	200	0
	7 Aug	200	0
	14 Aug	300	0
	21 Aug	200	0
	28 Aug	200	0
	5 Sep	300	0.1
11 Sep	300	0.3	
18 Sep	300	0.1	
Lone Pine Block 1989	30 Jun	48	0
	5 Jul	48	0
	21 Jul	80	0.5
	28 Jul	128	0.4
	3 Aug	128	0.2
	11 Aug	128	0.1
	24 Aug	128	0.3
	6 Sep	128	0
12 Sep	128	3.0	

Table II.8. Terminal growth rates (mean cm/day \pm standard deviation) at four mini-orchards and the mature unsprayed Power Block in the Hood River Valley, 1989. Sample size = 50 terminals/orchard/date.

Gale mini-		McCarty mini-		Valley Crest mini-		Power Block mini-		mature Power Block	
Date	X \pm SD	Date	X \pm SD	Date	X \pm SD	Date	X \pm SD	Date	X \pm SD
22 May	.42 \pm .44	19 Jun	.18 \pm .21	5 Jun	.39 \pm .45	12 Jun	.38 \pm .51	12 Jun	.44 \pm .66
29 May	.48 \pm .48	24 Jul	.05 \pm .22	12 Jun	.34 \pm .62	19 Jun	.09 \pm .37	26 Jun	.46 \pm .71
5 Jun	.55 \pm .71	4 Sep	.35 \pm .15	26 Jun	.15 \pm .38	10 Jul	.16 \pm .45	4 Sep	.06 \pm .16
17 Jul	.77 \pm .68			11 Sep	.02 \pm .10	4 Sep	.17 \pm .45		
21 Aug	.43 \pm .67								

Willett (1981) measured growth rate terminal shoots at two mature 'Bartlett' orchards near Pullman, Washington. Spur growth rates peaked at 0.42 cm/day and 0.25 cm/day during June and May, respectively. Growth declined to less than 0.1 cm/day by mid-July. Although Hood River trees were measured less frequently and sample sizes were smaller than those of the Pullman study, trends and magnitudes of terminal growth rate were similar. Trees remained vigorous and new leaves continued to be produced in all blocks except the 1988 Power Block. Therefore, one can conclude that factors other than declining tree vigor caused the observed reduction in decline in psylla density.

Maximum daily temperatures

Figure II.14 shows the maximum daily temperatures at MCAREC during 1988 and 1989 and at Valley Crest during 1989. While temperatures occasionally exceeded 90° F, the upper threshold for psylla development (Brunner 1984), at the MCAREC during 1988, they rarely did so at either site during 1989.

Incidence of biological control of pear psylla on unsprayed pear

Successful biological control of pear psylla by endemic natural enemies varied among the study orchards. Natural enemies had the strongest impact at the McCarty mini-orchard, where high psylla densities declined during early season and psylla russet was low. At the mature Power Block, natural enemies failed to maintain psylla below acceptable damage levels, but may have suppressed psylla during late season of both years. Natural enemy impact was more moderate, seasonally variable, and difficult to discern at the remaining three sites. Natural enemies appeared to be more effective at the Valley Crest mini-orchard.

At the Gale mini-orchard, natural enemies apparently failed to maintain psylla below damage levels, as psylla russet was unacceptably high. Compared to the other mini-orchards, natural enemies were fewer than one individual/tray for a longer portion of the growing season. However, both snakeflies and the parasitoid *T. insidiosus* were moderately abundant during early-season suppressed psylla nymphal development to some degree.

However, density of psylla nymphs at Gale was probably higher than indicated. The discrepancy between low psylla nymphal density (Figure II.6) and high russet marking (Table II.4) mostly likely resulted from sampling deficiencies. Leaf samples comprised equal

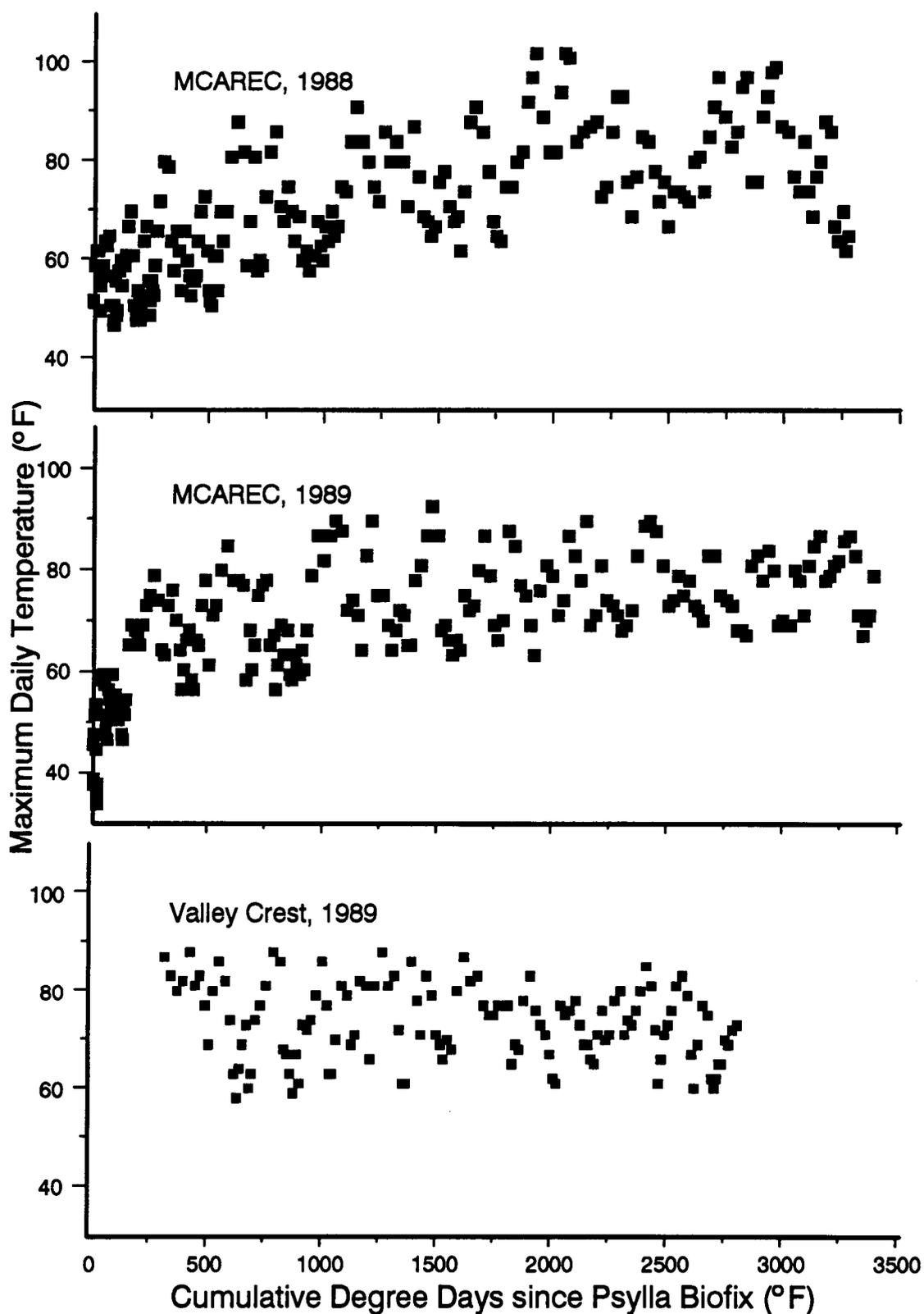


Figure II.14. Maximum daily temperatures from psylla biofix until October at MCAREC during 1988 and 1989 and at Valley Crest Orchards during 1989.

proportions of old and new leaves and so may have under represented the actual proportion of recent foliage in the mini-orchard, thus under-estimating psylla density. Given the relatively high terminal growth rates at Gale (Table II.8), this explanation seems plausible. This argument is tempered somewhat by the high numbers of psylla eggs sampled. Because adult female psylla prefer to oviposit on younger pear leaves (Horton 1990), egg counts would be expected to be lower if recent foliage was under represented in the samples.

Of the mini-orchards, McCarty had the most natural enemies, especially during early-season (Figure II.6). Psylla declined abruptly following an early-season peak in natural enemy abundance and remained below damage thresholds for the season's duration. Tree vigor, as indicated by terminal growth rates (Table II.8), declined somewhat during mid-season and may have partially slowed psylla development, but growth was certainly sufficient to allow substantially greater psylla development than that observed. Negligible psylla russetting (Table II.4) confirmed that psylla was adequately suppressed.

Numbers of generalist predators at the Valley Crest mini-orchard were the second lowest of the young orchards (Figure II.6). The few early-season generalist predators were present before any psylla were sampled and apparently suppressed any further psylla nymphal development. Psylla remained at low densities throughout the season at this site and the percentage of damaged fruit was negligible (Table II.4). Although terminal growth rate declined during the season (Table II.8), the leaves remained succulent and the trees were vigorous enough to support larger psylla populations.

At the Power Block mini-orchard, early-season counts of predaceous arthropods were low, but numbers rose substantially during late season (Figure II.6). Immature psylla densities rose steadily, surpassing damage thresholds by early-June. Although russet damage remained within USDA standards for economic downgrading, a large percentage of pears were slightly russeted (Table II.4). The degree of pear psylla biological control at this site was marginal.

At Lone Pine Block, natural enemies were never very abundant and also declined during mid-season (Figure II.7). Although pears were not graded for russet in this block, damage was low (Euwer, personal communication). Vespid wasps were also abundant during

late season (1.5 wasps/tree/minute on September 6 and 2.5 wasps/tree/minute on September 13) and these may have suppressed pear psylla. The mid-season decline in psylla densities at Lone Pine Block was well synchronized with decreasing foliar development and higher rates of parasitism (Figure II.9).

Natural enemies failed to effectively suppress pear psylla during both years at the mature Power Block. During 1988, immature psylla densities declined substantially during late-season (Figure II.7), most likely as a result of a mildew infection, high temperatures, and natural enemies. High temperatures during mid-season may also have contributed some psylla suppression. During 1989, psylla egg densities increased both earlier in the season and reached higher densities than at any of the other unsprayed orchard (Figure II.7). Nymphal psylla counts also rapidly increased during early-season and remained above damage threshold levels until late-season. Despite a relatively abundant and diverse assemblage of generalist predators during late season, the fruit was severely russeted by mid-season.

Discussion

Distribution of pear psylla natural enemies

Some psylla natural enemies are reportedly common in other pear growing regions of the Pacific Northwest but are not present in the Hood River Valley. *Anthocoris nemoralis* (F.) and *A. nemorum* (L.) are among the more important psylla natural enemies in Europe (Anderson 1962a, Atger and Fauvel 1981, Herard and Chen 1986). These species were introduced to the Okanagan Valley of British Columbia and the Yakima Valley of Washington State in 1963 (McMullen and Jong 1967) where they successfully established (Beirne and Fields 1973), but have not been documented in the Hood River Valley (Table II.2, Zwick and Fields 1977) or southern Oregon (Gut 1985). *Campylomma verbasci* (Meyer), an important natural enemy in British Columbian pear orchards (Edwards et al. 1991), has been previously documented in the Hood River Valley (Zwick and Fields 1977), but was not found in these studies (Table II.2). The three parasitoids reared from Hood River psylla (Table II.2) constitute a subset of more lengthy lists of psylla parasitoids from other pear growing regions (Jensen 1957, Westigard 1979, Herard 1985, Herard 1986, Grbic et al. 1988).

Some predaceous insects collected in Hood River pear orchards have not been previously reported as preying on pear psylla. These include *Plagiognathous* spp. and all *Deraeocoris* species except *D. brevis*. These species are predaceous and distributed in other parts of the Pacific Northwest (Kelton 1980, Kelton 1982, Razafimahatratra 1981). Several of the latter, notably *D. incertus* is present in British Columbia pear orchards managed under "soft" programs of pest control (Booth, unpublished data).

Many psylla natural enemies important in other pear growing regions of the Pacific Northwest are also common in the Hood River Valley. Of these, *D. brevis* is most often cited as a key predator of pear psylla (Westigard 1973, Zwick and Fields 1977, Lucius 1989, Burts 1970). *Campyloneura virgula* effectively suppressed pear psylla in orchards near Vancouver, Washington (Nelson 1985). Other predators common to most of the Northwest include *D. provancheri* (Burque) (McMullen and Jong 1967), the anthocorids *A. antevolens*, *A. melanocerus*, and *O. tristicolor* (Anderson 1962b, Fields and Beirne 1973), as well as chrysopid, cantherid, coccinellid, and encyrtid species (Gut 1985, Zwick and Fields 1977).

Despite the broad distribution of many species, local distribution and abundance of psylla natural enemies varied within the Hood River Valley (Figures II.11--II.12). In the case of *O. minutus*, distribution may be presently limited to lower elevations due to this species' recent introduction to the valley (Lattin et al. 1989). For most other taxa, occurrence was strongly influenced by the vegetational setting.

Species pool effects

The importance of the surrounding vegetation on the development of orchard arthropod communities has recently been documented for both pear (Gut 1985, Gut et al. 1988) and apple (Rathman 1988, Rathman and Brunner 1990). The concept of the species pool as the source of a community's "capacity for development" (Liss et al. 1986) provided the theoretical framework for those studies. The species pool has been defined as the "system" (Liss et al. 1986) or "spatio-temporal mosaic" (Gut et al. 1990) of arthropod communities that "contribute colonists to the developing community", but at other times is equated with vegetational setting (Gut et al. 1988). Rathman and Brunner (1990) gave some empirical substance to the species pool concept when they reported that arthropod communities on young apple orchards and the surrounding vegetation comprised similar percentages of arthropod orders. Notwithstanding the somewhat ambiguous definition and the lack of empirical tests, the species pool concept of arthropod community development is relevant to the development of the guild of psylla natural enemies.

The importance of the vegetational setting to successful psylla biological control has been demonstrated in southern Oregon (Liss et al. 1982, Gut et al. 1982, Gut et al. 1988), but particular non-pear hosts were not described. After two years, psylla were lower in mini-orchards of unsprayed pear grown in a mixed agricultural setting rather than a commercial setting (Gut et al. 1988). When mature unsprayed and commercial orchards were compared, an early season complex of natural enemies differed taxonomically and was more effective than a complex of natural enemies which invaded orchards later in the season (Gut et al. 1982). Although specific interactions were not detailed, orchards invaded by early season predators were located among a mosaic of non-cultivated communities which differed from the vegetational setting of orchards where biological control was less successful.

Species pool effects on the biological control of the pear psylla, *Psylla pyri* (L.), have been described in France, where natural enemies develop on vegetation surrounding orchards, chiefly hawthorn and nettle (Herard 1985, Herard 1986). Primary prey on hawthorn include a complex of four psyllids, *Psylla pyrisuga* Förster, *P. peregrina* Förster, *P. melaneura* Förster, and *P. crataegi* Shrank, all of which are univoltine and develop on hawthorn during early season (Fauvel and Atger 1981). A psyllid *Trioza urticae* L., an aphid *Microlophium evansi* (Theobald), and two cicadellids, *Eupteryx urticae* (F.) and *E. aurata* (L.) are present on nettle all summer (Herard 1985). An assemblage of 56 psylla natural enemies disperse from these and other hosts into pear orchards according to overlapping seasonalities so that control is effected throughout the growing season (Herard 1986).

In addition to the previously described faunal differences, psylla natural enemies occupied different non-pear hosts in Hood River compared to France. Hawthorn was eliminated from the Hood River Valley in the early 1980s to slow establishment of the apple maggot. Nettle is not abundant near most orchards. At Lone Pine Block, large numbers of aphids, scales, and chermids were present on grand fir throughout the growing season. Few prey were found on willow in the Hood River Valley (Booth, unpublished data) which may account for low abundances of *Anthocoris antevolens*, which aggregates on willow to feed on aphids and psyllids (Anderson 1962b). Native filbert is distributed throughout the Hood River Valley, but was common among these study sites only near Lone Pine Block (Booth, unpublished data).

The importance of species pools of arthropod generalist predators to successful biological control was demonstrated at some sites in the Hood River Valley. At the McCarty mini-orchard, the close proximity of two mature oak trees and associated natural enemies, particularly *P. guttatipes* and *P. pruinosis*, contributed to successful early season psylla suppression. In contrast, natural enemies were less abundant and less effective at the Gale site where non-pear vegetation was scarce and primarily herbaceous.

In both Europe and the Pacific Northwest, the majority of psylla natural enemies are mostly arboreal mirids. When the natural enemy fauna on pear, hawthorn, and nettle were compared in France, only one of 12 mirids (*Heterotoma meriopterum*) was occasionally

sampled on nettle (Herard 1986). In Canada, Kelton (1982) identified 47 predaceous mirids residing on 24 native and cultivated fruit trees. In the Hood River Valley, both oak and native filbert trees hosted several predaceous mirids (Figures II.11--II.15, Booth unpublished data). An inventory of the predaceous arthropod fauna on filbert in the Willamette Valley (Messing and AliNiazee 1985) resembles Table II.2.

Theoretically, trees support a more diverse and abundant arthropod fauna than shrubs, weeds or grasses due to greater architectural complexity, niche availability (Lawton and Schröder 1978, Strong 1979), greater 'apparency' (Feeny 1976), and longer life-span (Southwood 1978). Many predaceous mirids reside on deciduous trees year round with the majority overwintering as eggs inserted into recent twig growth (Kelton 1982). *Deraeocoris brevis* overwinters as adults inside bark crevices on oak, pine, and several other tree species (Westgard 1973, Razafimahatratra 1981). The anthocorids *A. antevolens* and *O. munitus* overwinter chiefly as fertilized females on trees (Anderson 1962b, Collyer 1953, Booth unpublished data).

Psylla natural enemies more commonly associated with herbaceous vegetation were not as abundant on unsprayed pear. *Orius tristicolor* is commonly found on a wide range of flowering herbaceous plants (Anderson 1962b), supplements its diet with pollen (Barber 1936), but was a relatively unimportant natural enemy of the pear psylla in these studies (Ch. II, III). Nabids are frequently found in grass (Slater and Baranowski, 1978) but were associated with scotchbroom at the Gale site (Figure II.13). Snakeflies, (*Agulla* spp.) which develop as larvae in rotting wood (Woglum and McGregor 1958), presumably emerged from the piles of rotting limb props and bins near the Gale mini-orchard. Snakefly adults were sampled on many hosts at the McCarty and Gale sites (Figures II.10, II.13).

The variability of natural enemy/host plant associations among the study sites (Figures II.10--II.13) emphasizes the complex interactions which lead to successful psylla biological control by endemic natural enemies. For example, dissimilar abundances on pear and non-pear hosts indicate that natural enemies do not immigrate to orchards in direct proportion to their abundance in the surrounding vegetation. For example, *D. incertus* and *D. brevis* remained on coniferous hosts which were highly infested with potential prey.

In addition, seasonal dynamics of natural enemies and pear psylla immatures tend to support conclusions of other investigations (Ch. III, Westgard et al. 1986, Gut et al. 1982) that late-season psylla populations are best suppressed when natural enemy levels are high during early season. The McCarty mini-orchard in particular demonstrates the early season dynamics of effective pear psylla biological control. Low natural enemy abundance during early season at the Power Block sites resulted in ineffective biological control despite high late season levels of natural enemies. Natural enemies also peaked during early season at the Valley Crest mini-orchard.

Although the "capacity" for the development of arthropod communities on agricultural crops may reside in the species pool, the organization and structure of the crop community are also important (Liss et al. 1986). Arthropod community organization is partially a consequence of member life-histories, which include attributes such seasonal behaviors and trophic level (Liss et al. 1986). Hence, overwintering strategies, voltinism, and the placement and magnitude of abundance peaks contribute to the efficacy of biological control agents (Luff 1983). Effects of the orchard community structure and natural enemy seasonality on the potential of pear psylla biological control are discussed in greater detail elsewhere (Ch. IV).

III. SELECTIVE CONTROL OF THE PEAR PEST COMPLEX IN COMMERCIAL ORCHARDS OF THE HOOD RIVER VALLEY

Introduction

In Hood River orchards, programs to control pear pests rely on broad-spectrum pesticides. The codling moth (CM), *Cydia pomonella* is the key pest but has been successfully controlled by the broad-spectrum organophosphates (OPs) azinphosmethyl (Guthion[®], Mobay Chemical Corp.) and phosmet (Imidan[®], ICI Americas) applied as three cover sprays per year according to a degree-day schedule (Fisher et al. 1990). The organotin fenbutatin-oxide (Vendex, DuPont Chemical Co.) is most often applied to control phytophagous mites, but the development of resistant populations increasingly limits its effectiveness (Croft et al. 1989). Current tactics to control the pear psylla, *Cacopsylla pyricola*, are primarily chemical. They include applications of dormant oils, pre-bloom sprays of synthetic pyrethroids (Pydrin[®], Shell Chemical Co.) against overwintering adults, and foliar sprays of amitraz (Mitac[®], Nor-Am Chemical Co.) or abamectin (Agri-Mek[®], Merck, Sharp & Dome) applied when psylla exceed action threshold levels (Westigard et al. 1979). Due to intensive insecticide use, the pear psylla has developed resistance to chemicals from several different classes (Follet et al. 1985, Van de Baan 1988, Croft et al. 1989).

The incorporation of natural enemies as part of pest control programs is one tactic to slow resistance development (Croft 1990). Although considered selective in Europe (Solomon et al. 1989), Amitraz is disruptive to many pear psylla natural enemies (Burts 1983, Westigard et al. 1986, Solomon et al. 1989). Abamectin shows some selectivity toward anthocorids (Undurraga and Dybas 1990), but is registered for use in the Hood River area only under an emergency exemption. Programs featuring the insect growth regulator diflubenzuron (Dimilin[®], Uniroyal Chemical Co.) have been studied in greater detail in other pear growing areas of the Pacific Northwest (Westigard et al. 1986, Burts 1983), and in England (Solomon et al. 1989). Diflubenzuron suppresses codling moth egg development while allowing many pear psylla natural enemies to survive (Hoying and Riedl 1980). Diflubenzuron-based programs of pear pest control have not been extensively tested in the Hood River Valley.

The primary goal of this study was to compare a selective diflubenzuron-based program of pear pest control with the standard chemical-based program. The study focused on the role of predaceous and parasitic arthropods to survive and provide a degree of biological control. Incidence of biological control was assessed at each site so that the relative abundances and effectiveness of particular natural enemies could be compared in a subsequent analysis (Ch IV).

Materials and Methods

Study Sites

The three commercial orchards selected as study sites were located at different elevations and in different vegetational settings of the Hood River Valley (Figure III.1). Detailed descriptions of the surrounding vegetation, both cultivated and non-cultivated, are presented elsewhere (Ch. II). Figures III.2--III.5 show the physical orientation of the experimental blocks at each commercial orchard study site. One half of each experimental block was managed by the grower according to standard pest management practices. The selective programs, diflubenzuron alone and diflubenzuron with oil, were applied to equal-sized portions of the other half. All blocks were irrigated and fertilized according to standard practices. Blocks consisted primarily of 'Anjou' variety pears, although some 'Bartlett' were present as pollenizers. Because Hood River County pest control regulations require psylla be maintained below damage thresholds in commercial orchards, blocks could not be left unsprayed to provide untreated check plots for comparison.

The 0.81 ha Quince block at the Mid-Columbia Research and Extension Center (MCAREC) (elevation 140 m) comprised eleven rows of 'Anjou' pears interspersed with four 'Bartlett' and two 'Bosc' rows. Similarly aged pear blocks managed with standard chemical control practices were located on the east and north sides, while new pear plantings bordered the block to the south. A block of mature 'Newtown' apples bordered the selective blocks on the west. The closest uncultivated vegetation bordered a small creek 100-125 m to the west and was dominated by ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziessi*), grand fir (*Abies grandis*), and native filbert (*Corylus* spp.).

McCarty was a 0.61 ha block (elevation 240 m) block consisted of 16 interplanted rows of 'Bartlett', 'Anjou', and 'Bosc' pears. The block was bordered on the south by a similar block of pears under standard chemical control. To the east, a band of Douglas fir, garry oak (*Quercus garyana*), and pine approximately 30 m wide separated the standard block from a 0.81 ha block of 'Newtown' apples managed according to standard practices. To the west, an open field of infrequently mowed orchard grass bordered the diflubenzuron only block. A stand of mature Douglas fir with a sparse grass ground cover bordered the

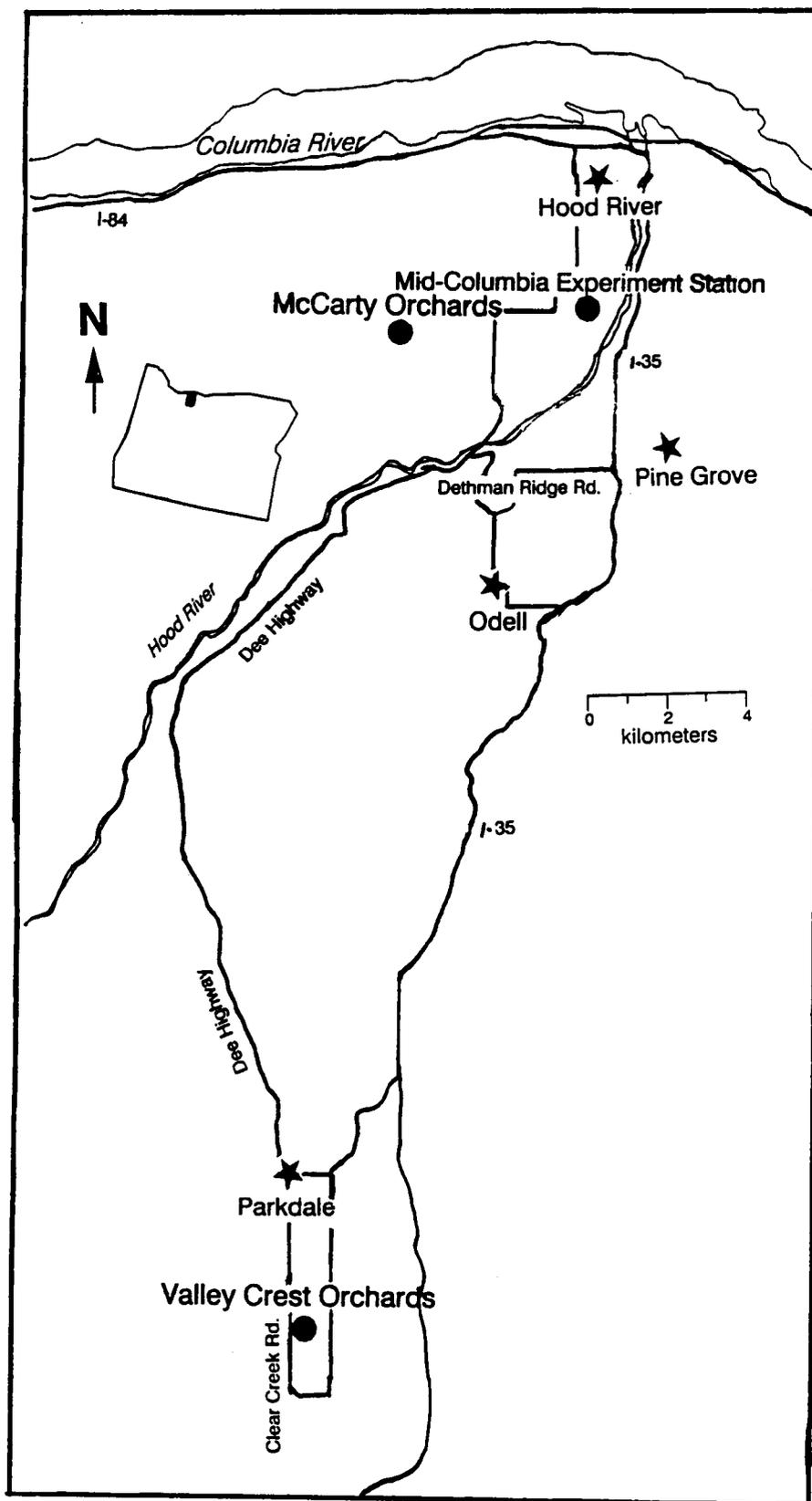


Figure III.1. Locations of commercial orchard study sites in the Hood River Valley, Oregon.

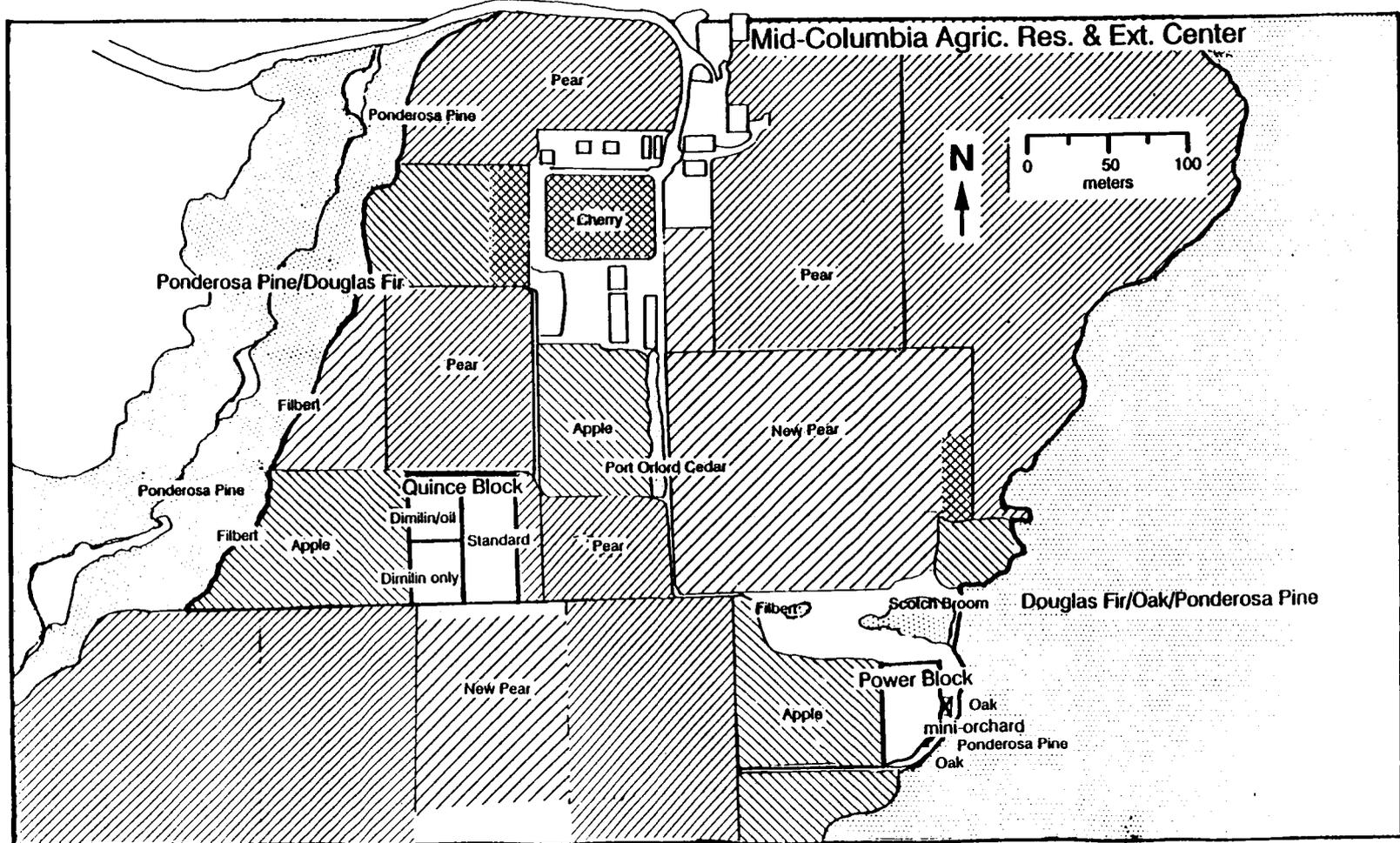


Figure III.2. Vegetational setting and orientation of MCAREC study sites.

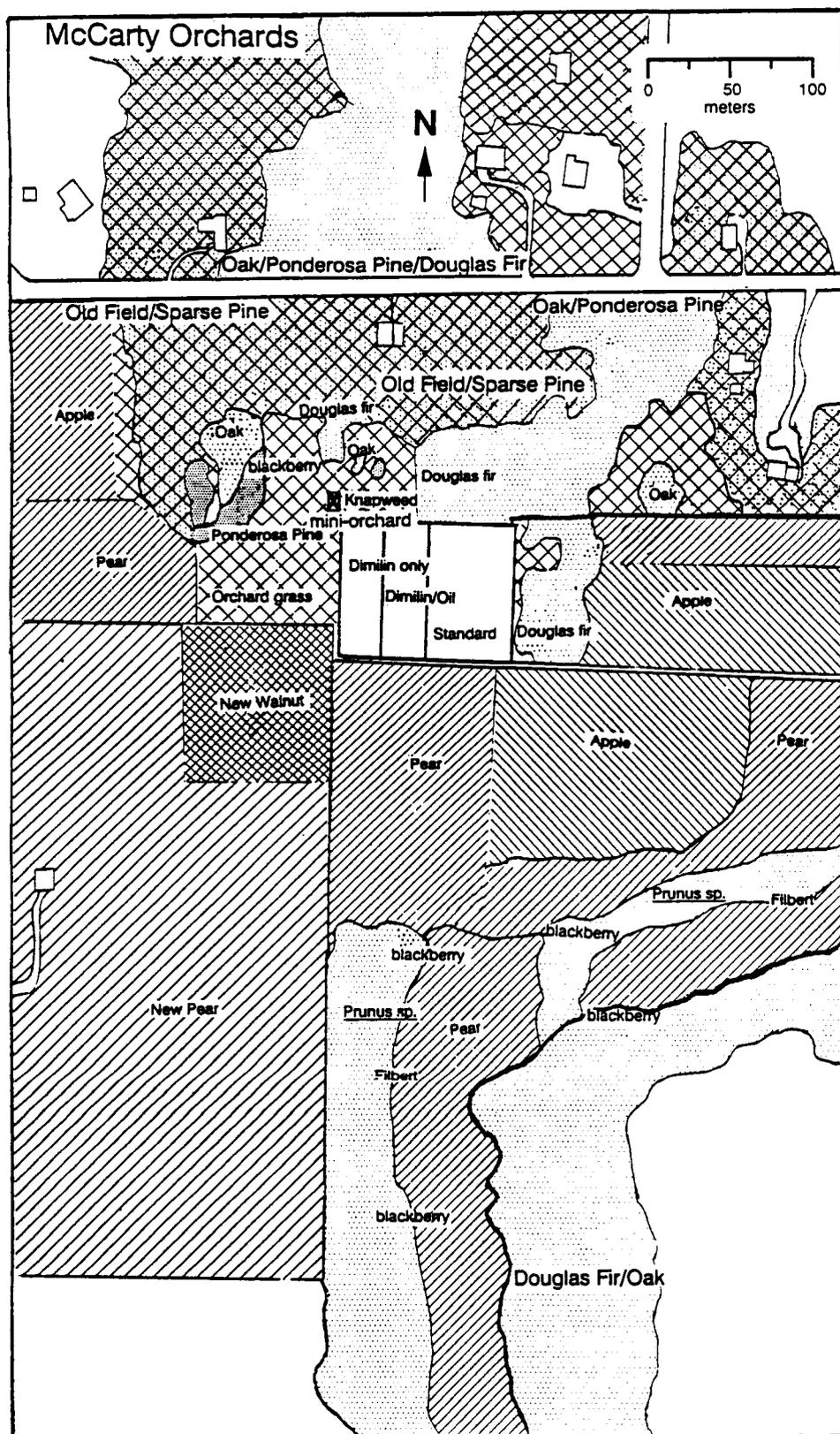


Figure III.3. Vegetational setting and orientation of McCarty study sites.

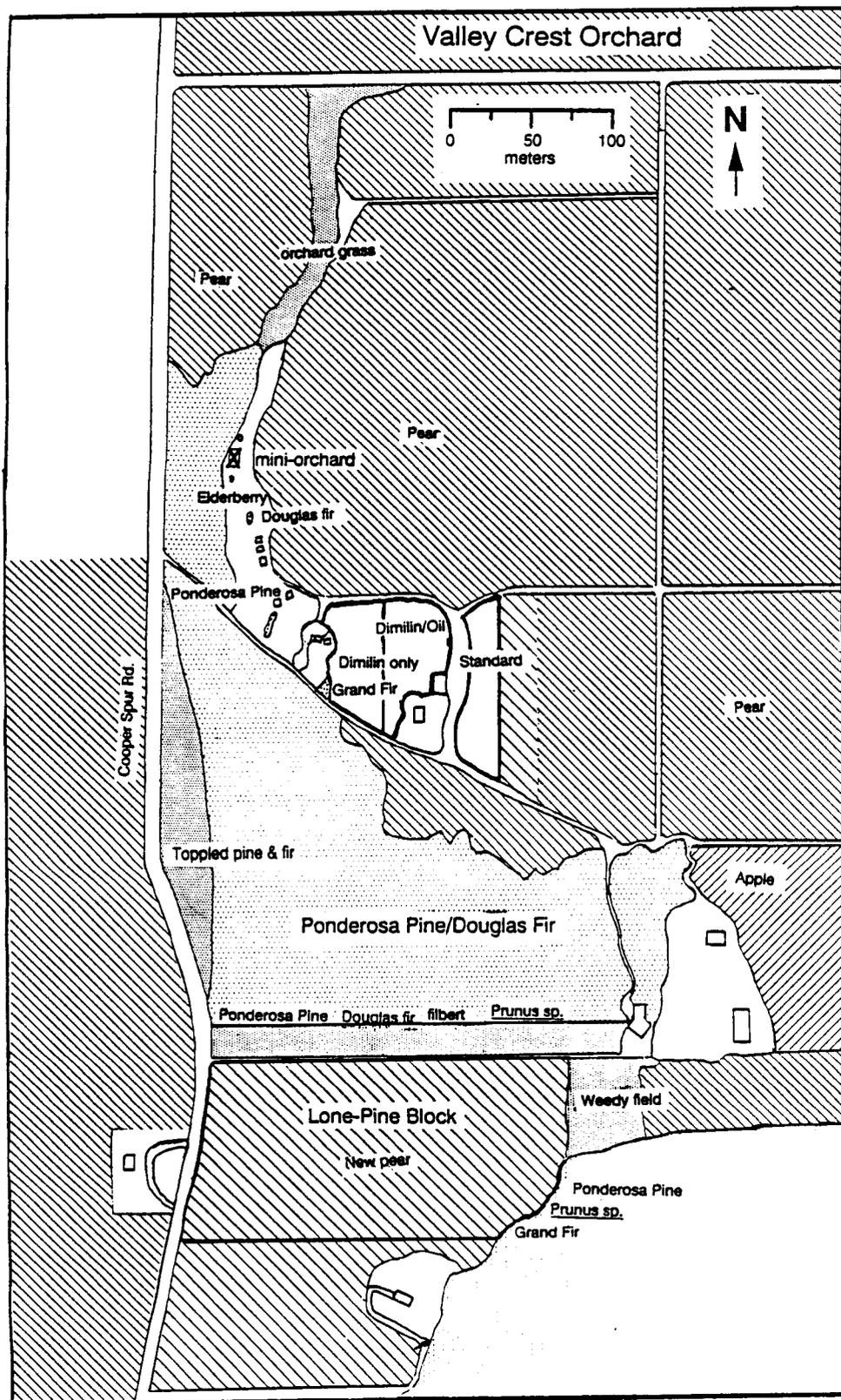


Figure III.4. Vegetational setting and orientation of Valley Crest study sites.

standard block to the north, while both selective blocks were bordered on the north side by uncultivated fields dominated by spotted knapweed, *Centaurea maculosa*. Isolated oaks and a stand of mature ponderosa pine were also located about 30 m from the selective blocks.

Valley Crest Orchards was located 3.2 km south of Parkdale (elevation 610 m) at the southern edge of the fruit-growing district. Orchards dominated the surrounding landscape, but large stands of mature forests were also present. A 3.8 ha tract of mature Douglas fir/ponderosa pine/grand fir was located 25 m from the southwest corner of the experimental block. The experimental block was bordered on the east and north by similarly aged pear blocks under standard chemical control. Diflubenzuron with oil was applied to the eastern portion of the block (0.61 ha), while the western portion (0.34 ha) received diflubenzuron only. The latter sloped westerly toward a creek dominated by ponderosa pine and Douglas fir.

Chemical programs

Tables III.1-III.8 list the chemicals and application dates for each chemical trial, according to site and year. During 1987 and 1988, two selective programs featuring three codling moth cover sprays of diflubenzuron alone and diflubenzuron with oil were compared with the grower's standard (azinphosmethyl) program at three commercial pear orchards, but only the diflubenzuron/oil program was compared to the standard during 1989. During 1987, Volck[®] supreme oil (Chevron Chemical Co.) was added to the first and second diflubenzuron covers at rates of 1% and 0.25%, respectively; oil was omitted from the third cover to limit phytotoxic effects. This is a 90 second viscosity narrow cut oil designed for prebloom and foliar application. During 1988 and 1989, oil rates were 1% and 0.5%, with the third cover including an oil application of 0.5%. Spray volume was 3740 l/ha.

Both diflubenzuron and azinphosmethyl were applied according to codling moth phenology as predicted by cumulative degree-days (DD) after first substantial pheromone trap catch (Biofix). Azinphosmethyl was applied to the standard blocks at 250 DD, 3 weeks later, and 1250 DD after codling moth Biofix to coincide with the beginning and peaks of egg hatch for each codling moth generation (Brunner et al. 1982). Diflubenzuron was applied at 75 DD, 3 weeks later, and 1000 DD after Biofix to coincide with codling moth oviposition.

Table III.1. Standard and selective insect and mite control programs, Quince 1987. Rates given as amount AI/ha.

Date	Timing	Standard Program	Selective Programs	
			Diflubenzuron	Diflubenzuron/Oil
20 Feb	Dormant	Superior oil 37.4 l Sulphur 5.14 kg	same as standard	same as standard
11 Mar	Delayed Dormant	Superior oil 56.1 l Fenvalerate 336 g	same as standard	same as standard
6 Apr	Pink	Oxythioquinox 1.12 kg Dodine 2.18 kg	same as standard	same as standard
25 Apr	Biofix	Fenvalerate 252 g		
4 May	1st Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 15.1 l
19 May	1st Cover	Azinphosmethyl 700 g		
21 May	2nd Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 3.8 l
3 Jun	2nd Cover	Azinphosmethyl 700 g		
11 Jul	3rd Cover		Diflubenzuron 280 g	Diflubenzuron 280 g
20 Jul	3rd Cover	Azinphosmethyl 700 g		
28 Jul		Amitraz 1.68 kg Fenbutatin-oxide 569 g	Mancozeb 6.72 kg	Mancozeb 6.72

Table III.2. Standard and selective insect and mite control programs, Quince 1988. Rates given as amount AI/ha.

Date	Timing	Standard Program	Selective Programs	
			Diflubenzuron	Diflubenzuron/Oil
18 Feb	Dormant	Superior oil 37.4	same as standard	same as standard
1 Mar	Delayed Dormant	Fenvalerate 336 g Superior oil 56.1 l	same as standard	same as standard
4 Apr	Pink	Oxythioquinox 1.12 kg Dodine 2.18 kg	same as standard	same as standard
24 Apr	Biofix			
17 May	1st Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 15.1 l
3 Jun	1st Cover	Azinphosmethyl 700 g		
7 Jun	2nd Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 7.6 l
24 Jun	2nd Cover	Azinphosmethyl 70 g Fenbutatin-oxide 420 g		
28 Jul	3rd Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 7.6 l
9 Aug	3rd Cover	Azinphosmethyl 70 g Fenbutatin-oxide 560 g	Fenbutatin-oxide 560 g	
10 Aug		Amitraz 50 WP 1.68 kg	Mancozeb 6.72 kg	Mancozeb 6.72 kg

Table III.3. Standard and selective insect and mite control programs, Quince 1989. Rates given as amount AI/ha.

Date	Timing	Standard Program	Diflubenzuron/Oil
24 Feb	Dormant	Supreme oil 37.4 l	same as standard
30 Mar	Delayed Dormant	Flucythrinate 350 g Supreme oil 37.4	same as standard
14 Apr	Pink	Oxythioquinox 25 WP 4 lb Dodine 65 WP 2.18 kg	same as standard
29 Apr	Biofix	Fenvalerate 420 g	
6 May	1st Cover		Diflubenzuron 280 g Supreme oil 15.1 l
30 May	1st Cover	Azinphosmethyl 700 g	
30 May	2nd Cover		Diflubenzuron 280 g Supreme oil 7.57 l
22 Jun	2nd Cover	Azinphosmethyl 700 g	
18 Jul	3rd Cover		Diflubenzuron 280 l Supreme oil 7.57 l
25 Jul		Amitraz 1.68 kg Fenbutatin-oxide 560 g	Fenbutatin-oxide 560 g
3 Aug	3rd Cover	Azinphosmethyl 700 g	
21 Aug		Formetanate 2.1 kg	

Table III.4. Standard and selective insect and mite control programs, McCarty 1987. Rates given as amount AI/ha.

Date	Timing	Standard Program	Selective Programs	
			Diflubenzuron	Diflubenzuron/Oil
26 Feb	Dormant	Superior oil 37.4 l	same as standard	same as standard
20 Mar	Delayed Dormant	Supreme oil 9.4 l Fenvalerate 252 g	same as standard	same as standard
9 Apr	Pink	Oxythioquinox 1.12 kg Fenvalerate 336 g	same as standard	same as standard
24 Apr	Biofix			
5 May	1st Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 15.14 l
20 May	1st Cover	Azinphosmethyl 700 g Mancozeb 6.7 kg		
29 May	2nd Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 3.8 l
14 Jun	2nd Cover	Azinphosmethyl 700 g		
12 Jul	3rd Cover		Diflubenzuron 280 g	Diflubenzuron 280 g
27 Jul	3rd Cover	Azinphosmethyl 700 g	Mancozeb 6.7 kg	Mancozeb 6.7 kg

Table III.5. Standard and selective insect and mite control programs, McCarty 1988. Rates given as amount AI/ha.

Date	Timing	Standard Program	Selective Programs	
			Diflubenzuron	Diflubenzuron/Oil
2 Mar	Dormant	Superior oil 37.4 l	same as standard	same as standard
10 Mar	Delayed Dormant	Superior oil 15.1 l Fenvalerate 336 g	same as standard	same as standard
25 Apr	Biofix			
19 May	1st Cover	not applied	Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 15.1 l
14 Jun	2nd Cover	Endosulfan 2.8 kg Azinphosmethyl 700 g	Diflubenzuron 280 g	Diflubenzuron 25 WP 1 lb Supreme oil 7.6 l
20 Jul		Fenbutatin-oxide 560 g	Fenbutatin-oxide 560 g	
28 Jul	3rd Cover		Azinphosmethyl 157 g Mancozeb 6.7 kg <i>B.t.</i> 36 g	Fenbutatin-oxide 560 g Azinphosmethyl 157 g Mancozeb 6.7 kg <i>B.t.</i> 36 g
2 Aug	3rd Cover	Endosulfan 2.8 kg Mancozeb 6.7 kg		

Table III.6. Standard and selective insect and mite control programs, McCarty 1989.
Rates given as amount AI/ha.

Date	Timing	Standard	Diflubenzuron/Oil
27 Feb	Dormant	Supreme oil 15.1 l	same as standard
28 Mar	Delayed Dormant	Supreme oil 3.8 l Fenvalerate 252 g	same as standard
17 Apr	Pink	Oxythioquinox 1.12 kg Fenvalerate 336 g	same as standard
29 Apr	Biofix		
6 Apr	Delayed Dormant	Superior oil 3.8 l Endosulfan 1.68 kg	Superior Oil 3.8 l
8 May	1st Cover		Diflubenzuron 280 g Supreme oil 15.1 l
1 Jun	2nd Cover		Diflubenzuron 280 g Supreme oil 7.6 l
11 Jun		Amitraz 50 WP 1.68 kg	
22 Jul	3rd Cover	Fenbutatin-oxide 560 g	Diflubenzuron 280 g Supreme oil 7.6 l Fenbutatin-oxide 560 g
27 Jul	3rd Cover	Azinphosmethyl 700 g	
12 Aug			Amitraz 50 1.68 kg

Table III.7. Standard and selective insect and mite control programs, Valley Crest 1987. Rates given as amount AI/ha.

Date	Timing	Standard Program	Selective Programs	
			Diflubenzuron	Diflubenzuron/Oil
29 Mar	Delayed Dormant	Superior oil 35.4 l Fenvalerate 378 g	same as standard	same as standard
22 Apr	Pink	Oxythioquinox 1.12 kg	same as standard	same as standard
5 May	Biofix			
15 May	1st Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 15.1 l
30 May	1st Cover	Azinphosmethyl 700 g		
11 Jun	2nd Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 3.8 l
23 Jun		Amitraz 50 1.68 kg Fenbutatin-oxide 560 g		
15 Jul			Mancozeb 8.4 kg	Mancozeb 8.4 kg
23 Jul	3rd Cover		Diflubenzuron 280 g	Diflubenzuron 280 g

Table III.8. Standard and selective insect and mite control programs, Valley Crest 1988. Rates given as amount AI/acre.

Date	Timing	Standard Program	Selective Programs	
			Diflubenzuron	Diflubenzuron/Oil
15 Mar	Dormant	Superior oil 37.4 Fenvalerate 336 g Piperonyl butoxide 560 g	same as standard	same as standard
9 Apr	Delayed Dormant	Superior oil 3.8 l Fenvalerate 336 16 oz	same as standard	same as standard
20 Apr	Pink	Oxythioquinox 1.4 kg	same as standard	same as standard
10 May	Biofix			
6 Jun	1st Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 15.4 l
15 Jun	1st Cover	Azinphosmethyl 700 g		
28 Jun	2nd Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 7.6 l
7 Jul		Abamectin 21 g		
2 Aug	3rd Cover		Diflubenzuron 280 g	Diflubenzuron 280 g Supreme oil 7.6 l
9 Aug		Amitraz 1.68 kg		Mancozeb 6.7 kg
18 Aug			Amitraz 1.68 kg	

Daily temperatures were recorded at each site with hygrothermographs housed in standard weather stations. Degree days (DD) were calculated from minimum and maximum temperatures according to a sine-wave approximation method (Baskerville and Emin 1969) for both codling moth and psylla. For codling moth, standard upper and lower developmental thresholds of 50°F and 88°F were used and DDs were accumulated from first substantial male moth catch (Brunner et al. 1982). Psylla thresholds and Biofix are described in Ch. II.

For chemical control of psylla, amitraz or abamectin was applied to standard blocks while mancozeb (Manzate 200[®], Dupont Chemical Co.) was applied to selective blocks when psylla nymphs exceeded 0.3/leaf (Burts 1988). Mancozeb has some demonstrated psyllacidal activity but allows natural enemies to survive (McMullen and Jong 1971, Westigard et al. 1986). If psylla densities in the selective blocks remained above thresholds after mancozeb application, amitraz was applied to prevent economic loss to the cooperating orchardist.

Fenbutatin-oxide (Vendex[®], Dupont Chemical Co.) was applied as a miticide to both standard and selective blocks when 2.0 mites/leaf were exceeded (Westigard et al. 1979). Formetanate (Carzol[®], Nor-Am Chemical Co.) was applied to the 1989 Quince block after fenbutatin-oxide failed to suppress mites.

The selective program was modified during the 1988 McCarty trials. Under its current experimental use permit, diflubenzuron cannot be applied within 28 days to harvest. In 1988 at the McCarty site, 'Bartlett' harvest was predicted to occur within 28 days after the planned third diflubenzuron cover. An attempt to conserve the predaceous fauna of the selective blocks was made by applying a low rate of azinphosmethyl and standard rates of *Bacillus thuringiensis* (Dipel 2X[®], Abbot Labs) for codling moth control.

Sampling methods

To monitor codling moth activity and determine dates of chemical application, Pherocon II pheromone traps (Trece Inc.[®], Salinas, Calif.) were placed in treated areas. Because areas under the selective programs were smaller than 0.2 ha, they received only one trap, while two traps were placed in the standard block.

Beginning in April, immature psylla were sampled about every ten days until harvest. During early season, two leaves from each of two spurs per tree were sampled from twenty

trees per treated block (80 leaves). After terminal elongation, leaves were collected from the top, middle, and bottom of a terminal from both the upper and lower thirds of each tree (120 leaves). Psylla nymphs and eggs, parasitized nymphs (mummies), and aphid immatures per leaf were counted with the aid of a stereomicroscope.

Natural enemies and adult psylla were monitored with thirty-five to fifty beating tray samples (Burts and Retan 1973) in each block during cool early morning hours. Some individuals were saved as voucher specimens, but most were returned to the tree after counting. Arthropods were identified as predaceous or not and classified to Operational Taxonomic Units (OTU) according to criteria explained elsewhere (Ch. II).

To monitor mite densities, five leaves were collected from trunk to branch tip along a mature scaffold limb from each of twenty trees per treated block (100 leaves). Mites were removed onto a glass plate with a mite-brushing machine and were identified and counted under a stereomicroscope. The following species were combined to quantify the complex of phytophagous mites: twospotted spider mite, *Tetranychus urticae* Koch, McDaniel spider mite, *T. mcdanieli* McGregor, yellow mite, *Eotetranychus carpini borealis* (Ewing), and European red mite, *Panonychus ulmi* (Koch). Pear rust mites, *Epitrimerus pyri* (Nalepa) were counted separately under higher magnification.

Pest damage to 'Anjou' and 'Bartlett' pears was assessed during harvest by examining at least 300 fruit per block. Only 150 fruit were examined during 1989 'Bartlett' harvest. Fruit was examined from six or more different locations within the treated block. Each location served as a replicate to provide variance for parametric statistical tests. Psylla russeted fruit was graded according to USDA standards with only #2 and culls being downgraded. Fruit was also examined for codling moth entries.

Data Analysis

Statistical differences among treatment means for damaged fruit were determined with analysis of variance (ANOVA). Separation of means was determined by LSD ($P = .05$). During 1989, significant differences between the two treatments were tested with a two-tailed Student's t-test ($P = .05$). Percent damaged fruit was transformed to the logarithmic scale ($\ln(x + 1)$) prior to statistical testing.

Cases of successful and unsuccessful biological control were determined primarily by comparing seasonal dynamics of pear psylla immatures and their natural enemies against the background chemical regime. Because psyllacide application often suppressed psylla and confounded the effects of natural enemies, degree of psylla russet damage is a less meaningful, yet still economically important indicator of program success.

Results

Seasonal abundance patterns of pear psylla immatures and their natural enemies

Figures III.5--III.7 show the seasonal patterns of pear psylla density and natural enemy abundance for all trials at each study orchard. Despite variation among chemical programs, years, and locations, seasonal transitions in the development of both pear psylla and their natural enemies occurred at about 1300 and 2400 accumulated degree days (DD). Psylla egg densities remained low until about 1000 DD (mid-June). Densities of psylla nymphs usually began to increase shortly thereafter (~ 1300 DD). Late season psylla egg densities rose or fell according to predation and/or psyllacide application. Psylla nymphal densities often followed similar late season patterns at lower levels. Natural enemy abundance also changed at similar accumulated degree days, and sometimes resembled but lagged behind seasonal patterns of psylla density (e.g., Quince 1989 diflubenzuron/oil, Quince 1988 diflubenzuron only, McCarty 1989 diflubenzuron/oil, McCarty 1988 diflubenzuron only; Figures III.5F, III.5H, III.6F, III.6H).

In most cases, psylla natural enemies were more abundant in selective as opposed to standard blocks, especially during late season (Figures III.5--III.7). This difference was most visible at Quince, where natural enemies in the selective blocks increased during August and September (Figure III.6). At McCarty, natural enemies peaked earlier in the season, but usually declined by mid- to late season (Figure III.7). Differences in natural enemy abundance between standard and selective trials were least apparent at Valley Crest. Natural enemies were relatively abundant during early season in most Valley Crest trials, but always declined to low levels by late season.

In the standard blocks, developing populations of both immature psylla and natural enemies dropped abruptly after azinphosmethyl and amitraz were applied. In the 1989 McCarty standard block, numbers of natural enemies rebounded to relatively high levels while psylla remained at low densities after an early season application of amitraz. Early season azinphosmethyl sprays were also omitted in this block.

In the selective blocks, natural enemies rarely became abundant until after the first two diflubenzuron applications. In most blocks where natural enemies were present (1987

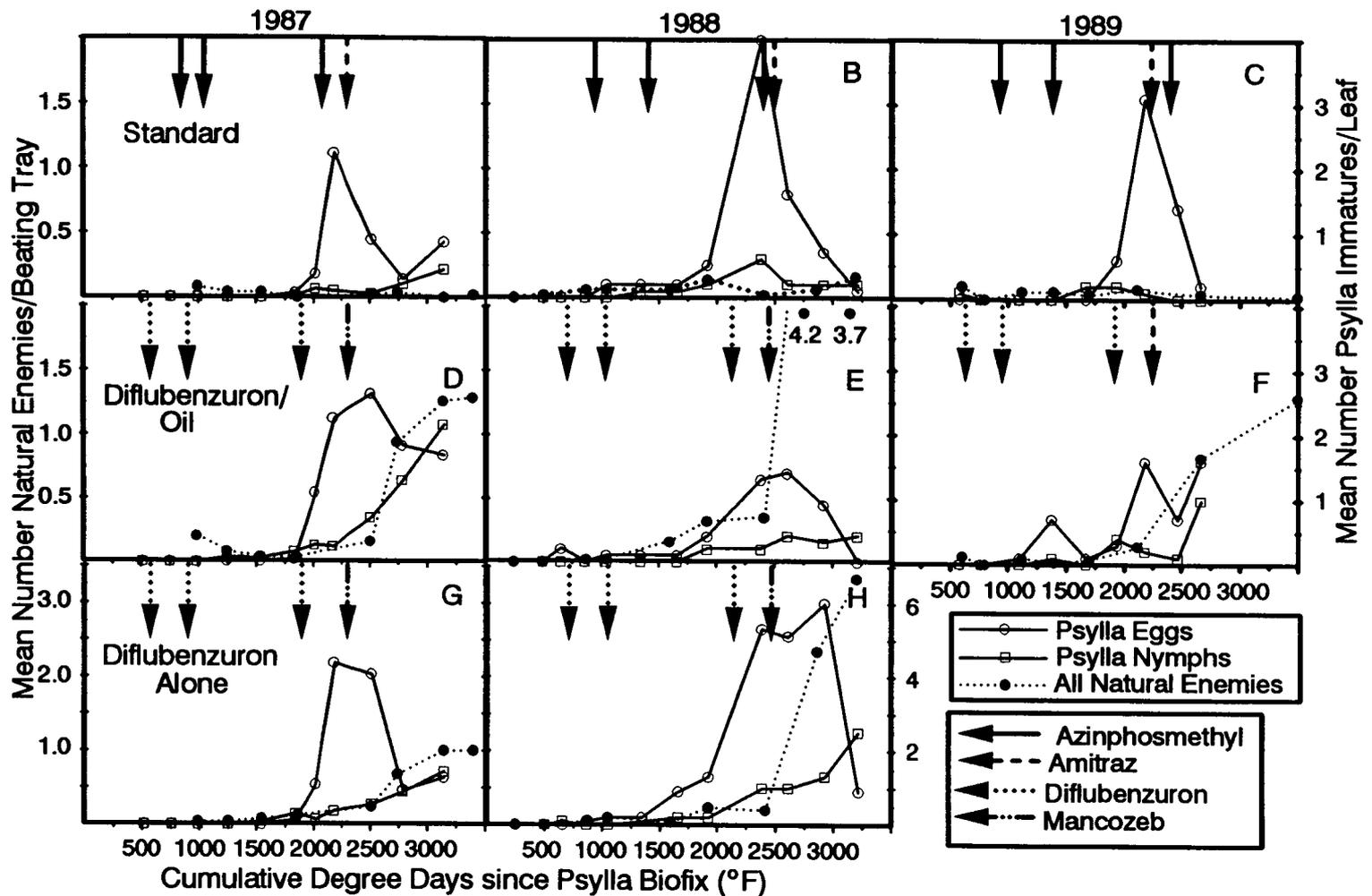


Figure III.5. Natural enemy/psylla dynamics during all standard and selective trials at Quince, 1987-1989. Arrows indicate pesticide applications.

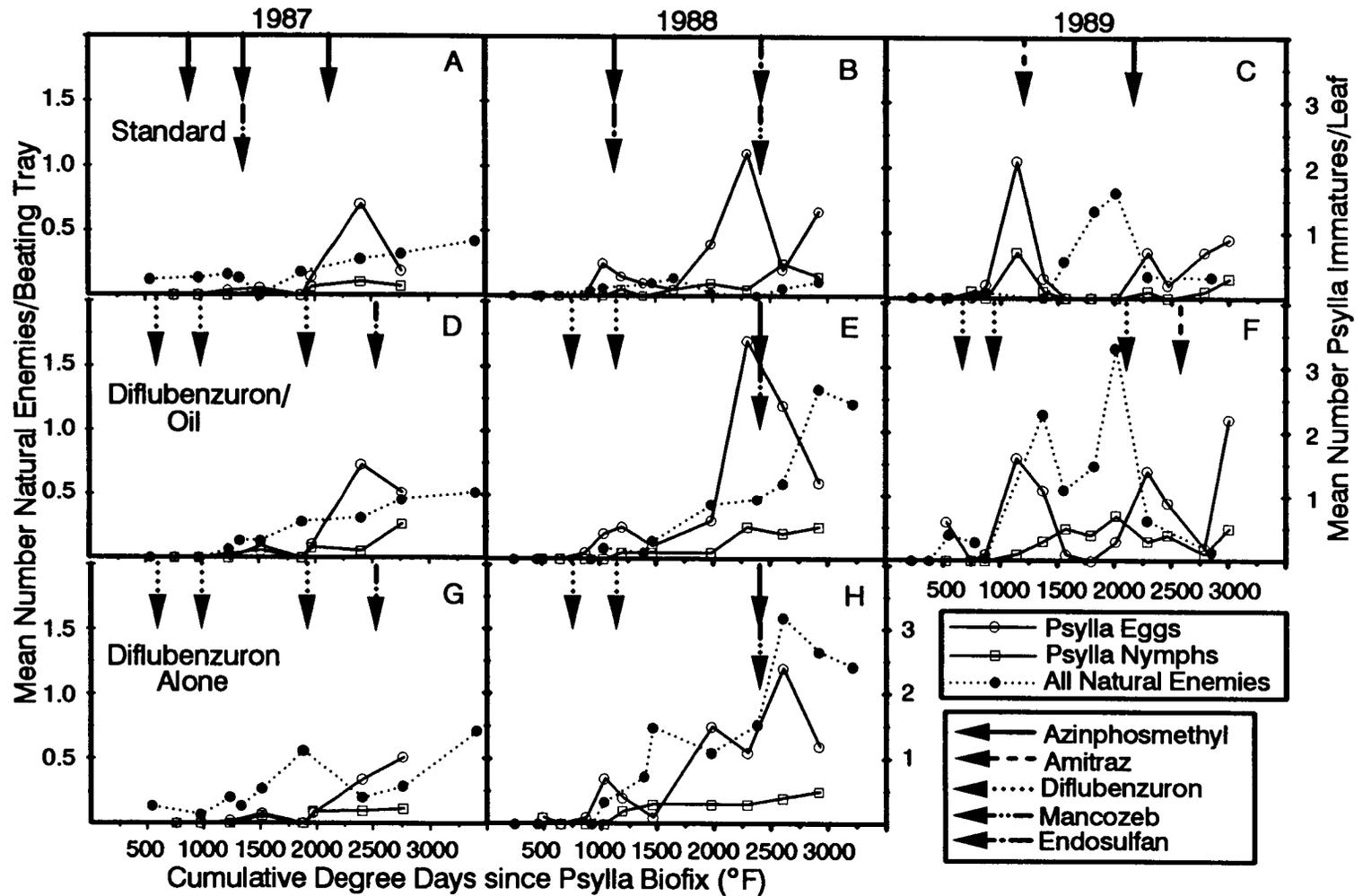


Figure III.6. Natural enemy/psylla dynamics during all standard and selective trials at McCarty, 1987-1989. Arrows indicate pesticide applications.

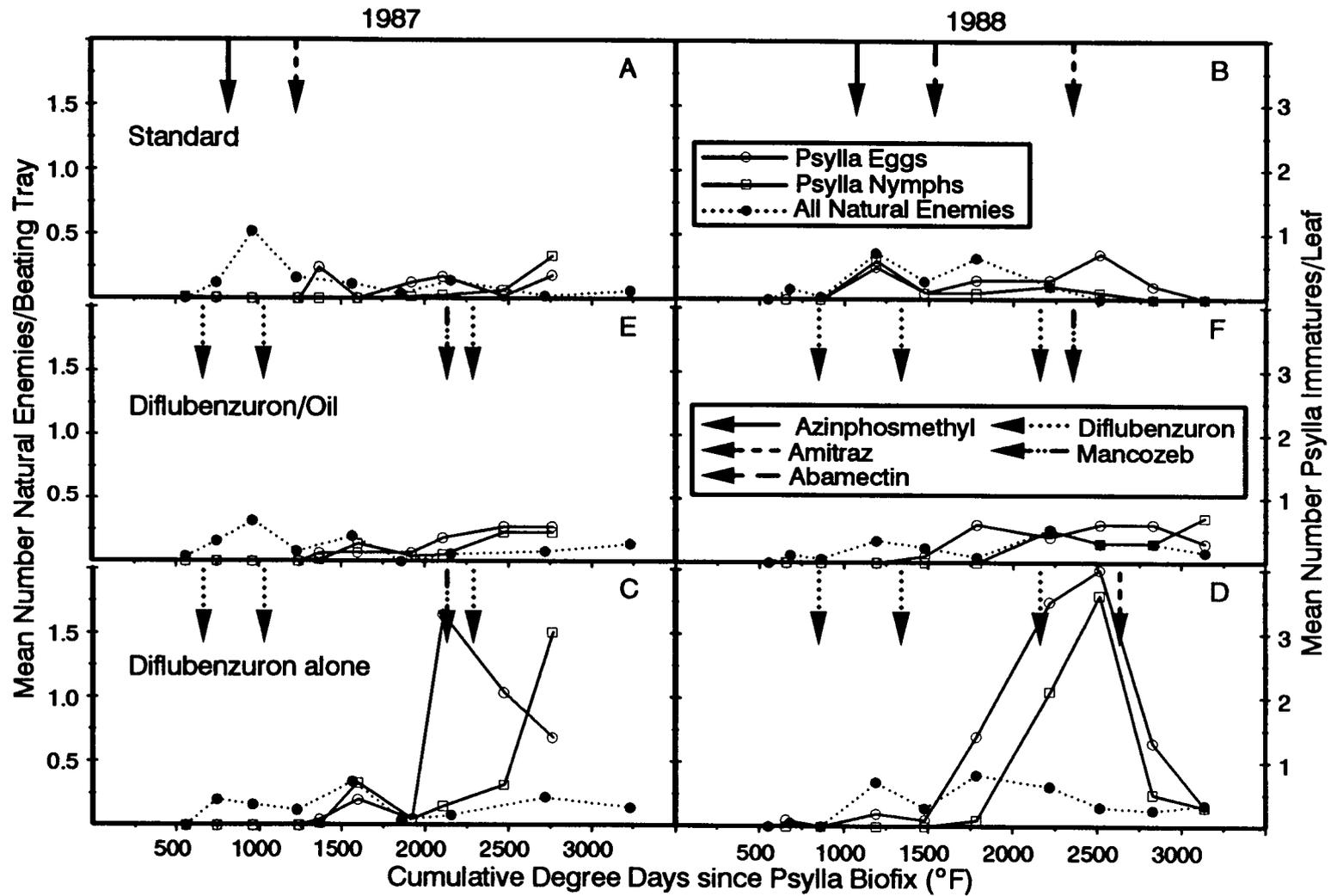


Figure III.7. Natural enemy/psylla dynamics during all standard and selective trials at Valley Crest, 1987-1989. Arrows indicate pesticide applications.

Quince diflubenzuron/oil, 1987 and 1989 McCarty diflubenzuron only), natural enemies declined slightly following the second diflubenzuron cover spray. Numbers of natural enemies were higher during early season in the Valley Crest selective blocks compared to the lower valley sites, but failed to increase during mid-season. By late season, natural enemies were always more abundant in the diflubenzuron/oil block at Quince, but the diflubenzuron only trials had more natural enemies during late season at McCarty and Valley Crest.

In general, psylla was better suppressed in the diflubenzuron/oil trials than in the diflubenzuron only trials. Psylla frequently exceeded action thresholds earlier in the diflubenzuron only than in the diflubenzuron/oil blocks. The greatest disparity between the two selective programs occurred at Valley Crest. In both 1988 and 1989 at Valley Crest, psylla densities increased suddenly prior to 'Bartlett' harvest in the diflubenzuron only block, but remained near action thresholds in the diflubenzuron/oil blocks.

Trials which did not show high levels of natural enemies until late season also showed higher late-season psylla levels. Natural enemy abundance remained low during both early and mid-season in the 1987 Quince selective trials and during early season in the 1988 Quince diflubenzuron only trial (Figures III.5B, III.5C, III.5H). Psylla eggs reached especially high levels in these blocks and nymphal psylla numbers failed to decline despite mancozeb application. In contrast, trials where psylla were effectively suppressed had higher levels of natural enemies during the early season (Figures III.6 D, III.6F, III.6G, and III.6H).

Psylla russet damage

Pre-harvest psyllacides were required in all fourteen selective trials. Psylla usually declined after these applications, preventing severe fruit damage. Both cullage and total percent downgraded fruit due to psylla russet exceeded 5% twice 2% also twice (Tables II.9--11). In the standard blocks, total russeted fruit exceeded 5% once and cullage never exceeded 2%. Except at McCarty in 1989, percent downgraded fruit from the diflubenzuron/oil program did not differ significantly from that of the standard. Total percent downgraded fruit was significantly greater in the diflubenzuron only blocks than in either the standard or the diflubenzuron/oil blocks in three of twelve comparisons.

Table III.9. Percent psylla russetted pears¹ under standard and selective pest control programs during harvest at Quince, 1987-89². Total downgraded are combined #2 and culls. Sample size, 300 fruit/treatment, 1987-88; N, 1989. Means in each column followed by the same letter are not significantly different, ns = not significant (P = .05).

1987										
Program	'Bartlett'				'Anjou'					
	#1	#2	Cull	Total Downgraded	#1	#2	Cull	Total	Downgraded	
Standard	0.3	0	0	0.3ns	0.7	0	0		0ns	
Diflubenzuron	0.3	0	0	0.3	0.7	0.3	0		0.3	
Diflubenzuron/Oil	0	0	0	0	1.0	0.3	0		0.3	

1988										
Program	'Bartlett'				'Anjou'					
	#1	#2	Cull	Total Downgraded	#1	#2	Cull	Total	Downgraded	
Standard	3.3	0.3	0	0.3ns	3.0	1.0	0.3		1.3a	
Diflubenzuron	2.7	0.7	0	0.7	6.0	5.0	2.3		7.3b	
Diflubenzuron/Oil	2.3	0.7	0	0.7	2.0	0.3	0.3		0.7a	

1989										
Program	'Bartlett'				'Anjou'					
	N	#1	#2	Cull	Total Downgraded	N	#1	#2	Cull	Total Downgraded
Standard	150	12.0	0	0	0ns	400	6.0	1.5	0.8	2.2ns
Diflubenzuron/Oil	300	4.7	0.3	0	0.3	400	5.2	0.8	0.5	1.2

¹ USDA standards

² 1987: 'Bartlett' -- 11 Aug; 'Anjou' -- 25 Aug
 1988: 'Bartlett' -- 24 Aug; 'Anjou' -- 9 Sep
 1989: 'Bartlett' -- 18 Aug; 'Anjou' -- 7 Sep

Table III.10. Percent psylla russetted pears¹ under standard and selective pest control programs during harvest at McCarty, 1987-89². Total downgraded are combined #2 and culls. Sample size, 300 fruit/treatment, 1987-88; N, 1989. Means in each column followed by the same letter are not significantly different, ns = not significant (P = .05).

1987										
Program	'Bartlett'				'Anjou'					
	#1	#2	Cull	Total Downgraded	#1	#2	Cull	Total	Downgraded	
Standard	0	0	0	0	0	0	0		0	
Diflubenzuron	0	0	0	0	0	0	0		0	
Diflubenzuron/Oil	0	0	0	0	0	0	0		0	

1988										
Program	'Bartlett'				'Anjou'					
	#1	#2	Cull	Total Downgraded	#1	#2	Cull	Total	Downgraded	
Standard	2.3	0	0	0ns	0.3	0.7	0		0.7ns	
Diflubenzuron	1.3	0	0	0	3.3	1.0	0		1.0	
Diflubenzuron/Oil	1.0	0	0	0	1.3	0.7	0		0.7	

1989										
Program	'Bartlett'					'Anjou'				
	N	#1	#2	Cull	Total Downgraded	N	#1	#2	Cull	Total Downgraded
Standard	300	1.7	0.7	0	0.7a	400	1.2	0.2	0	0.2a
Diflubenzuron/Oil	400	17.27	2.15		8.8b	300	4.3	1.7	0.7	2.3b

¹ USDA standards

² 1987: 'Bartlett' -- 12 Aug; 'Anjou' -- 8 Sep
 1988: 'Bartlett' -- 24 Aug; 'Anjou' -- 12 Sep
 1989: 'Bartlett' -- 22 Aug; 'Anjou' -- 15 Sep

Table III.11. Percent psylla russeted pears¹ under standard and selective pest control programs during harvest at Valley Crest, 1987-89². Total downgraded are combined #2 and culls. Sample size, 300 fruit/treatment, 1987-88; N, 1989. Means in each column followed by the same letter are not significantly different, ns = not significant (P = .05).

1987										
Program	'Bartlett'				'Anjou'					
	#1	#2	Cull	Total Downgraded	#1	#2	Cull	Total	Downgraded	
Standard	0	0	0	0	0	0	0		0ns	
Diflubenzuron	0	0	0	0	1.3	1.3	0		1.3	
Diflubenzuron/Oil	0	0	0	0	0	0	0		0a	

1988										
Program	'Bartlett'				'Anjou'					
	#1	#2	Cull	Total Downgraded	#1	#2	Cull	Total	Downgraded	
Standard	1.0	0	0	0a	0	0.3	0		0.3a	
Diflubenzuron	8.2	3.0	0.8	3.8b	12.7	3.3	2.7		6.0b	
Diflubenzuron/Oil	1.4	0	0	0a	1.0	0	0		0.3a	

¹ USDA standards

² 1987: 'Bartlett' -- 25 Aug; 'Anjou' -- 18 Sep
1988: 'Bartlett' -- 7 Sep; 'Anjou' -- 26 Sep

Incidence of pear psylla biological control

Based on the seasonal dynamics of pear psylla and natural enemy abundance and pear russet damage, natural enemy impact was most convincingly demonstrated in two trials: 1988 Quince diflubenzuron/oil and 1989 McCarty diflubenzuron/oil. Compared to the adjacent selective block receiving similar cultural treatments, psylla densities declined in the presence of abundant natural enemies in these blocks, but continued to increase in adjacent blocks under similar chemical control (Figures II.6, II.7). Downgraded russeted 'Anjou' pears were also significantly lower in the 1988 Quince diflubenzuron/oil block than in the adjacent diflubenzuron only block (Table 9). The number of downgraded pears due to russetting was significantly higher in the 1989 McCarty diflubenzuron/oil block.

Natural enemies were moderately effective in the 1987 McCarty selective trials and in the 1989 McCarty standard trial. In these blocks, psylla densities rose gradually in the presence of natural enemies alone, but nymphal densities remained below action thresholds until shortly before harvest when mancozeb was applied. Psylla russet was minimal in these blocks, but the role of natural enemies was less apparent here than in other blocks. The 1989 McCarty standard trial, differed from other standard trials. Amitraz was applied earlier in the season, psylla remained low until harvest (Figure III.6C), and russet damage was minor (Table III.10). The nine weeks between amitraz application and harvest is substantially longer than the normal field effectiveness of amitraz (Burts 1990, personal communication).

These trials contrast with most other selective trials, where natural enemies were relatively scarce and psylla densities were not suppressed even after psyllacide application. At Valley Crest, psylla densities are traditionally lower than in orchards at lower-elevations (Euwer, personal communication), presumably due to cooler spring temperatures. The number of natural enemies in the Valley Crest selective trials were also low compared to other trials and apparently had little impact on psylla populations.

Codling moth levels

Both selective programs using diflubenzuron prevented codling moth damage. Codling moth infested fruit never exceeded one percent in any blocks during the three years of investigation. Pheromone trap catches of male moths were moderate (Table III.12).

Table III.12. Total number of adult codling moths/control program at three orchards in the Hood River Valley 1987-1988. Values in the standard block are means of two traps. One trap was placed in each of the selective blocks.

Orchard	Program	1987	1988
Quince	Standard	3.5	8.0
	Diflubenzuron	12.0	9.0
	Diflubenzuron/Oil	12.0	7.0
McCarty	Standard	0	6.0
	Diflubenzuron	15.0	21.0
	Diflubenzuron/Oil	5.0	19.0
Valley Crest	Standard	7.0	14.0
	Diflubenzuron	2.0	5.0
	Diflubenzuron/Oil	9.0	8.0

Mite densities

Figure III.8 shows seasonal trends in tetranychid mites among the chemical control programs for each commercial orchard and year. Tables III.13–III.15 show the numbers of pear rust mites per sample date for each chemical trial. Miticides were required more often in the standard blocks than in the diflubenzuron/oil blocks (7 versus 3). In trials where no miticides were applied, mite densities were often lower in the diflubenzuron/oil blocks than in the diflubenzuron only blocks.

For example, tetranychid mite densities in the Quince standard and diflubenzuron only blocks during 1988 surpassed action thresholds by mid-season, while densities in the diflubenzuron/oil block remained low until late-season. Fenbutatin-oxide was applied twice to the standard block, once to the diflubenzuron only block, and not at all to the diflubenzuron/oil block (Figure III.8B). In 1989, a single application of fenbutatin-oxide suppressed spider mites in the diflubenzuron/oil block, but the standard block required an additional application of formetanate (Figure III.8C).

At McCarty, mite densities remained below action thresholds during 1987 (Figure III.8D), but a miticide was applied in 1988 to suppress the pear rust mite. In 1989, both mite mobiles and eggs increased during mid-July and a prophylactic spray was applied to both blocks before thresholds were reached (Figure III.8F). Subsequent mite densities were lower in the diflubenzuron/oil block (Table III.14).

Although miticides were not required in any of the Valley Crest blocks (Figure III.8G), the grower applied fenbutatin-oxide to the standard block in 1987. As in the 1988 Quince selective trials, late-season tetranychid mite densities were higher in the diflubenzuron only block than in the diflubenzuron/oil block at the Valley Crest site (Table III.15).

Phytophagous mites were usually less abundant in those blocks where predaceous insects were abundant. At Quince, phytophagous mites were lower and predaceous insects were higher in the Quince diflubenzuron/oil blocks than in the diflubenzuron blocks. At McCarty, phytophagous mites were lower and predaceous insects were higher in the diflubenzuron only blocks than in the diflubenzuron/oil blocks.

Densities of predator mites were low at all sites during all years (Table III.18).

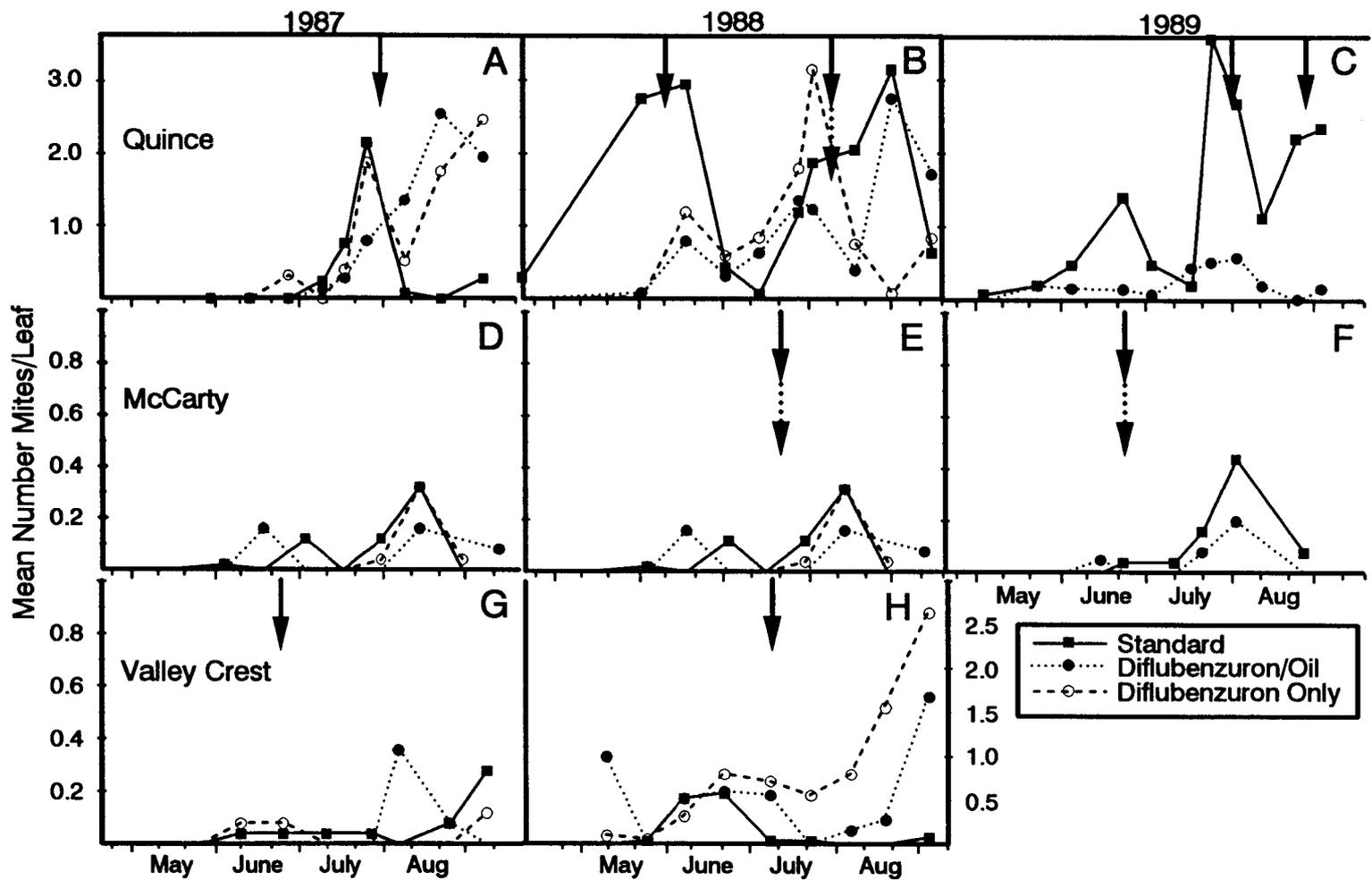


Figure III.8. Densities of tetranychid mites sampled in all standard and selective trials. Solid, dashed, and dotted arrows indicated miticide applications to standard, diflubenzuron/oil, and diflubenzuron only blocks, respectively.

Table III.13. Mean number of pear rust mites per ten leaves under three pest control programs at Quince Block, Hood River 1987-1989. Sample size = 100 leaves/sample.

1987									
Program	29 May	12 Jun	26 Jun	8 Jul	16 Jul	24 Jul	7 Aug	Aug 10	4 Sep
Standard	0	0	0	0	0	0	0	0	0
Diflubenzuron	0	0	0	0	0	0	0	1	1
Diflubenzuron/Oil	0	0	0	0	0	0	1	1	1

1988										
Program	20 Apr	1 Jun	17 Jun	1 Jul	13 Jul	27 Jul	1 Aug	16 Aug	29 Aug	12 Sep
Standard	0	0	0	0	0	0	0	0	0	0
Diflubenzuron	0	0	0	0	3	67	64	15	0	0
Diflubenzuron/Oil	0	0	0	0	2	1	7	8	0	0

1989											
Program	5 May	24 May	5 Jun	23 Jun	3 Jul	17 Jul	24 Jul	2 Aug	11 Aug	23 Aug	1 Sep
Standard	0	0	0	0	11	3	15	0	0	0	0
Diflubenzuron/Oil	0	0	2	6	7	1	2	0	0	0	0

Table III.14. Mean number of pear rust mites per ten leaves under three pest control programs at McCarty, Hood River 1987-1989. Sample size = 100 leaves/sample.

1987						
Program	28 May	11 Jun	25 Jun	10 Jul	3 Aug	19 Aug
Standard	0	0	0	0	0	0
Diflubenzuron	0	0	0	0	0	0
Diflubenzuron/Oil	0	0	0	0	0	0

1988								
Program	12 May	2 Jun	16 Jun	1 Jul	14 Jul	28 Jul	11 Aug	26 Aug
Standard	0	0	20	16	46	1	4	5
Diflubenzuron	0	0	2	40	106	4	3	8
Diflubenzuron/Oil	0	0	0	5	8	1	3	

1989								
Program	22 May	1 Jun	14 Jun	22 Jun	10 Jul	20 Jul	1 Aug	25 Aug
Standard	0	1	0	3	0	8	0	0
Diflubenzuron/Oil	0	3	0	0	0	3	0	0

Table III.15. Mean number of pear rust mites per ten leaves under three pest control programs at Valley Crest, Parkdale 1987-1989. Sample size = 100 leaves/sample.

1987							
Program	24 May	8 Jun	23 Jun	8 Jul	3 Aug	21 Aug	3 Sep
Standard	0	0	0	0	0	0	0
Diflubenzuron	0	0	0	0	0	0	0
Diflubenzuron/Oil	0	0	0	0	0	0	0

1988									
Program	19 May	2 Jun	15 Jun	29 Jun	15 Jul	29 Jul	12 Aug	24 Aug	8 Sep
Standard	0	0	0	0	0	1	0	5	0
Diflubenzuron	0	0	0	0	0	2	25	37	0
Diflubenzuron/Oil	0	0	0	0	0	0	2	6	0

Table III.16. Mean number of predator mites per ten leaves under three pest control programs at Quince, Hood River 1987-1989. Sample size = 100 leaves/sample.

1987															
Program	Quince					McCarty					Valley Crest				
	May	Jun	Jul	Aug	Sep	May	Jun	Jul	Aug	Sep	May	Jun	Jul	Aug	Sep
Standard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diflubenzuron	0	0	0	0.5	1.0	0	0	0	0	0	0	0	0	0	0
Diflubenzuron/Oil	0	0	0	1.0	1.0	0	0	0	0	0	0	0	1.3	0	0

1988															
Program	Quince					McCarty					Valley Crest				
	May	Jun	Jul	Aug	Sep	May	Jun	Jul	Aug	Sep	May	Jun	Jul	Aug	Sep
Standard	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0
Diflubenzuron	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diflubenzuron/Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1989										
Program	Quince					McCarty				
	May	Jun	Jul	Aug	Sep	May	Jun	Jul	Aug	Sep
Standard	0	0	0.7	0	0	0	0	0	0	0
Diflubenzuron/Oil	0	0	0	0	0	0	0	0	0	0

Discussion

Pear psylla control

Although direct effects of diflubenzuron on the development of early-instar psyllids has been noted (Grosscurt 1978), field trials suggest that diflubenzuron indirectly suppresses psylla development by allowing for the colonization and development of psylla natural enemies (Riedl and Hoying 1980). The success or failure of diflubenzuron trials in other regions has been attributed to the number and kind (Burts 1983, Solomon et al. 1989), as well as the seasonality (Westigard et al. 1986) of natural enemies. In the Hood River trials, successful biological control seems to be related to the seasonal placement and magnitude of natural enemy abundance.

Compared to other trials of diflubenzuron for pear psylla control, the Hood River trials were moderately successful at controlling pear psylla. In the Medford region of southern Oregon, a selective program of four diflubenzuron cover sprays adequately controlled psylla in three of four trials (Westigard et al. 1986). Zineb was required in a fourth trial, which the authors labelled "modified selective". In Wenatchee, "soft" programs of diflubenzuron, mancozeb, and pre-harvest tree washes failed to control psylla (Burts 1983).

In the Medford trials, the presence of an early season predator complex enhanced late season psylla control (Westigard et al. 1986). In those trials, early and late season predator complexes were distinguished by the relative height and season of peaks of natural enemy abundance. Psylla was better suppressed in orchards where natural enemies peaked at high levels during early season. In most orchards, a mid- to late season predator complex was generally less effective.

A similar scenario was apparent in Hood River commercial pear orchards under selective programs. As in the Medford trials, abundance of predaceous arthropods in the Hood River selective trials rarely peaked during early season. However, those trials which showed relatively high levels of psylla natural enemies during early season also showed psylla suppression during mid- and late season (e.g., Quince 1988 diflubenzuron/oil, McCarty 1987 diflubenzuron only trials). Conversely, those selective trials which did not show high levels of predaceous arthropods until late season also showed the highest late season psylla densities.

Compared to Medford selective blocks, early season natural enemies were less abundant in the Hood River selective blocks. For example, the mean number of natural enemies remained below 0.5/tray until August in one of the more successful Hood River trials (1988 Quince diflubenzuron/oil), whereas this level was surpassed by June at a Medford orchard showing biological control (Westigard et al. 1986).

The abundance of pear psylla natural enemies depends on many factors. The importance of the vegetational setting was demonstrated in Ch. II. Detailed analyses of the taxonomic composition of effective and ineffective seasonal assemblages of pear psylla natural enemies are presented in Ch. IV. The low abundance of natural enemies in the Hood River selective blocks is due partly to the chemical regime.

Pesticide applications at dormant and delayed-dormant timings, especially fenvalerate, undoubtedly hindered natural enemy colonization and development. Fenvalerate is fairly toxic to most arthropod generalist predators (Croft 1990). Early season dormant sprays may also lower densities of psylla and other prey of generalist predators below that required for colonization and survival (Brunner 1975). In southern Oregon, the deletion of fenvalerate from delayed dormant sprays did not result in significantly higher russet damage except in cases of high overwintering psylla densities (e.g. 12 adults/tray) (Westigard, personal communication). Omitting early season applications of pyrethroids from the selective programs might enhance early season natural enemy colonization.

Diflubenzuron may not be as selective a compound as is necessary to ensure biological control of the pear psylla in Hood River. Although biological control did not always occur in unsprayed mini-orchards located near these commercial blocks, numbers of natural enemies were often higher there (Ch. I). At the McCarty site, for example, large numbers of *Plagiognathous guttatipes* colonized a mini-orchard of unsprayed pear but failed to colonize the immediately adjacent commercial block under diflubenzuron control.

The failure of the Hood River selective trials relative to the Medford trials are also due to the limited efficacy of mancozeb. This fungicide has been applied to Hood River pear orchards for at least 14 years (Spotts, personal communication), so resistance may have developed among local psylla populations. Initial investigations of the insecticidal efficacy of

mancozeb were made in British Columbia and included dual sprays applied during mid-June and early July (McMullen and Jong 1971). In those trials, mancozeb was quite effective against psylla nymphs, apparently killing few eggs or adults. The Hood River mancozeb applications were made later in the season, when all psylla life-stages were present.

Mancozeb may have been more effective if it had been applied earlier in the season against when young nymphs were dominant.

The addition of oil to the diflubenzuron sprays accounted, in part, for the superiority of that program. Petroleum oil inhibits and delays psylla oviposition when applied pre-bloom (Zwick and Westgard 1978) and presumably performed similarly here when added to the early diflubenzuron sprays. Foliar applications of superior-type oils have been used for pear psylla control (Zwick and Pfeiffer 1968) but have been largely discontinued due to foliage and fruit injury (Burts 1983). Few studies have been conducted on the effects of petroleum oils on natural enemies of the pear psylla. Direct applications of Volck Supreme oil caused lower mortality to *D. brevis* nymphs and adults than applications of OPs (Westgard 1973).

Phytophagous mite control

Diflubenzuron is not a miticide and had no direct effect on phytophagous mites in these studies. However, the selective nature of diflubenzuron and the miticidal effects of oil helped control phytophagous mites on pear. Petroleum oils are toxic to tetranychid eggs (Cranham and Helle 1985) and undoubtedly helped suppress mites in the diflubenzuron/oil blocks. Because additional miticides were required at times in the selective blocks, the addition of oil to foliar sprays of diflubenzuron may not assure mite control.

Predaceous insects also contributed to the regulation of phytophagous mites. Many of the species sampled in the selective blocks are documented natural enemies of mites (Chazeau 1985). *Orius spp.* and *Stethorus spp.* consume tetranychid mites (McMurtry et al. 1970, Hull et al. 1977), both of which were sampled in the selective blocks. In unsprayed pear blocks in the Hood River Valley, phytophagous mites remained low throughout the season due to the presence of predaceous insects while predator mites were absent or remained low (Ch. II).

The lack of predator mites in these blocks is noteworthy. Although oils selectively allow for the development of phytoseiid eggs (Croft and McGroarty 1977), pre-bloom

applications of pyrethroids, which can be especially disruptive to predator mites (Riedl and Hoying 1983), hindered biological mite control during these studies. The dominant predatory mites of Hood River apple orchards are substantially less abundant on pear (Zwick 1972).

Codling moth control

The successful codling moth control demonstrated in these trials corroborates results of other studies of diflubenzuron-based programs. Aside from a recent instance of diflubenzuron resistance in a small pear orchard in southern Oregon (Moffitt et al. 1988), diflubenzuron applied in three cover sprays has effectively controlled codling moth in the Medford and Wenatchee regions for the past several years (Westigard 1979, Burts 1983). Although the Medford resistance case may indicate future problems, the surrounding circumstances are not well understood (Moffitt et al. 1988). Other cases of diflubenzuron resistance currently under investigation in California suggest the phenomenon may represent cross resistance to OPs (Welter, personal communication).

IV. TAXONOMIC COMPOSITION OF SEASONAL NATURAL ENEMY COMPLEXES AND THEIR PEAR PSYLLA PREY AND THE POTENTIAL FOR BIOLOGICAL CONTROL IN COMMERCIAL AND UNSPRAYED ORCHARDS OF THE HOOD RIVER VALLEY

Introduction

In two previous sections (Ch. II, Ch. III), successful cases of pear psylla biological control were identified among Hood River orchards of differing vegetational setting, chemical regime, age, size. In the first study (Ch II), important natural enemies of the pear psylla and their non-pear host plants were identified in the Hood River Valley. The second study (Ch. III) addressed the role of natural enemies in a selective chemical control program. Both studies corroborated other investigations (Gut et al. 1982, Westigard et al. 1986) that the seasonality of dominant psylla natural enemies strongly influenced their effectiveness as biological control agents of the pear psylla. Late season psylla densities seemed to be best suppressed when levels of natural enemies were high during early season.

Although broad in scope, these studies (Ch. II, Ch. III) were limited in two ways. First, abundances of particular natural enemies were obscured by describing the guild as the total number of natural enemies, regardless of life stage, species, or species group. Second, since mature unsprayed pear trees were not available, most pear psylla natural enemies were sampled in three year old mini-orchards (Ch. II). These orchards differed from commercial orchards in size, age, and tree spacing. Effects of orchard type (mini- or commercial) have not been directly addressed.

The purpose of this chapter is two-fold. First, to compare effects of orchard site, chemical regime, orchard type (commercial or mini-), and season on their taxonomic composition, complexes of natural enemies and their pear psylla prey were compared with an objective classification analysis. Second, the taxonomic compositions of seasonal natural enemy complexes from pear blocks which demonstrated different levels of biological control success were contrasted. These comparisons helped define the potential of natural enemies to regulate pear psylla.

Materials and Methods

Observations from each of the orchard trials described in the two previous sections were partitioned into two seasons based on cumulative degree days (DD) from psylla biofix (date upon which the first psylla egg was found). Samples collected before 1350 DD represented early season, while samples collected between 1350 DD and 2450 DD represented mid-season. These accumulated degree days corresponded to shifts in the trends of psylla population development and natural enemy abundance which were observed in all study orchards regardless of orchard location or year (Ch. II, Ch. III). Because the trajectory toward successful biological control seems to be established during early and mid-season (Gut 1985, Westgard et al. 1986, Ch. II, Ch. III), late season natural enemy guilds were omitted from these analyses.

The most common 45 natural enemies, identified as operational taxonomic units (OTUs, Ch. II) were included in these analyses. Except for a few rare species, these 45 natural enemy OTUs represent the guild of predaceous and parasitic arthropods preying on pear psylla in the Hood River Valley (Ch. II). As applied here, a seasonal complex of pear psylla natural enemies was characterized by these 45 natural enemies plus pear psylla eggs and nymphs sampled within each orchard, year, and season expressed as the abundance of each OTU relative to abundance of all natural enemies (#/beating tray) plus density of psylla immatures (#/ten leaves). Given the importance of predator/prey ratios in the development of arthropod communities (Glasser 1982), the abundance of a natural enemy relative to all other natural enemies plus their pear psylla prey provided a meaningful descriptor of the composition of natural enemy guilds and their pear psylla prey. In addition, the relativized scale allowed complexes which differ greatly in absolute abundances to be compared.

In addition to season, complexes of natural enemies were characterized as effective or not according to their demonstrated level of biological control. These designations were made in previous sections for complexes in unsprayed (Ch. II) and commercial (Ch. III) orchards.

Although resemblance functions (indices of similarity) provide useful analytical techniques to the study of arthropods (Southwood 1978a), they have infrequently been applied to studies of tree-fruit arthropod communities. Brown and Adler (1989) used percent

similarity to compare arthropod communities among orchards under differing management strategies. The squared Euclidean distance (SED) is one of the more common indices of similarity and has been described as an appropriate measure of ecological similarity among species assemblages (Austin and Orloci 1966). SED expresses species associations in terms of an n -dimensional conceptual hyperspace and is calculated as:

$$SED = \Sigma(n_{ij} - n_{ik})^2$$

where i = OTU index, j and k are complex indices, and n_{ij} is the abundance of OTU i in complex j .

Hierarchical classification analysis is a preferred technique to compare species assemblages among either different habitats or time periods (Gauch 1981). Seasonal guilds of natural enemies and their pear psylla prey were hierarchically classified according to an agglomerative algorithm based on SED available in the SPSSPC+ V 3.0 statistical package (Norusis/SPSS Inc. 1988). For each classification, SED was rescaled to a maximum value of 25. Complexes of similar taxonomic composition were combined according to the default average-linking process. The output was a dendrogram depicting clusters of seasonal natural enemy guilds of similar taxonomic composition linked at smaller values of the rescaled squared Euclidean distance (RSED) compared to more dissimilar guilds linked at higher values.

Altogether, eight classifications were conducted. First, to generally compare the effects of season, chemical regime, orchard type, and natural enemy effectiveness, all seasonal complexes were classified. Such a comprehensive classification analysis provides little information on the relative impact of these variables. Instead, effects of each variable were investigated by classifications of seasonal natural enemy complexes from similar orchards and from the same season. Four classifications were conducted on complexes from the same season and commercial control program (early season selective, mid-season selective, early season standard, and mid-season standard). Three classifications were conducted on complexes from the unsprayed block. Because psylla immatures were not sampled at Lone Pine Block until mid-season, that complex was excluded from the early season classification. To allow comparisons, two classifications of mid-season complexes were conducted, one with

the Lone Pine Block fauna and one without.

These last three classifications represented orchards differing not only in site, but also in size, age, and years without pesticide application. Unfortunately, the number of orchards in each category was low, limiting the ability to compare the effects of each variable. Still, the two Valley Crest orchards offered an opportunity to compare the natural enemy composition in two pear blocks of the same age and location, but of differing size. The mature Power Block, left unsprayed since 1987, offered an opportunity to compare complexes during the second and third years after insecticides were discontinued.

To depict the taxonomic composition of several similar complexes (suite), the proportion of each OTU among those complexes (prop) was multiplied by its ubiquity (B) to calculate an index representing both proportional abundance and ubiquity (PAU). The ubiquity index B, introduced by Levins (1968) as an index of 'niche-breadth' was formulated as:

$$B = Q_i^2 / \sum p_{ij}^2$$

where i = OTU index, j = complex index, p_{ij} is the proportion (relative abundance) of OTU i in complex j , and Q_i = summed p_{ij} for OTU i . B was calculated with a PC version of the AIDN program (Overton et al 1987). The proportion of a given OTU within a suite of complexes was calculated as:

$$\text{prop} = Q_i / \sum Q_i$$

where Q_i is the same as above.

Compared to the sum of B and prop, the product of these two measures extends the range between OTUs of low with low relative abundance and ubiquity compared to those with high relative abundance and ubiquity, enhancing its discriminatory power. To compare suites of differing numbers of complexes, PAU was relativized among complexes to calculate a relative measure of proportional abundance and ubiquity (RPAU). The sum of RPAUs for all natural enemies within an assemblage always equaled 1. The formula for RPAU is as follows:

$$\text{RPAU} = \{(Q_i / \sum Q_i) \times (Q_i^2 / \sum p_{ij}^2)\} / \sum \{(Q_i / \sum Q_i) \times (Q_i^2 / \sum p_{ij}^2)\}$$

Criteria for similarity was arbitrarily set at an average linkage of ten rescaled SED

units. Complexes linked below ten RSED were considered similar while those linked above ten were considered dissimilar. A threshold of ten RSED partitioned three to five similar complexes into a suite, a number small enough to discriminate differences among complexes, but large enough to allow generalization.

Because guilds of predaceous arthropods and pear psylla immatures in the mini-orchards were so dissimilar among themselves, and because observations were made at only four sites for a single year, RPAU were not calculated for any of the unsprayed sites. Instead, histograms of the proportional abundances of the thirty selected OTUs were visually compared.

Results

Similarity of seasonal complexes of natural enemies and pear psylla immatures

Figure IV.1 is a dendrogram depicting similarity of taxonomic composition among 53 early and mid-season complexes which include both natural enemies (Table II.2) and pear psylla eggs and nymphs sampled during these studies (Ch. II, Ch.III). Although not clear cut, some general patterns are visible. For example, most complexes linked at an average value of less than five RSED comprised samples from the same season. Most complexes in the Valley Crest commercial blocks are closely linked. The comprehensive classification confirmed previous results (Ch. II, Ch. III) that their taxonomic composition was strongly influenced by site, orchard chemical regime, and season. Orchard type (commercial or mini-) also influenced patterns of taxonomic similarity. In general, complexes in unsprayed mini-orchards are dissimilar from complexes in commercial blocks managed under standard chemical programs.

In addition, Figure IV.1 indicates that seasonal complexes from blocks where biological control was successfully demonstrated were often taxonomically similar. In particular, four of six very similar mid-season complexes effectively suppressed pear psylla. Other effective complexes are not as tightly linked, but are strongly dissimilar from most complexes in pear blocks where biological control failed to occur.

Taxonomic composition of seasonal complexes of pear psylla natural enemies and pear psylla immatures in commercial blocks under programs of selective chemical control

Figure IV.2 indicates that orchard site, season, and natural enemy effectiveness affected the taxonomic composition of seasonal complexes of natural enemies in commercial orchards under selective chemical control. Three of four complexes in the Valley Crest blocks are relatively tightly clustered and dissimilar from those in the lower valley, especially during mid-season. Aside from the distinction between upper and lower valley sites, natural enemy effectiveness appears to be the most visible variable affecting early season patterns of similarity. Complexes which showed effective biological control were more taxonomically similar during early season than during mid-season.

Effective early season complexes in the selective blocks had higher levels of pear

psylla immatures, lacewing larvae, earwigs, and the parasitoid, *T. insidiosus* (Figure IV.3A) compared to the other less effective, yet taxonomically similar suites (Figure IV.3B). Suites of less effective complexes were primarily spider dominated (Figure IV.3B, IV.3C).

Effective mid-season complexes in the selective block had relatively higher levels of both *D. brevis* nymphs and adults, as well as both lacewing adults and nymphs (Figure IV.4A). The two closely-linked mid-season complexes in the McCarty selective trials were dominated by earwigs, but adult *D. brevis* and chrysopids were also present (Figure IV.4B). The five less effective, yet very similar complexes were largely psylla and spider dominated (Figure IV.4C) as were the remaining Valley Crest complexes (Figure IV.4D).

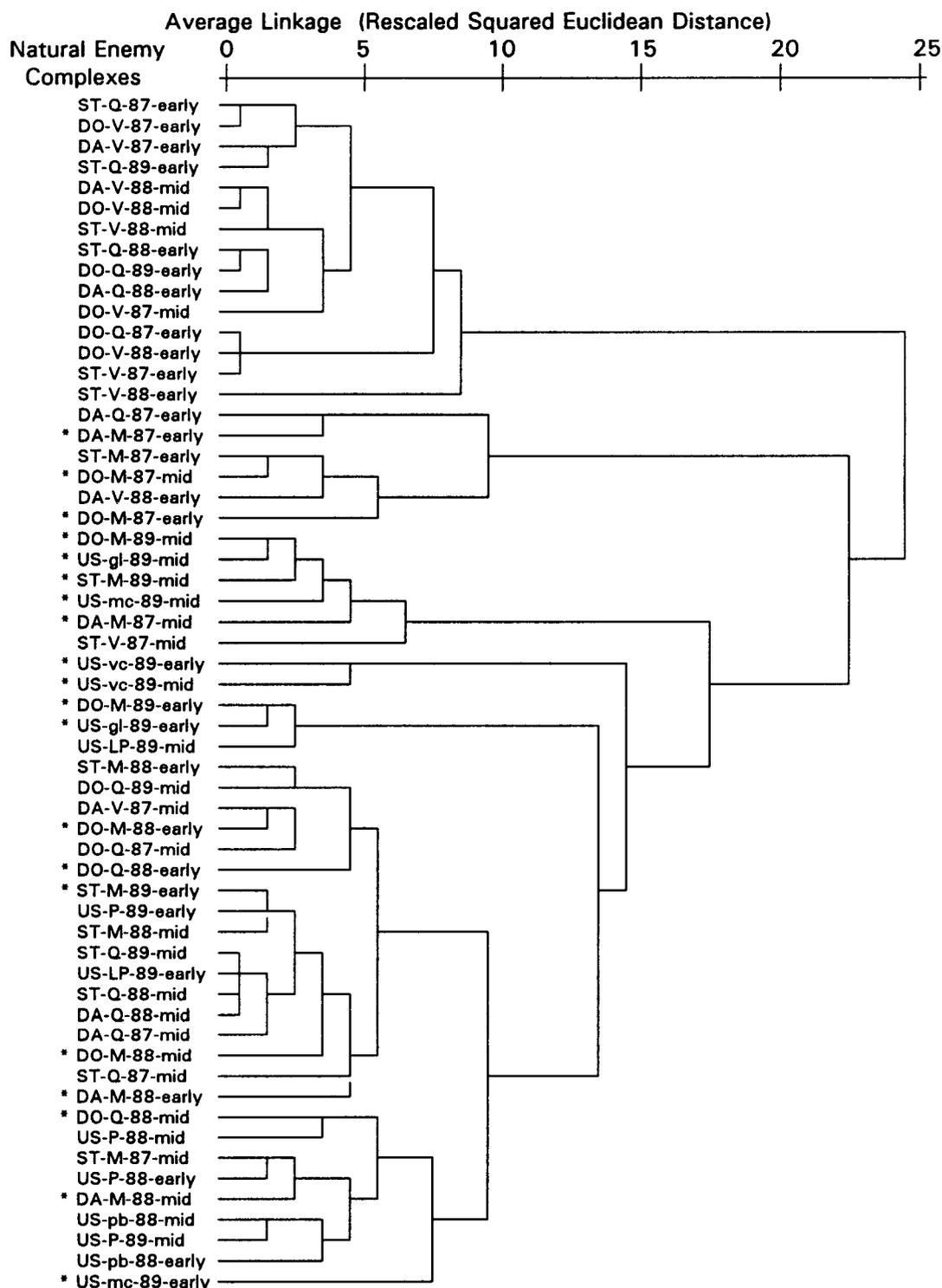


Figure IV.1. Comprehensive classification of 53 seasonal complexes of natural enemies and pear psylla immatures. Complexes are coded by chemical program (DO=diflubenzuron/oil, DA=diflubenzuron alone, US=unsprayed), site & type (Q=Quince, M=McCarty, VC=Valley Crest, PB=mature Power Block, mc=McCarty mini-orchard, gl=Gale mini-orchard, vc=Valley Crest mini-orchard, pb=Power Block mini-orchard, lp=Lone Pine Block at Valley Crest), year (87=1987, 88=1988, 89=1989) and season of samples (early or mid), and biological control success (* = successful).

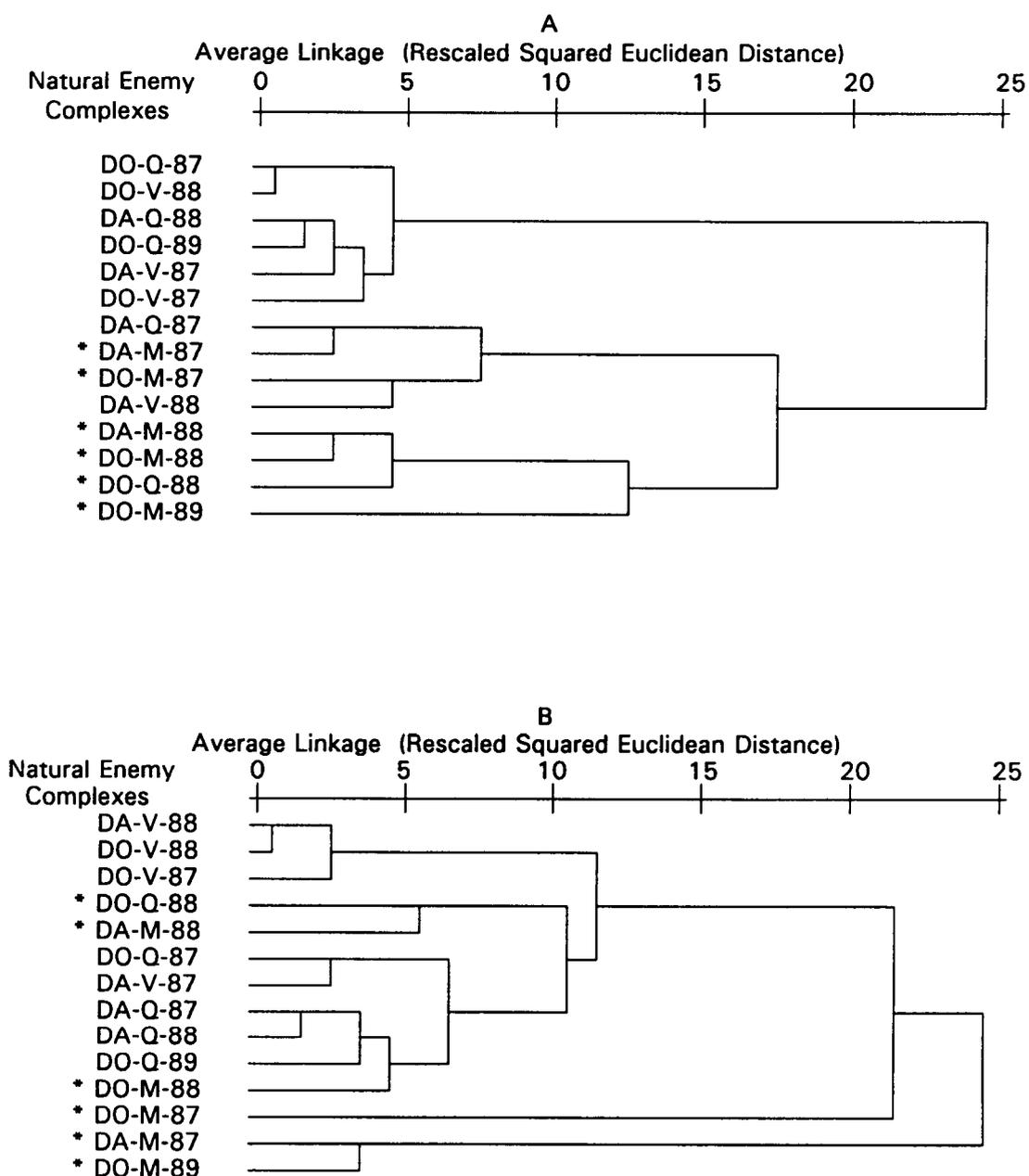


Figure IV.2. Classification of A) early- and B) mid-season complexes of natural enemies and their pear psylla immatures in commercial pear blocks under selective pest control programs (DO = diflubenzuron/oil, DA = diflubenzuron alone), site, (Q = Quince, M = McCarty, VC = Valley Crest), year of samples (87 = 1987, 88 = 1988, 89 = 1989), and biological control success (* = successful).

Selective Trials -- Early-Season

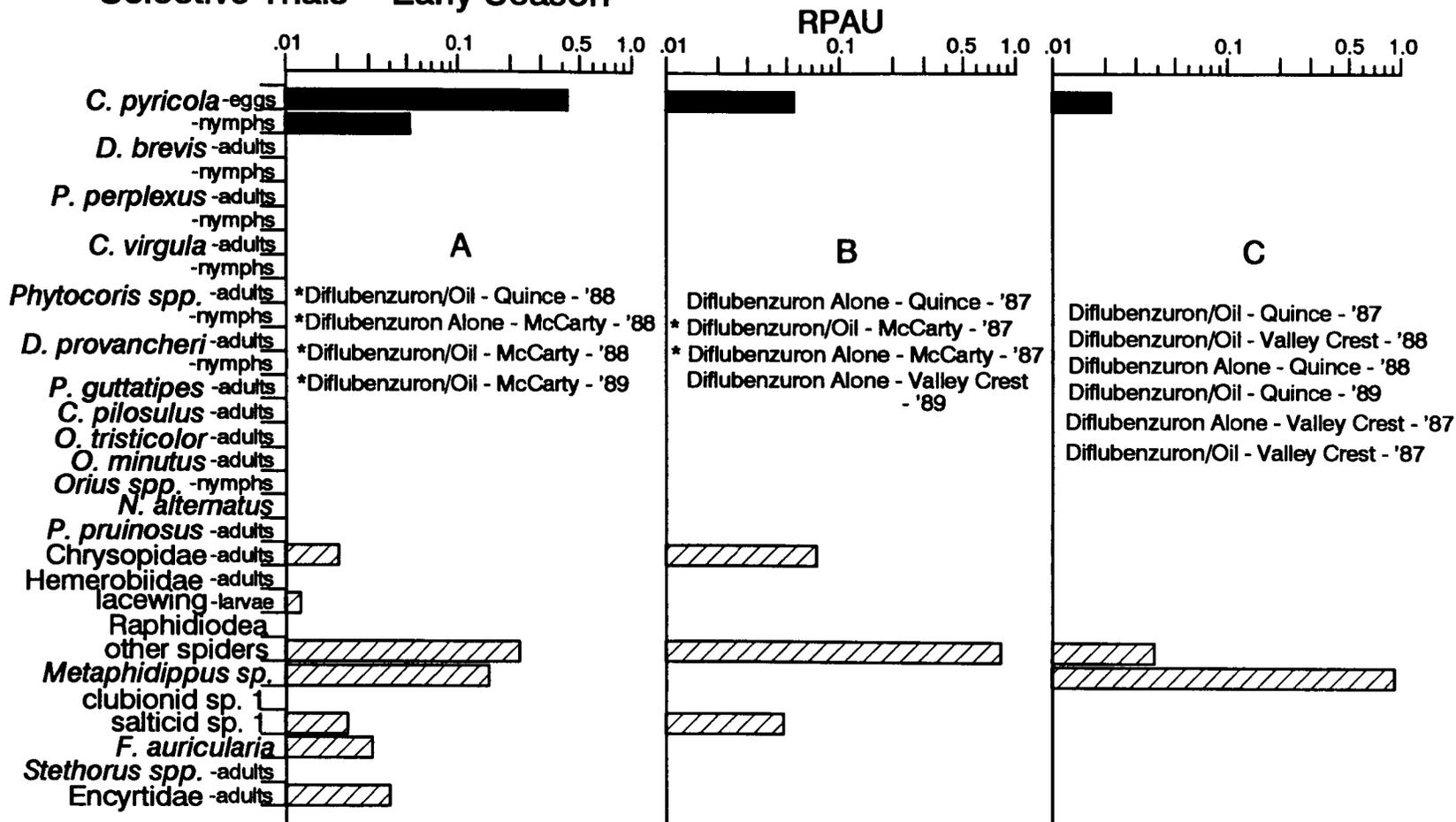


Figure IV.3. Relative proportional abundance and ubiquity (RPAU) of 28 natural enemies and pear psylla eggs and nymphs sampled during early season in commercial pear blocks under selective chemical control. Each histogram represents assemblages within a suite of assemblages of similar taxonomic composition. Asterisks indicate trials where successful biological control was demonstrated.

Selective Trials -- Mid-Season

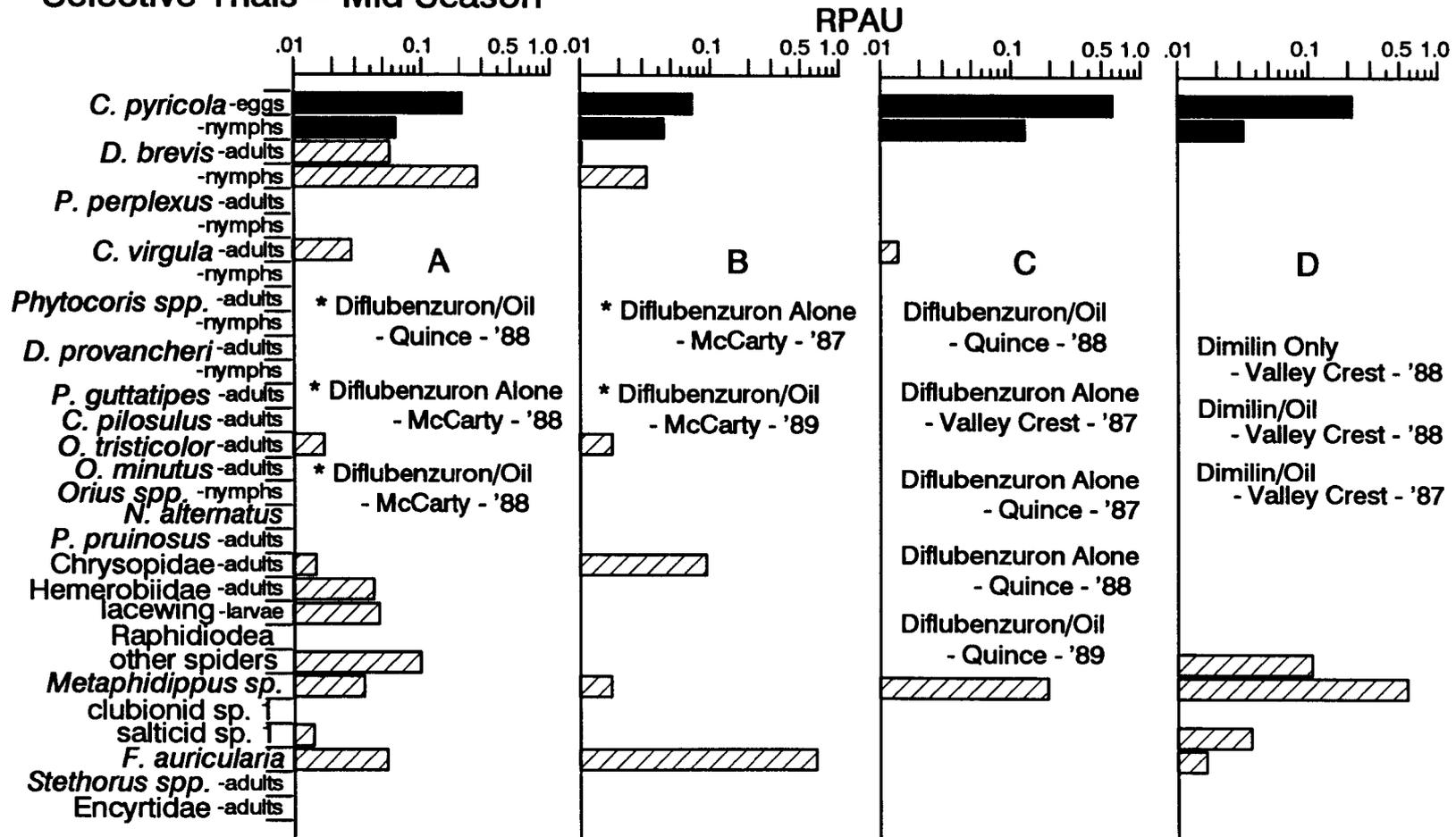


Figure IV.4. Relative proportional abundance and ubiquity (RPAU) of 28 natural enemies and pear psylla eggs and nymphs sampled during mid-season in commercial pear blocks under selective chemical control. Each histogram represents assemblages within a suite of assemblages of similar taxonomic composition. Asterisks indicate trials where successful biological control was demonstrated.

Taxonomic composition of seasonal complexes of natural enemies and pear psylla immatures in commercial blocks under programs of standard chemical control

Early-season natural enemy complexes in commercial pear blocks under standard chemical control showed patterns of similarity which were strongly associated by site (Figure IV.5). Unlike the dendrograms representing the selective blocks, early season complexes from McCarty blocks were dissimilar from all other blocks. The effect of site was less apparent during mid-season, when patterns of similarity appeared more random. However, the mid-season 1989 McCarty complex was dissimilar from all others. Natural enemies suppressed psylla to some degree in that block (Ch. III).

In general, the standard blocks were largely spider and psylla dominated during both early and mid-season (Figures IV.6, IV.7, respectively). The suite representing most of the early season standard blocks was dominated primarily by psylla immatures (Figure IV.6A). In addition, compared to other early season complexes from the standard trials, those from the 1988 and 1989 McCarty standard blocks show higher levels of hemerobiid adults and psylla immatures (Figure IV.7B).

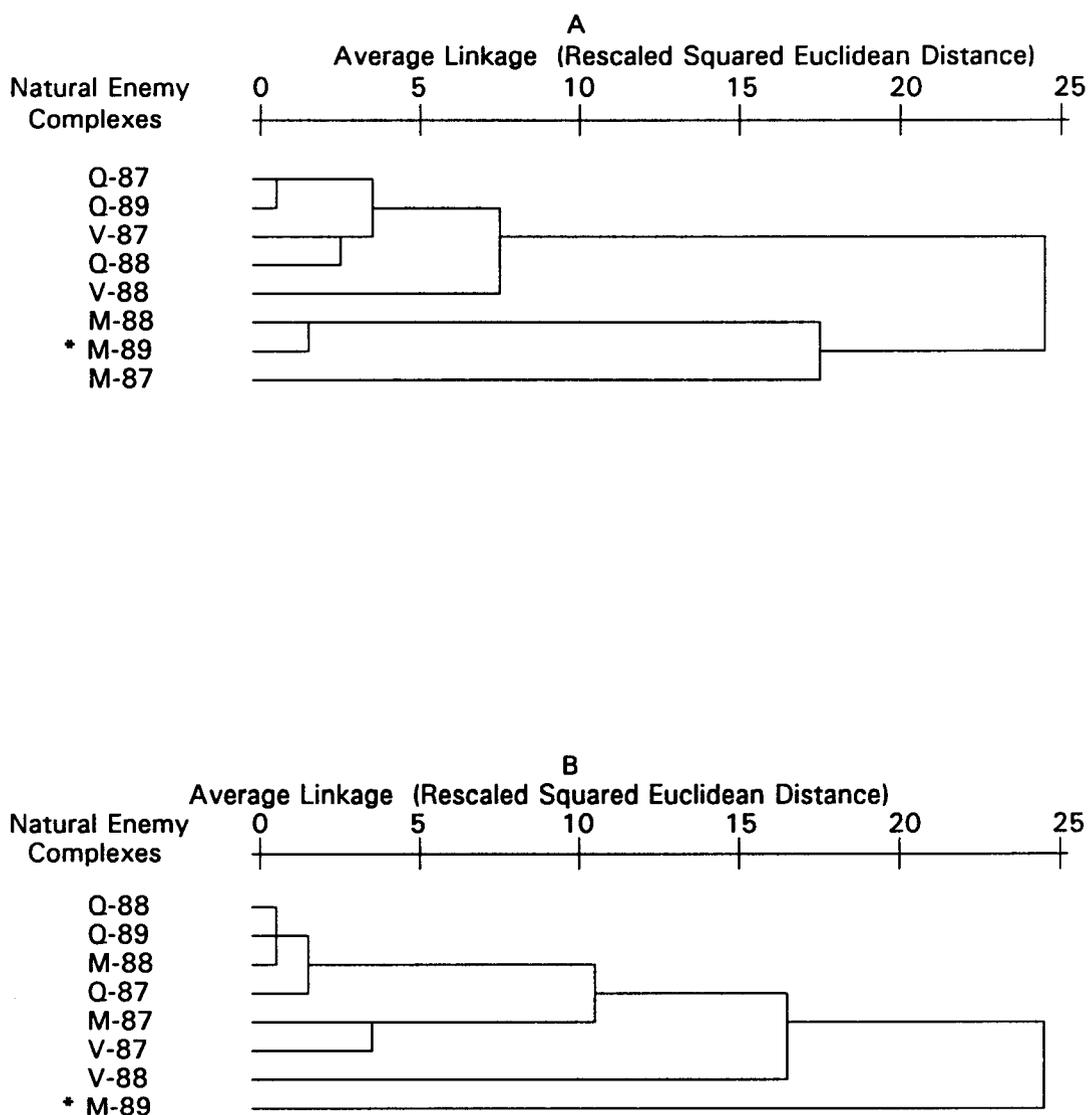


Figure IV.5. Classification of A) early and B) mid-season complexes of natural enemies and pear psylla immatures in commercial pear blocks under standard programs of pest control. Assemblages are characterized by site (Q = Quince, M = McCarty, VC = Valley Crest, year of samples (87 = 1987, 88 = 1988, 89 = 1989), and biological control success (* = successful).

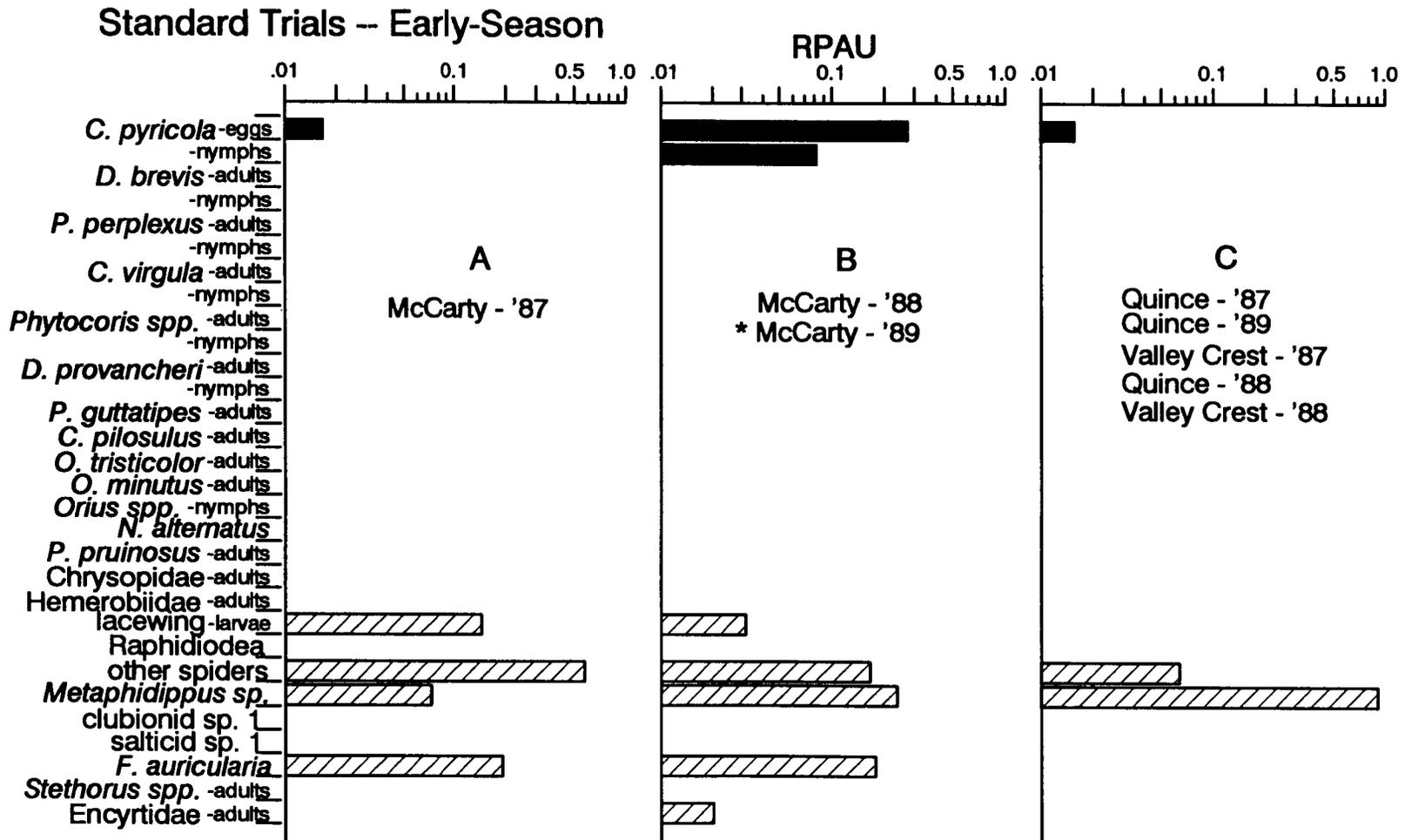


Figure IV.6. Relative proportional abundance and ubiquity (RPAU) of 28 natural enemies and pear psylla eggs and nymphs sampled during early season in commercial pear blocks under standard chemical control. Each histogram represents assemblages within a suite of assemblages of similar taxonomic composition. Asterisks indicate trials where successful biological control was demonstrated.

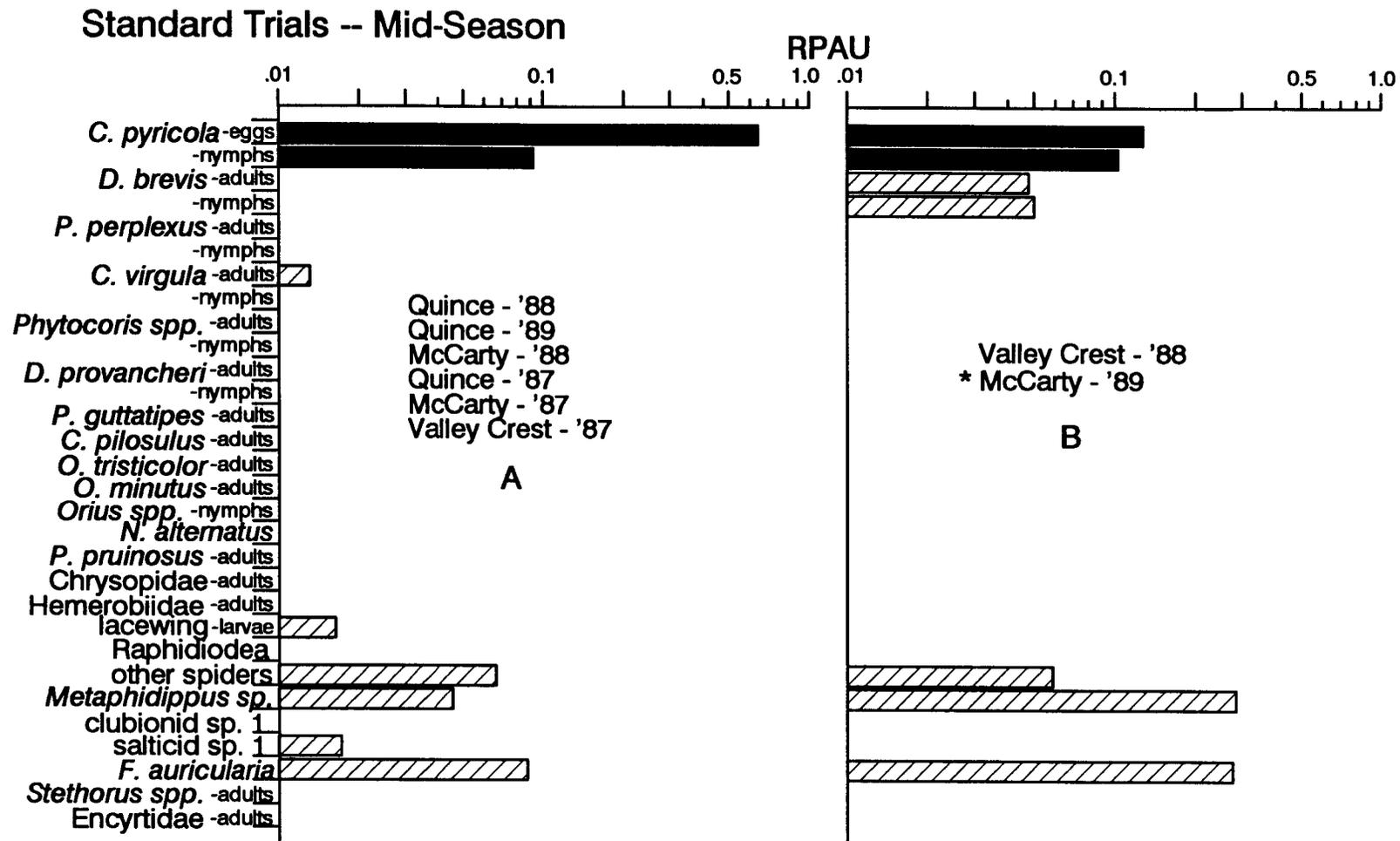


Figure IV.7. Relative proportional abundance and ubiquity (RPAU) of 28 natural enemies and pear psylla eggs and nymphs sampled during mid-season in commercial pear blocks under standard chemical control. Each histogram represents assemblages within a suite of assemblages of similar taxonomic composition. The asterisk indicates a trial where successful biological control was demonstrated.

Taxonomic composition of seasonal complexes of natural enemies and pear psylla immatures in unsprayed pear blocks

Dendrograms of seasonal natural enemy complexes from unsprayed pear are shown in Figure IV.8. Like all previous dendrograms, these show that orchard site strongly influences taxonomic composition of the natural enemy complex. Complexes in orchards at the Power Block site were taxonomically similar during both early and mid-season, despite differences in orchard size and age.

However, the complex in the large commercial planting at Valley Crest, Lone Pine Block, was taxonomically dissimilar from the Valley Crest mini-orchard and all other unsprayed blocks during mid-season. The early season complex was not sampled at Lone Pine Block, and so could not be included in that classification. Differences in size and tree spacing between these two orchards of similar site and age were important here.

Figure IV.9 show the relative abundance of pear psylla and their natural enemies within each mini-orchard during early season. At the McCarty mini-orchard, where psylla were immediately and effectively suppressed (Ch. II), *P. guttatipes*, *P. pruinosis*, *F. auricularia*, and pear psylla immatures were dominant during early season. Both *D. provancheri* adults and immatures dominated the Valley Crest mini-orchard, where pear psylla immatures were lacking. Snakeflies and parasitoids dominated the Gale mini-orchard, where biological control was less successful.

During mid-season, the natural enemy complex at the McCarty mini-orchard was dominated by earwigs, parasitoids, and some spiders (Figure IV.10), as proportions of *P. pruinosis*, *P. guttatipes*, and pear psylla immatures were much reduced from early season. Proportions of the predaceous mirids, especially *D. provancheri* adults and nymphs, were larger at the Valley Crest mini-orchard. Parasitoids and snakeflies continued to dominate the Gale mini-orchard. Although natural enemies were present in small proportions at the Power Block mini-orchard, psylla immatures dominated the complex.

Compared to other study orchards, more natural enemies, especially predaceous Hemiptera, were sampled at the Power Block sites during both early and mid-season (Figures IV.11, IV.12). In all Power Block seasonal natural enemy complexes except the 1988 early

season mature Power Block, proportions of psylla nymphs were quite high. While 13 of the 28 natural enemies were present at the Power Block mini-orchard during early season, pear psylla immatures were dominant.

In addition, the dominant species at the mature Power Block were different in 1988 compared to 1989. While the block was dominated by *D. brevis* and *F. auricularia* during 1988, *P. perplexus* and encyrtid spp. were relatively more abundant during 1989. The shift in taxonomic composition between years is most apparent when early season complexes are compared. More predaceous mirids, especially nymphs were present during 1989.

The taxonomic composition of the natural enemy complexes at the two Valley Crest orchards during early and mid-season are compared in Figures IV.16 and IV.17, respectively. While practically no psylla eggs and nymphs were present in the mini-orchard during both seasons, they dominated the commercial young planting, Lone Pine Block. Immature pear psylla comprised a much larger proportion of the complex in the mini-orchard as opposed to Lone Pine Block, especially during early season.

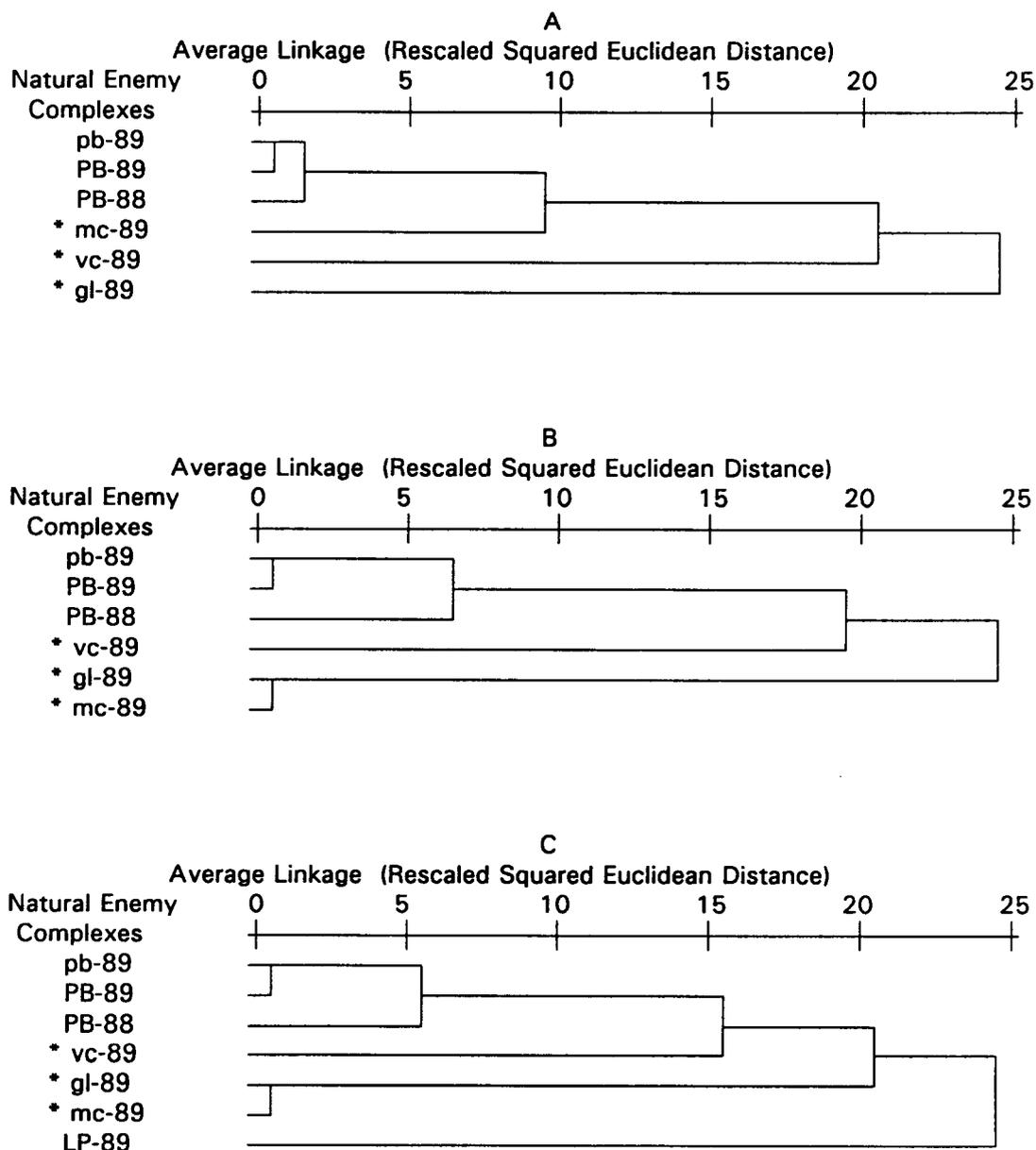


Figure IV.8. Classification of natural enemy complexes in A) unsprayed mini-orchards and mature pear blocks during early season, B) unsprayed mini-orchards and mature pear blocks during mid-season, and C) unsprayed mini-orchards, mature pear blocks, and young commercial planting during mid-season. Complexes are characterized by site & type (PB = mature Power Block, mc = McCarty mini-orchard, gl = gale mini-orchard, vc = Valley Crest mini-orchard, pb = Power Block mini-orchard, LP = Lone Pine Block at Valley Crest), year of sample (87 = 1987, 88 = 1988), and biological control success (* = successful).

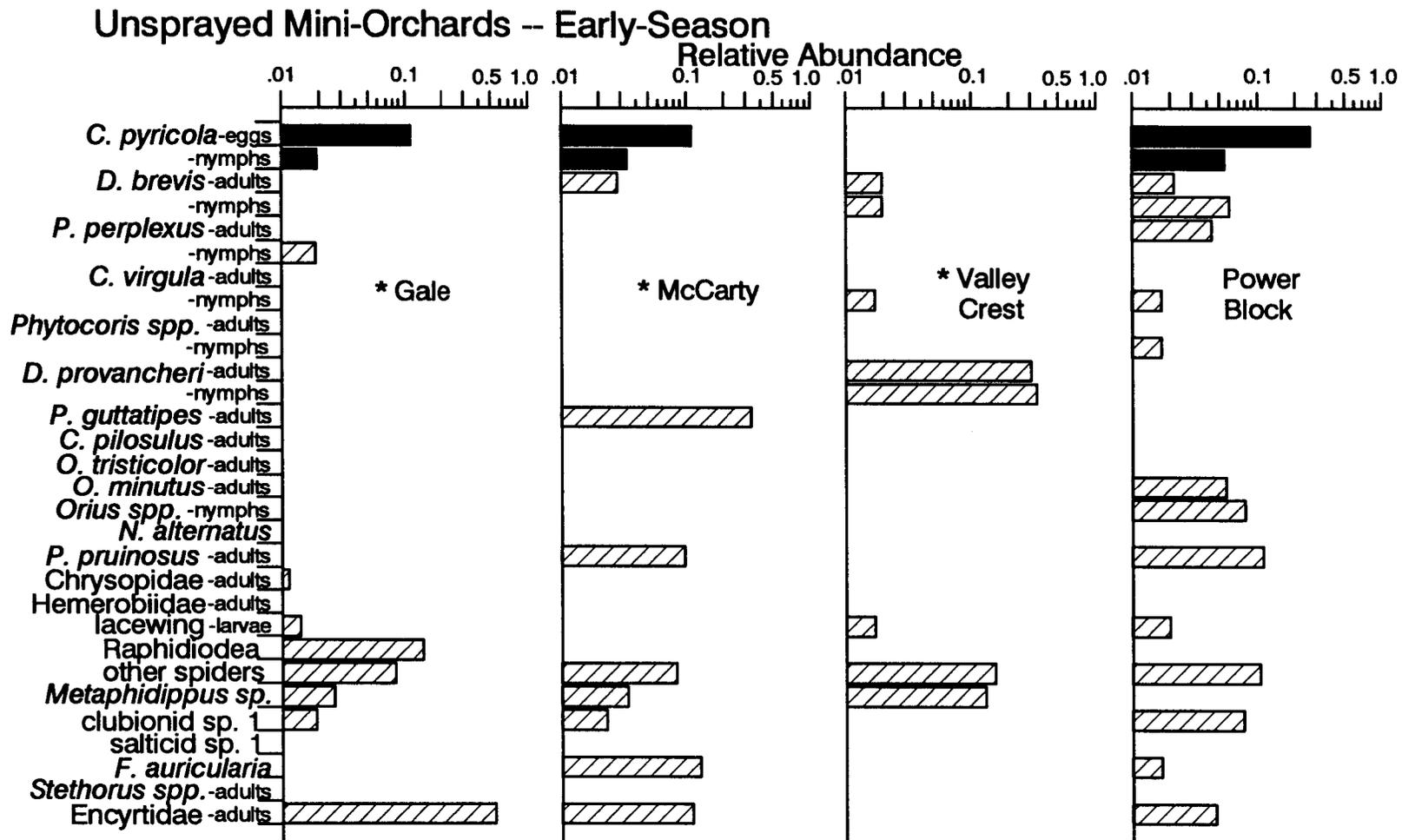


Figure IV.9. Relative abundance of 28 natural enemies and pear psylla eggs and nymphs sampled during early season in unsprayed mini-orchards of young pear. Asterisks indicates orchards where successful biological control was demonstrated.

Unsprayed Mini-Orchards -- Mid-Season

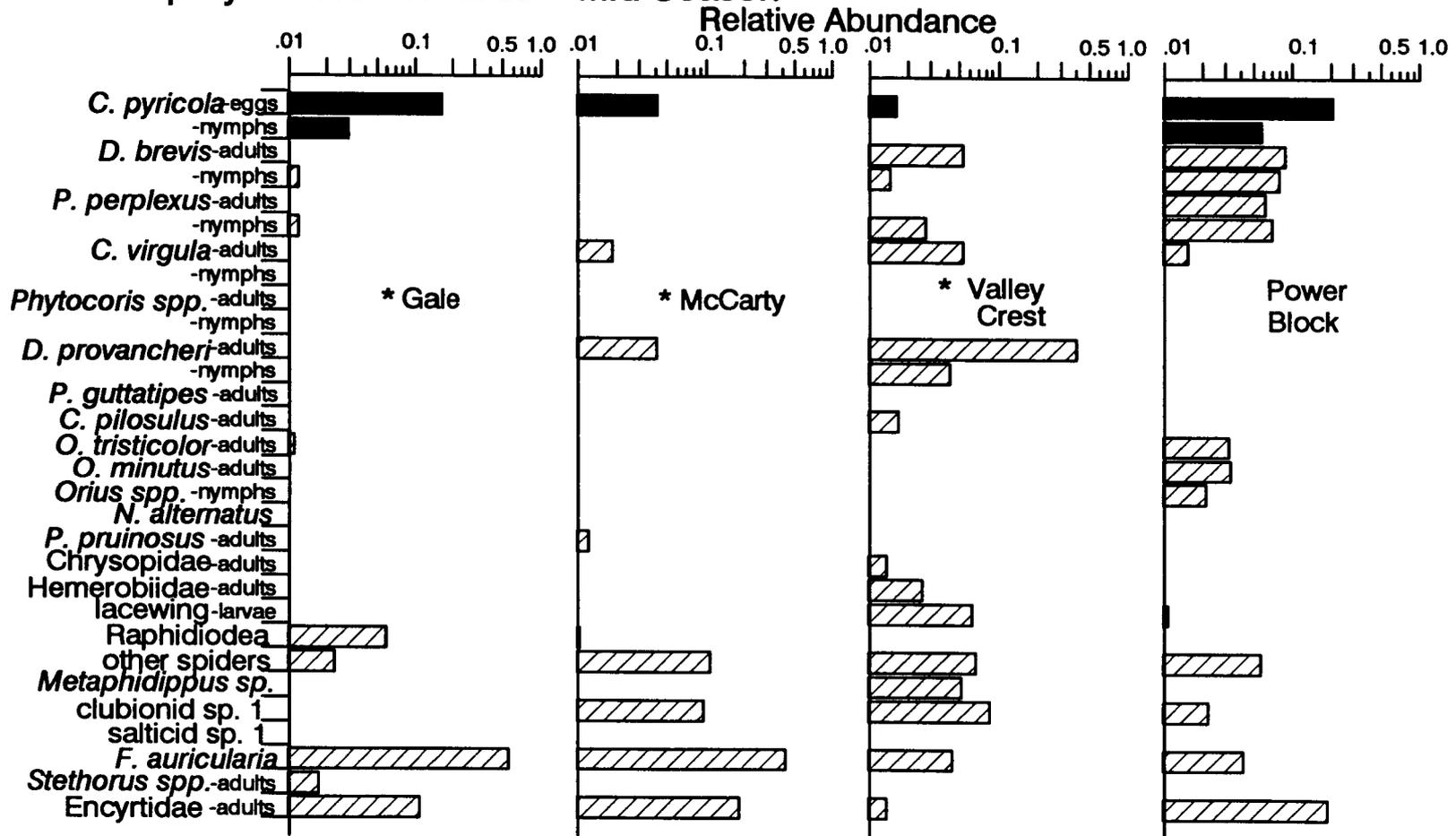


Figure IV.10. Relative abundance of 28 natural enemies and pear psylla eggs and nymphs sampled during mid-season in unsprayed mini-orchards of young pear. Asterisks indicates orchards where successful biological control was demonstrated.

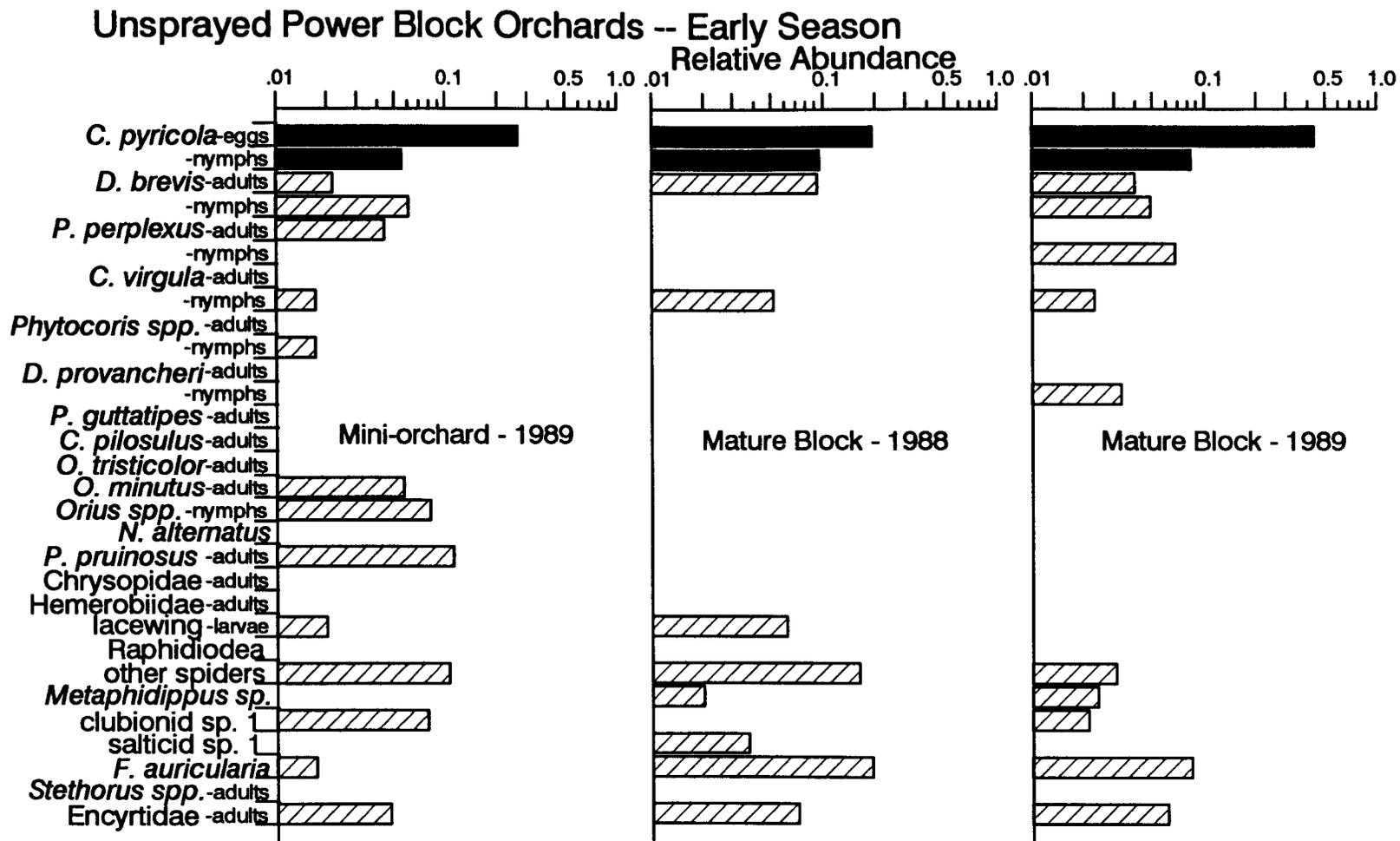


Figure IV.11. Relative abundance of 28 natural enemies and pear psylla eggs and nymphs sampled during early season in unsprayed pear orchards at the Power Block site.

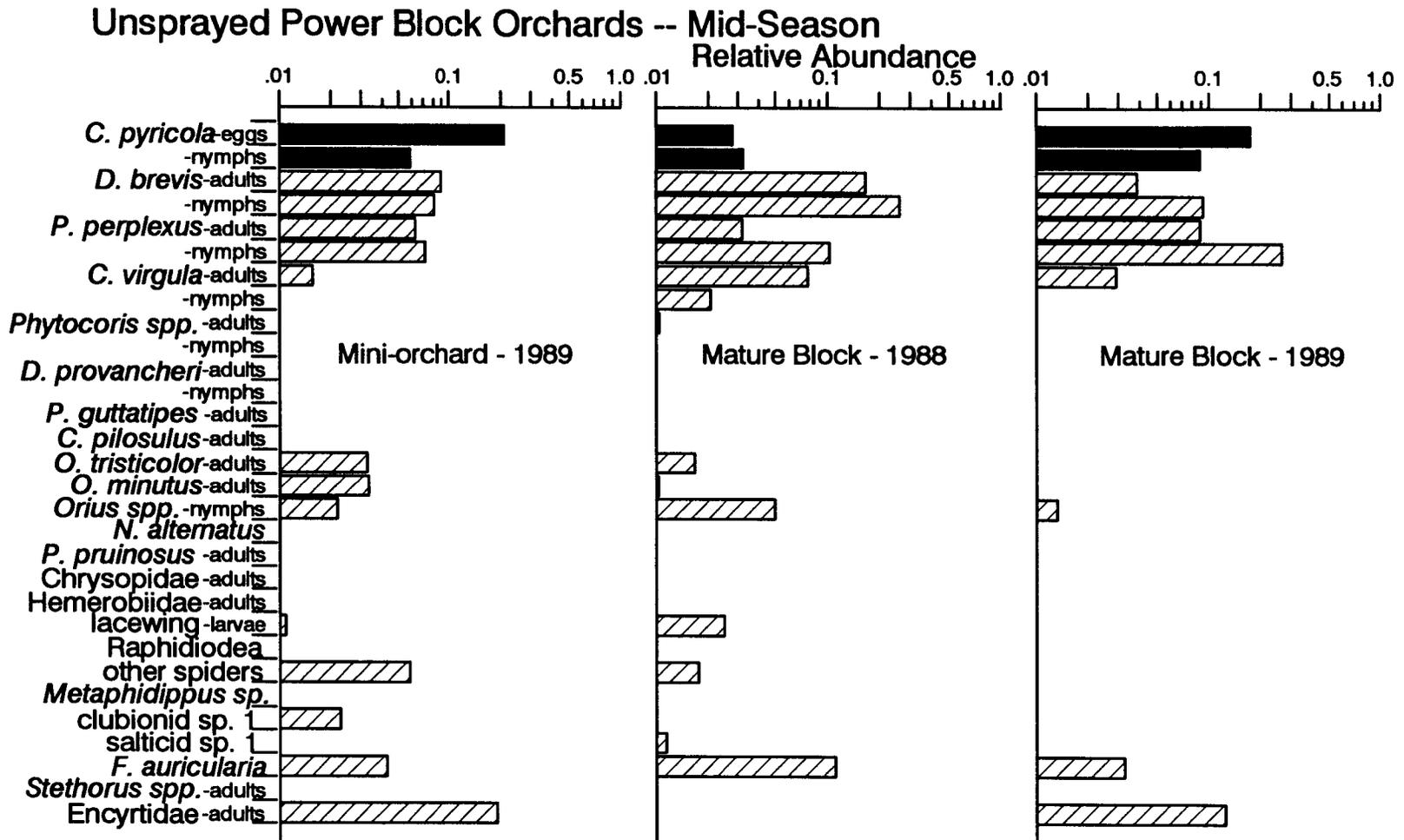


Figure IV.12. Relative abundance of 28 natural enemies and pear psylla eggs and nymphs sampled during mid-season in unsprayed pear orchards at the Power Block site.

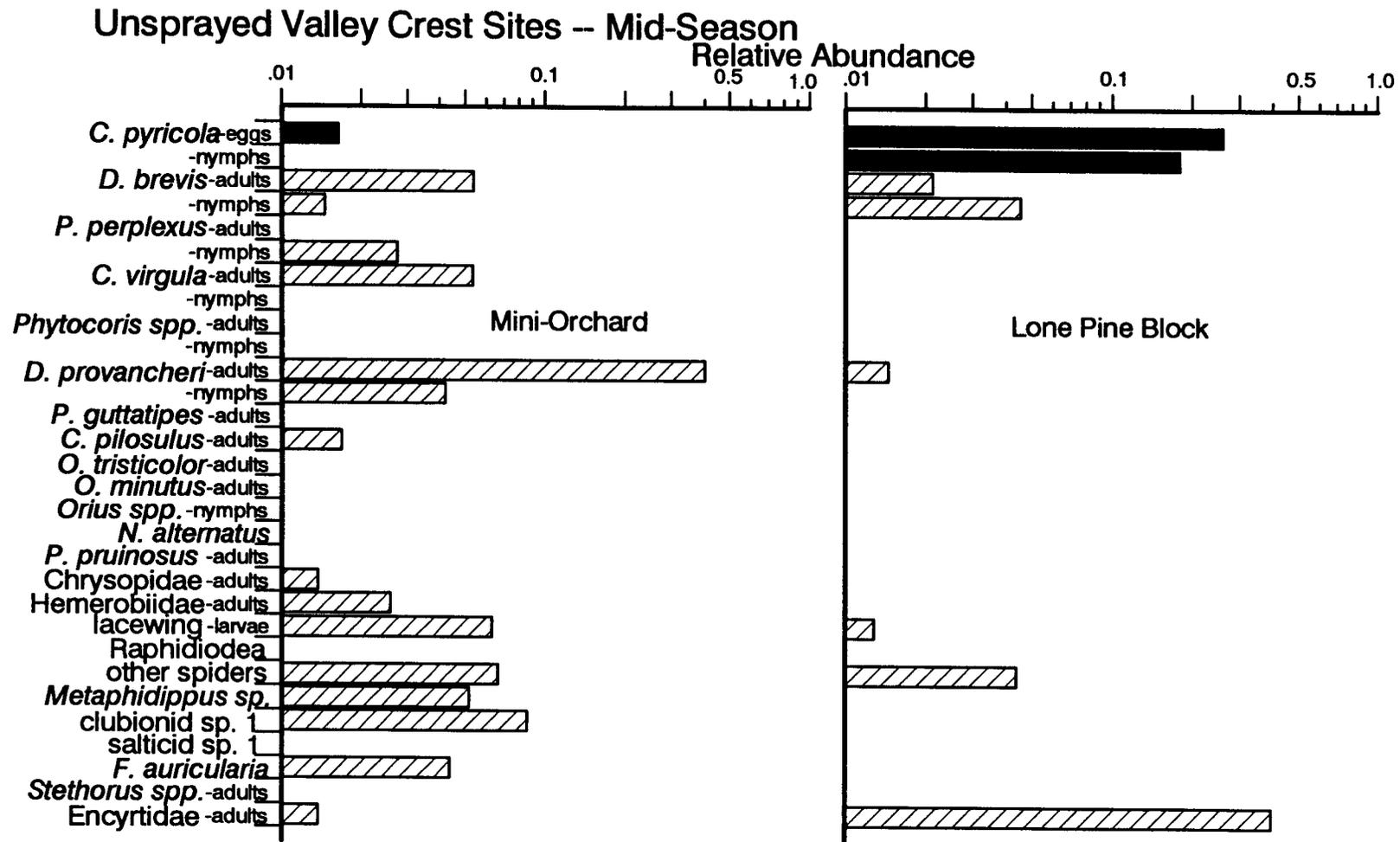


Figure IV.13. Relative abundance of 28 natural enemies and pear psylla eggs and nymphs sampled during mid-season in unsprayed pear orchards at the Valley Crest site.

Discussion

The only natural enemy which consistently dominated effective complexes of natural enemies and was lacking among ineffective complexes was *F. auricularia*. Earwigs were dominant members of effective complexes despite orchard site, type, chemical regime, or season. Although *F. auricularia* has not been previously described as an important psylla natural enemy, current investigations have validated its importance (Edwards et al. 1991).

Spiders have been documented as important generalist predators in a number of agricultural crops (Reichert and Lockley 1984), but appear to be relatively unimportant psylla predators. Spiders dominated ineffective assemblages more often than effective ones. However, the consistently high relative abundance of the two salticid species across all orchards and seasons demonstrates their ubiquity, colonization ability, rate of increase, and apparent tolerance of standard chemical controls. Because spiders are prey primarily on psylla adults (Booth, unpublished data), these analyses focus on pear psylla immatures and only indirectly describe the potential of spiders to suppress the pear psylla.

In the Medford area, two rather distinct seasonal guilds of pear psylla natural enemies were recognized (Gut et al. 1982, Westigard 1986). In some orchards, cantharids, chrysopids, hemerobiids, and snakeflies effectively suppressed psylla during the early season. At other orchards, a mid- to late season complex of *D. brevis*, *Pilophorus* sp., *C. carnea*, and *Hemerobius* spp. was generally not as effective as the early season complex.

Some natural enemies in Hood River orchards were more abundant during early rather than mid-season. In two mini-orchards, these were the same early season species as those in Medford orchards (e.g., snakeflies at Gale, *P. pruinosus* at McCarty). Species not previously described as psylla natural enemies were important early season predators at two other mini-orchards (e.g., *P. guttatipes* at McCarty and *D. provancheri* at Valley Crest).

Early season natural enemies were not proportionally abundant in Hood River commercial blocks managed with selective chemicals, whether or not biological control was demonstrated. Instead, effective natural enemy complexes were dominated by natural enemies described in the Medford studies as mid- or late season species. For example, *Deraeocoris brevis* nymphs and adults were lacking among effective early season complexes in blocks

managed with selective (Figures IV.3A) and standard chemical programs (Figure IV.7B), but were proportionally more abundant among mid-season effective complexes (Figures IV.4A, IV.4B).

Early season proportions of pear psylla immatures figured prominently in the biological control potential of their natural enemies. Except at the Valley Crest mini-orchard, all unsprayed pear blocks where biological control was demonstrated had moderate early season proportions of pear psylla immatures. Adult *P. guttatipes* and *P. prunosus* colonized the McCarty mini-orchard during early season apparently in response to the rapid increase of psylla eggs (Ch. II, Figure II.6) and psylla were suppressed for the remainder of the season. At Power Block, early season proportions of pear psylla were apparently too large to be subsequently suppressed. Early season abundances of pear psylla immatures were quite small relative to natural enemies in the 1987 McCarty selective blocks (Figure IV. 3), but both the role of natural enemies was questionable here (Ch. III). In general, moderate relative abundances of pear psylla immatures among effective early season complexes indicated that a minimum early season prey density enhanced successful biological control.

Simulations of predator/psylla development have substantiated the importance of early season prey densities on subsequent predator effectiveness. Brunner (1975) simulated *D. brevis*, and *Anthocoris nemoralis* development in response to different early season pear psylla densities as regulated by number of dormant sprays. Booij (1990) simulated *Psylla pyri* and *A. nemoralis* development according to both initial psylla density and rate of *A. nemoralis* development and immigration. According to the latter study, immigration rates of *A. nemoralis* must be very high if psylla is to be controlled after very high early season psylla densities. Both simulations excluded factors such as competition, cannibalism and habitat development.

Findings here and elsewhere (Gut 1985, Gut et al. 1988) also indicate that the immigration of arthropod generalist predators to pear orchards depends on the inter-related effects of the vegetational setting, orchard age and orchard size. The importance of the vegetational setting and its attendant species pool has been demonstrated elsewhere (Ch. II), and is also apparent here, as pear blocks from the same site are often taxonomically similar

compared to blocks from other sites. Species pool effects were obviously important at the Power Block site, where the mini-orchard was taxonomically more similar to the mature block than to other mini-orchards at different locations. However, effects of orchard size and tree spacing affected natural enemy abundance at Valley Crest.

In addition to prey density and habitat effects, the seasonal behaviors of pear psylla natural enemies strongly determine immigration rates to pear (Gut et al 1982, Herard 1986). Luff (1983) suggests that overwintering life-stage and voltinism are seasonal life history traits important to the potential of arthropod generalist predators to control prey. The former seemed particularly important in some Hood River orchards.

The mirid *D. provancheri* overwinters in the egg stage in British Columbia (Kelton 1980a) and apparently at the Valley Crest mini-orchard, where nymphs were sampled before adults (Booth unpublished data). In addition, relatively large numbers of fruit clusters in this mini-orchard (Booth unpublished data) may have attracted first generation adults during early season, as *D. provancheri* aggregated to apple trees bearing high proportions of fruit clusters in Nova Scotia (Lord 1968). In either case, large proportions of both adults and nymphs during early season (Figure IV. 9) probably enhanced biological control of psylla at this site.

In addition, overwintering traits also contributed to a shift in the taxonomic composition of the natural enemy guild at Power Block between 1988 and 1989 (Figures IV.11, IV.12). Those species which overwintered in the block as eggs were presumably able to respond numerically to psylla earlier in the season than those species which reinvaded the block during 1989. In particular, *D. provancheri*, *P. pilophorus* and *Phytocoris* spp. reportedly overwinter as eggs (Sanford 1964, Kelton 1982, respectively) and probably did so at the Power Block sites during winter 1988 as nymphs were found before adults during spring 1989 (Ch. II, Figure II.9). Relatively few *D. brevis* overwintered as adults in the pear block in 1989, as adults were abundant in the surrounding vegetation before they appeared in the pear block in 1989 (Booth unpublished data).

According to two perspectives of orchard community development (Brown and Adler 1989, Gut et al. 1988), the potential for biological control is enhanced as the time since pesticides were applied increases. The level of biological control of two pear psyllids, *P. pyri*

and *P. pyrisuga* in Yugoslavian pear orchards is reported to have improved dramatically three years after pesticides were halted (Grbic personal communication). Species shifts in orchards have most often been documented by comparing orchards which have been either conventionally managed or abandoned for several years (Brown and Adler 1989). More than two years is necessary to thoroughly document how discontinued pesticide use may affect the potential for biological control.

V. THE FUNCTIONAL RESPONSE OF FIVE MIRID SPECIES TO EGGS OF THE PEAR
PSYLLA, *CACOPSYLLA PYRICOLA* FÖRSTER

Introduction

In previous sections (Chs. II, III, IV), the endemic fauna of predaceous and parasitic arthropods which prey on pear psylla was described and compared among different locations in the Hood River Valley. In the first two chapters, natural enemy effectiveness was determined by correlating within-orchard seasonal dynamics of natural enemies and their pear psylla prey. A subsequent analysis (Ch. IV) compared the taxonomic composition of effective and ineffective seasonal complexes of natural enemies and pear psylla immatures. These studies were holistic in scope, directed at species complexes rather than individual species, and results were sometimes confounded by uncontrollable factors. Descriptions of predatory ability can be more precisely made in the laboratory, where confounding influences can be reduced.

Predaceous mirids comprised an important group of pear psylla natural enemies in unsprayed orchards in the Hood River Valley, particularly the mature unsprayed Power Block (Ch II). Five species dominated the mirid members of Power Block. Psylla consumption rates have been measured in the laboratory for *Campyloneura virgula*, *Anthocoris nemoralis*, and *Deraeocoris brevis* (Nelson 1985, Brunner and Burts 1975, Brunner 1975, Fye unpublished data, and Westigard 1973, respectively), but experimental protocols have differed enough to hinder comparisons among species. Consumption of psylla by *Diaphnocoris provancheri*, *Pilophorus perplexus*, and *Phytocoris fraterculus* has not been documented.

The functional response (Solomon 1949) of a predator to different prey densities provides one accepted description of predator's ability to consume prey under controlled conditions (Hagen et al. 1976, Luff 1983). As a mathematical expression of the number of prey consumed/predator at different prey densities, the functional response is usually considered a species-specific attribute of a predator's feeding behavior (Luff 1983). The most common form of the functional response for invertebrate predators is Holling's (1959) type II (disc) equation:

$$N_p/TP = aN/(1 + aT_pN)$$

where N_a = the number of successful attacks, T = total time of exposure, P = the number of predators, N = initial prey density, a = the search constant, and T_h = handling time.

The search constant, a , measures both the searching speed of the predator as well as the ability of the prey to be detected. The handling time, T_h , measures the time spent capturing, subduing, and digesting a prey item. At low prey densities, a predator will consume prey at a rate determined by the attack constant which is directly proportional to those densities. Consumption rates are increasingly slowed at higher prey densities by behaviors incorporated in T_h . Handling time can be used to predict the maximum number of prey consumed in a given time period (F_{max}) according to the general relationship:

$$F_{max} = 1/T_h$$

These tests evaluated the ability of five predaceous mirids to destroy pear psylla eggs under controlled laboratory conditions. Functional response parameters are compared among the five species to determine the relative predatory ability of each test group. The results are also discussed relative to alternative experimental protocols.

Materials and Methods

Experimental protocol

In many tests of prey consumption by generalist predators, laboratory conditions frequently differ profoundly from those in the field. In particular, investigators of pear psylla predation have enclosed prey in small arenas, severely reducing predator search time (Anderson 1962c, Westigard 1973, Fye 1985b, Nelson 1985). In most of these trials, psylla were presented on a single field-collected leaf, where densities may have been below the predator's maximum consumption ability.

In addition, immature pear psylla are more difficult to manipulate than are prey used in other laboratory studies of hemipteran predators (Lord 1971, O'Neil 1988, Wiedenmann and O'Neill 1991). Psylla densities are difficult to experimentally manipulate, because eggs are attached to the pear leaf during oviposition (Westigard and Zwick 1972) and nymphs are highly mobile immediately after eclosion and immersed in honey-dew at later developmental stages.

The experimental protocol used here presented the predator with a more natural environment than a petri-dish, yet allowed the researcher some flexibility in adjusting prey density. The experimental arena consisted of an egg-infested pear shoot inside a plastic cylinder. Young terminal shoots were pruned from unsprayed pear trees. All but five adjacent leaves of similar size were removed from the final 12 inches of the shoot. The two most terminal leaves were always removed because they were smaller and younger than adjacent older leaves. The elastic tree-wound healer (Seal & Heal[®]) was placed over the clipped-tip to slow terminal dehydration. The shoot was washed in water to remove dust and any previously oviposited psylla eggs, nymphs or other arthropods. Several shoots were placed in water-filled cups inside a cubic meter frame covered with cheesecloth where they were exposed to approximately 300 fertile adult female psylla for two to three days. After the shoots were sufficiently infested with psylla, the number of psylla eggs per leaf were counted with a stereomicroscope. Each infested shoot was placed inside a clear mylar cylinder 18 cm long and 11 cm in diameter so that the stem extended through the petri dish floor of the

cylinder into a cup of water. A small sponge strip (~ 10cm long x .5 cm in diameter) plugged the hole around the stem and also provided water to the predator. A fine mesh cloth over the top and small perforations in the sides of the cylinder allowed ventilation and prevented condensation on the sides of the cylinder.

Predators were collected from an unsprayed pear block (Power Block) and were stored individually in 10 by 7cm diameter plastic cylinders at 7°C and in complete darkness until the each experiment was begun. A moist cotton wick prevented dehydration, but no nutritional sources were provided. Test insects were starved in these conditions from 24 to 72 hours before the experiment was begun.

A single test insect was placed in an arena inside a controlled temperature cabinet at 24°C (\pm 1°C) and L:D 16:8. After 24 hours, predators were removed from the cylinders and again were individually stored at 7°C and in complete darkness. Frequently, the same individual predators were used repeatedly over many trials. These individuals were stored at the same conditions for at least 24 hours, but less than 72 hours between experimental trials.

Whole, intact, psylla eggs were recounted within 24 hours after exposure to the predator. Shoots were stored at 7°C and under dark conditions until they were counted. Shoots which were still vigorous and adequately infested with psylla eggs were used in subsequent trials. The number of whole intact eggs on all five leaves after exposure to predation was subtracted from the total number of eggs prior to exposure, giving total number of eggs destroyed/terminal shoot.

Controls consisted of infested terminal shoots placed under experimental conditions without an accompanying test insect. Control terminal shoots were treated the same as those of the other trials. Numbers of eggs on control terminals before and after exposure were compared with linear regression analysis.

The experimental protocol varied the number of psylla eggs/terminal among experimental trials, but numbers could not be exactly replicated. The number of trials also varied among test species. Cases where individual predators died, became injured, or failed to feed were eliminated from the data.

Functional response analysis

Williams and Juliano (1985) listed four different linearizations of the disk equation which have been used to deduce the search constant and handling time from observations of prey consumption at different prey densities. Of these, the Lineweaver-Burk double reciprocal transformation (Dowd and Riggs 1965) has most often been applied to functional response experiments (Livedahl and Stiven 1983). Nonlinear regression, however, describes functional response curves more accurately than any of the linear statistical techniques (Juliano and Williams 1984, Williams and Juliano 1985).

Accordingly, these observations were analyzed with the nonlinear regression analysis in the SPSSPC+ V3.0 statistical package (Norusis/SPSS Inc. 1988). The package derives by iteration those variables which best fit the data, but requires initial parameter estimates for the non-linear model. These initial parameters were derived from a Lineweaver-Burk double reciprocal transformation of the data.

Results

Figures V.1--V.8 show the functional response of the life stage and species of test animals to pear psylla eggs. In most cases, the curves resemble the typical type II response for invertebrate predators (Holling 1959). That is, they are linear at low prey densities, curvilinear at moderate prey densities, and approach an asymptote at high prey densities. Observations of *C. virgula* fit the type II functional response the best, while those of fifth instar *D. brevis* subjects showed a more linear (Type I) response. All five mirids destroyed large numbers of psylla eggs, especially when presented with larger prey densities. Linear regression showed that the number of eggs on control terminals before treatment did not change significantly after treatment ($r^2 = .98$, $P = .00001$, $N = 17$) (Figure V.9).

Table V.1 presents important functional response parameters and the r^2 value of each non-linear regression. Because F_{\max} is the most useful descriptor of predatory behavior in these trials, test groups are ranked from highest to lowest F_{\max} . The nearly linear (Type I) functional response of *D. brevis* 5th instar nymphs gave an extremely exaggerated and obviously inaccurate prediction of maximum number of psylla eggs consumed/day and so was omitted from Table V.1. The r^2 value of each non-linear regression indicates how well the data from each test group fits the Type II non-linear model.

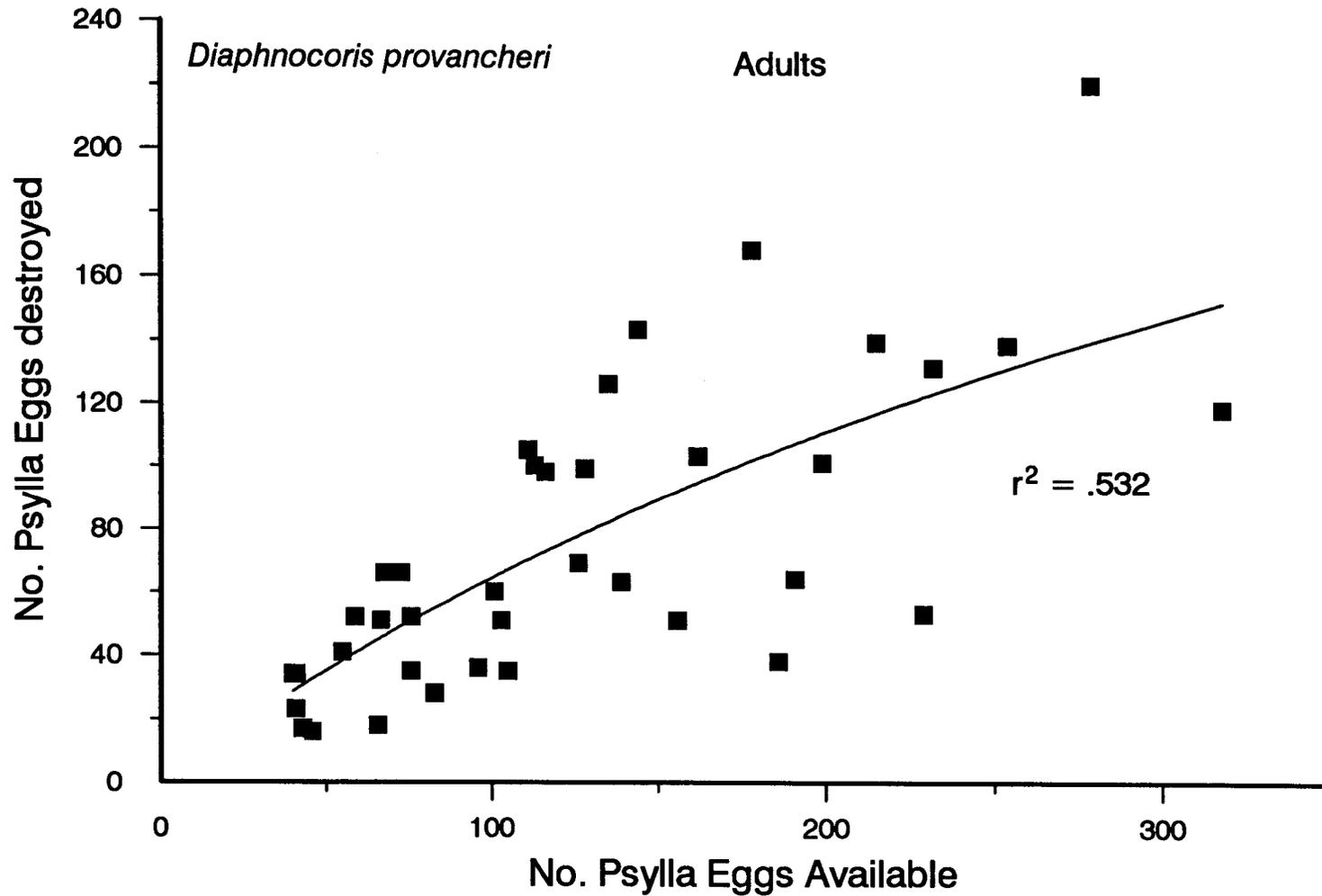


Figure V.1. The type II functional response (solid line) of *Diaphnocoris provancheri* (Burque) adults to eggs of the pear psylla, *Cacopsylla pyricola* Förster, under standard laboratory conditions. Functional response equation and r^2 were calculated by non-linear regression of 39 observations (squares).

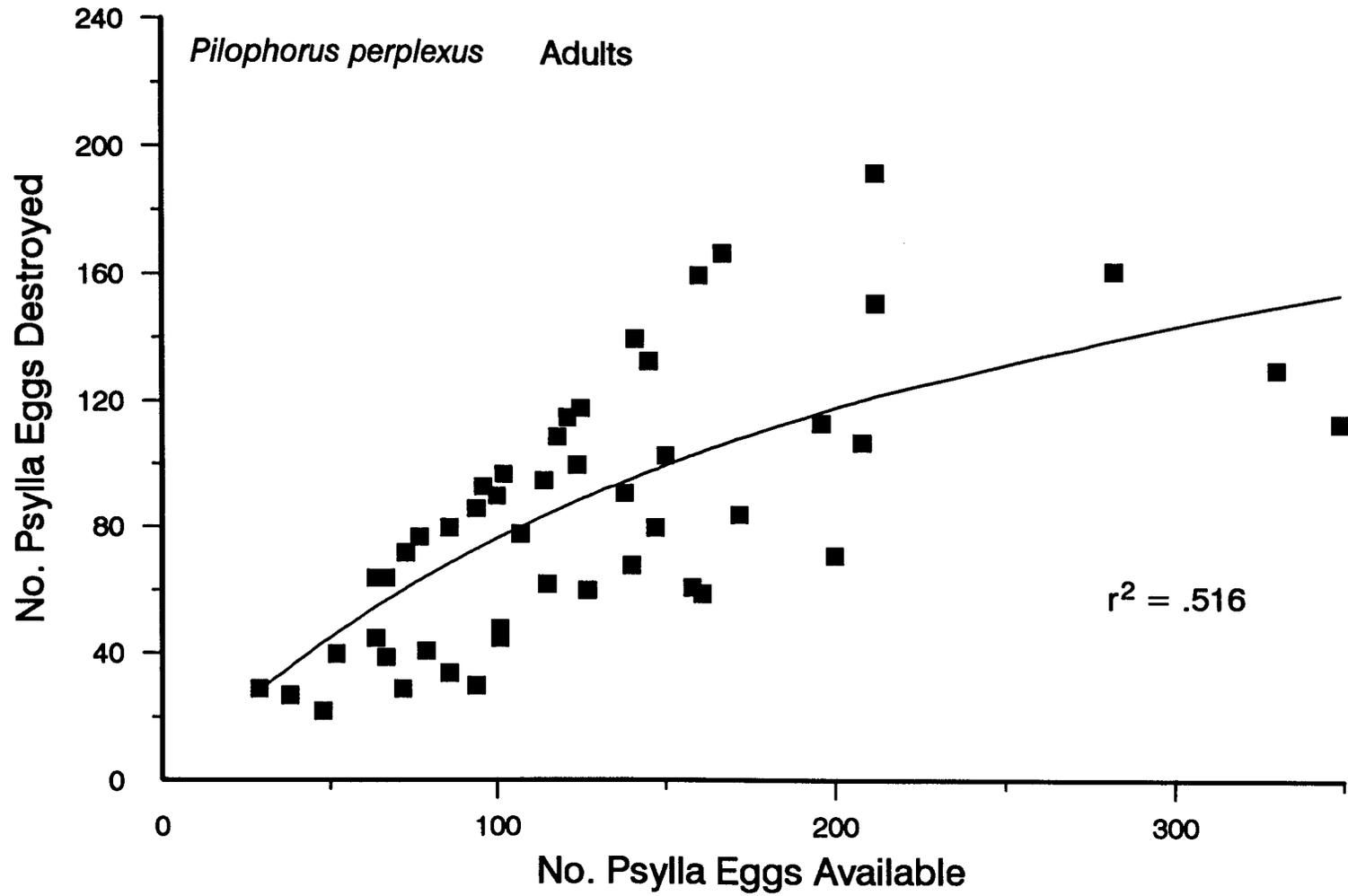


Figure V.2. The type II functional response (solid line) of *Pilophorus perplexus* Douglas & Scott adults to eggs of the pear psylla, *Cacopsylla pyricola* Förster, under standard laboratory conditions. Functional response equation and r^2 were calculated by non-linear regression of 48 observations (squares).

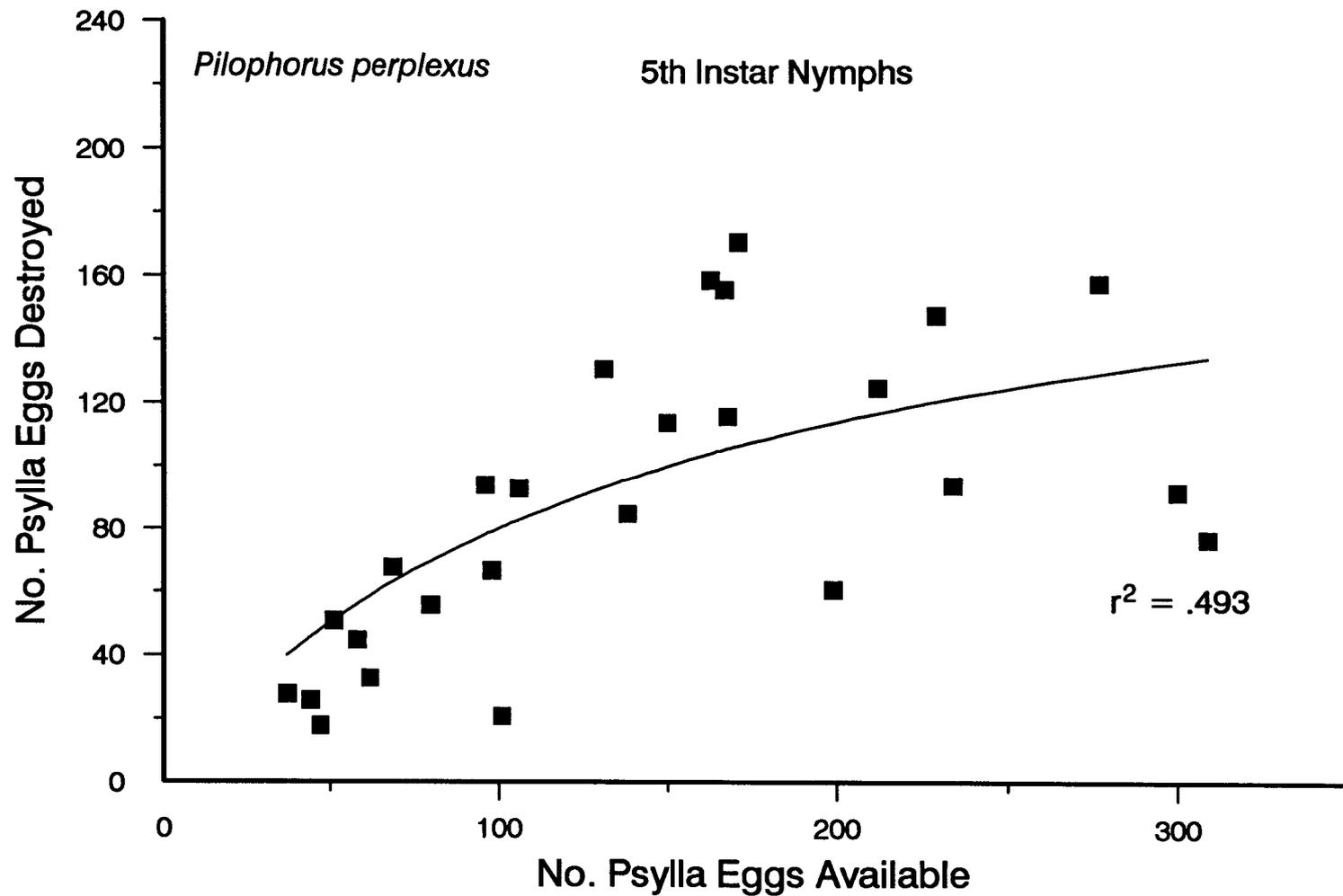


Figure V.3. The type II functional response (solid line) of *Pilophorus perplexus* Douglas & Scott fifth instar nymphs to eggs of the pear psylla, *Cacopsylla pyricola* Förster, under standard laboratory conditions. Functional response equation and r^2 were calculated by non-linear regression of 26 observations (squares).

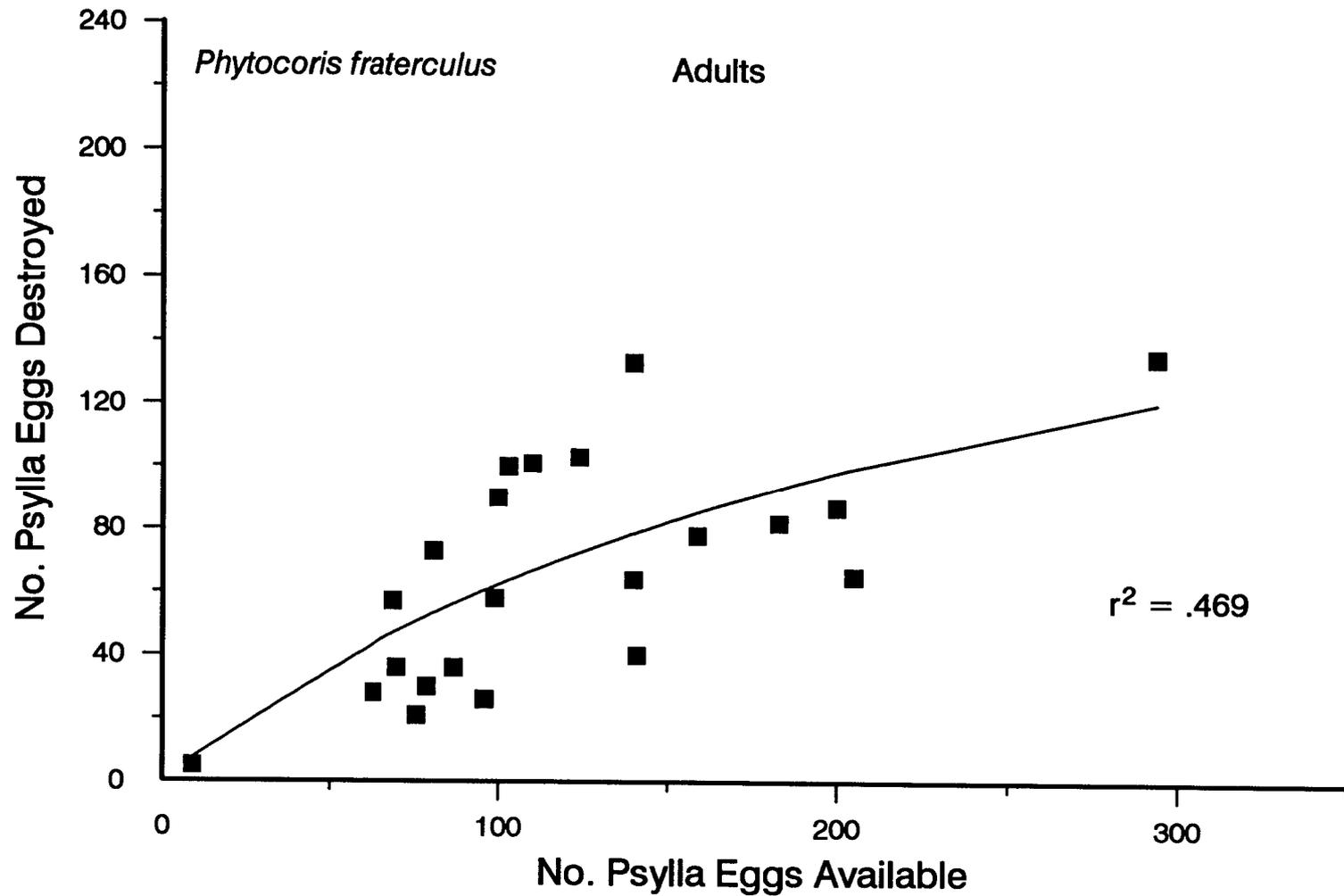


Figure V.4. The type II functional response (solid line) of *Phytocoris fraterculus* Van Duzee adults to eggs of the pear psylla, *Cacopsylla pyricola* Förster, under standard laboratory conditions. Functional response equation and r^2 were calculated by non-linear regression of 22 observations (squares).

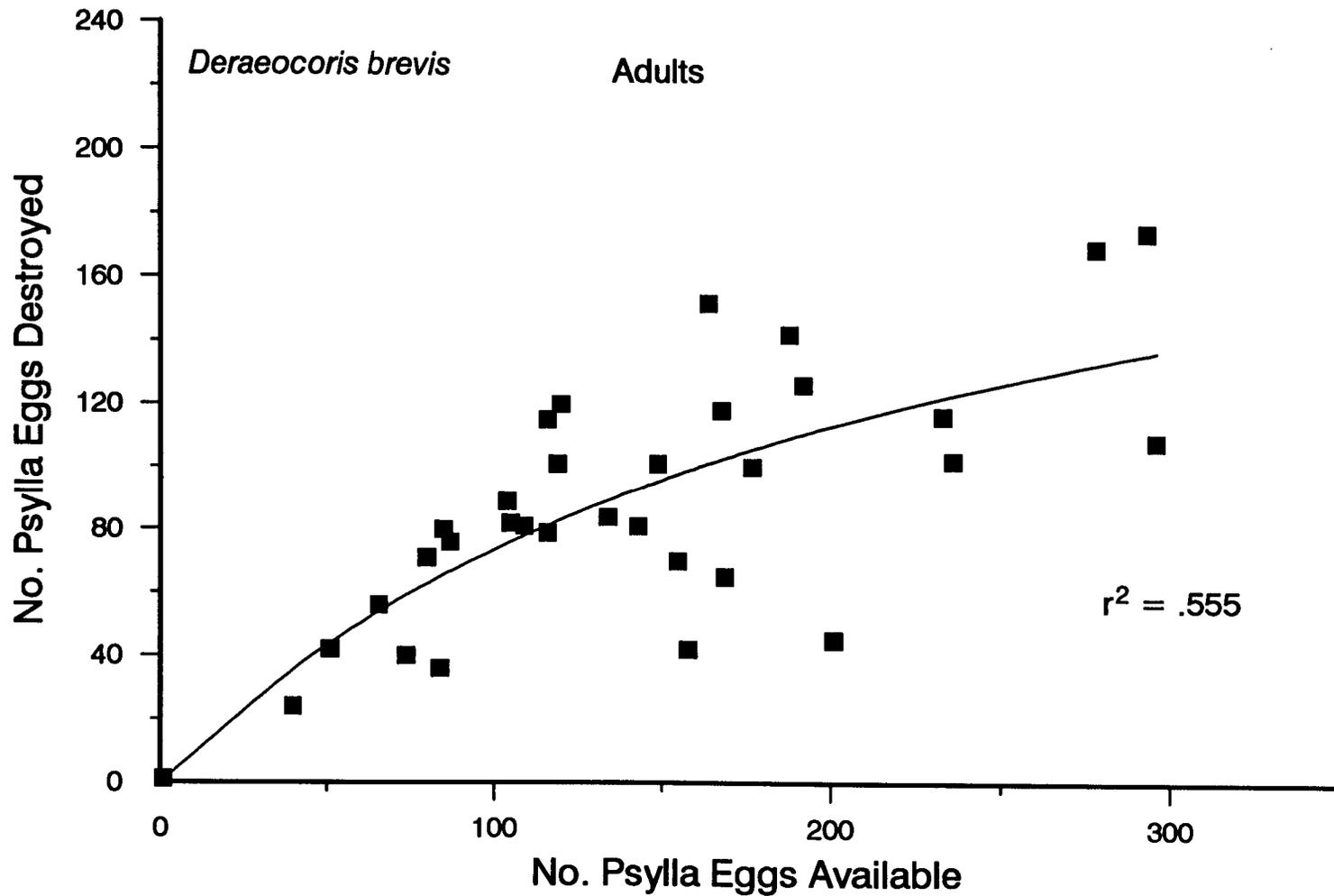


Figure V.5. The type II functional response (solid line) of *Deraeocoris brevis* (Uhler) adults to eggs of the pear psylla, *Cacopsylla pyricola* Förster, under standard laboratory conditions. Functional response equation and r^2 were calculated by non-linear regression of 33 observations (squares).

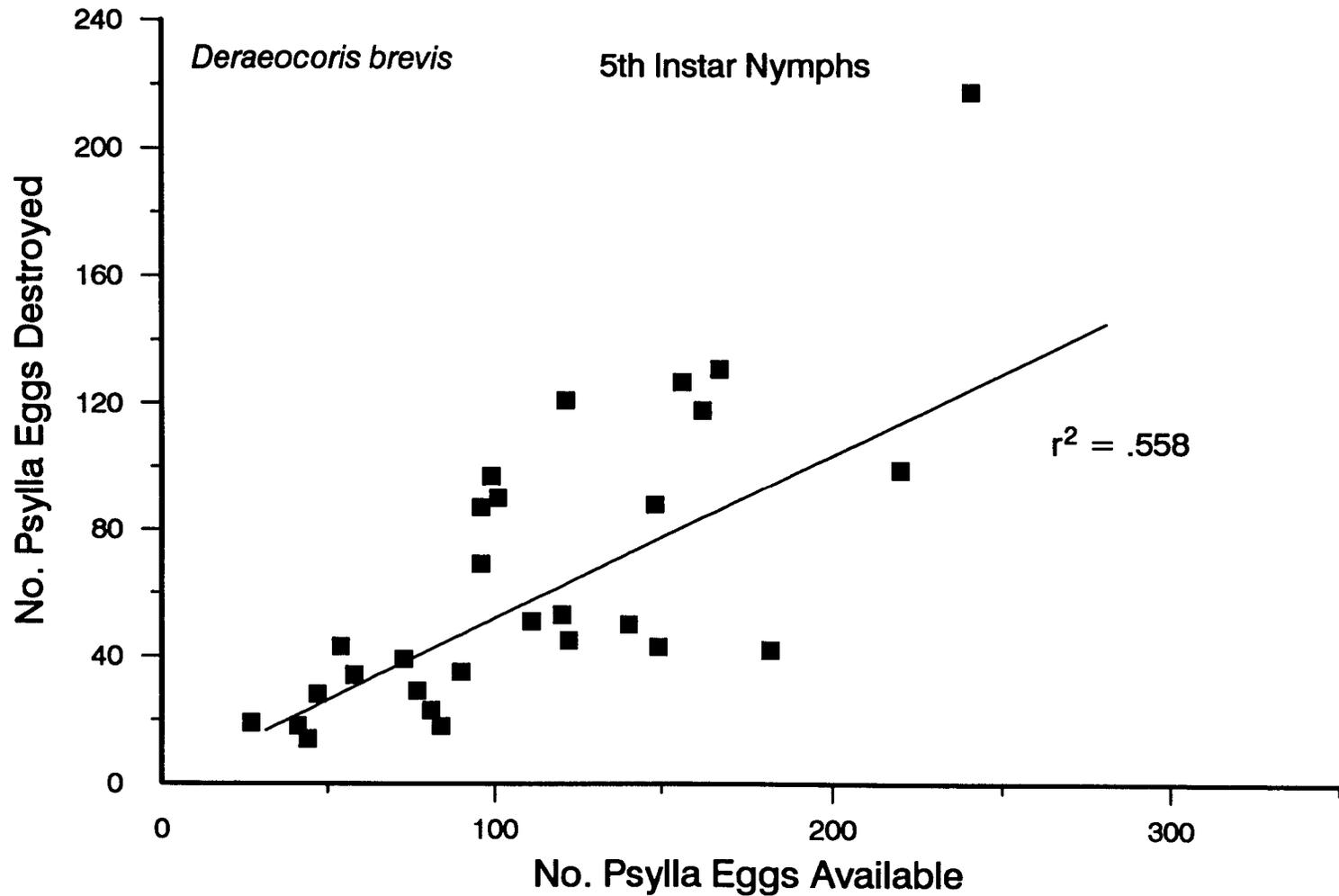


Figure V.6. The type II functional response (solid line) of *Deraeocoris brevis* (Uhler) fifth instar nymphs to eggs of the pear psylla, *Cacopsylla pyricola* Förster, under standard laboratory conditions. Functional response equation and r^2 were calculated by non-linear regression of 28 observations (squares).

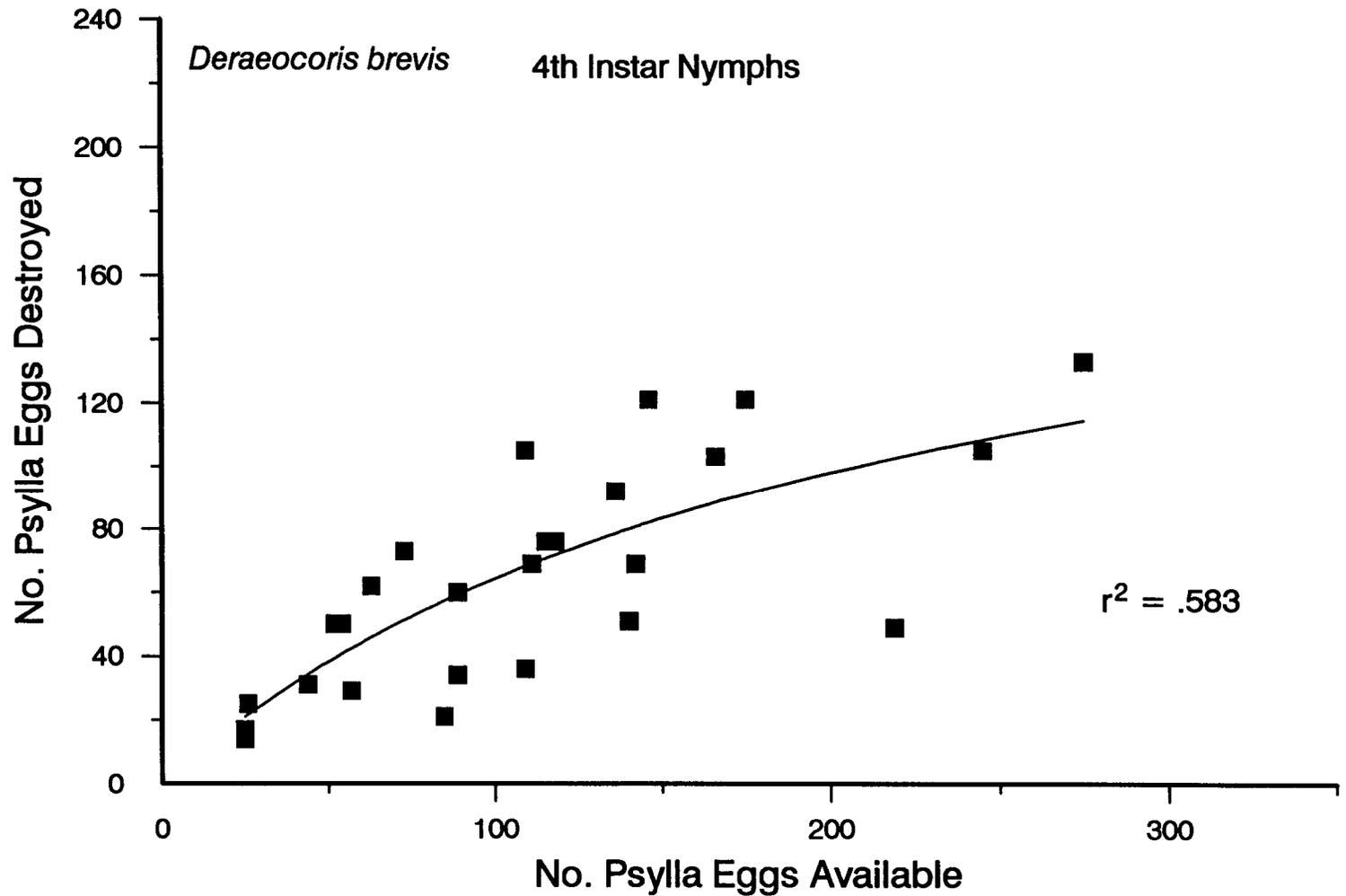


Figure V.7. The type II functional response (solid line) of *Deraeocoris brevis* (Uhler) fourth instar nymphs to eggs of the pear psylla, *Cacopsylla pyricola* Förster, under standard laboratory conditions. Functional response equation and r^2 were calculated by non-linear regression of 26 observations (squares).

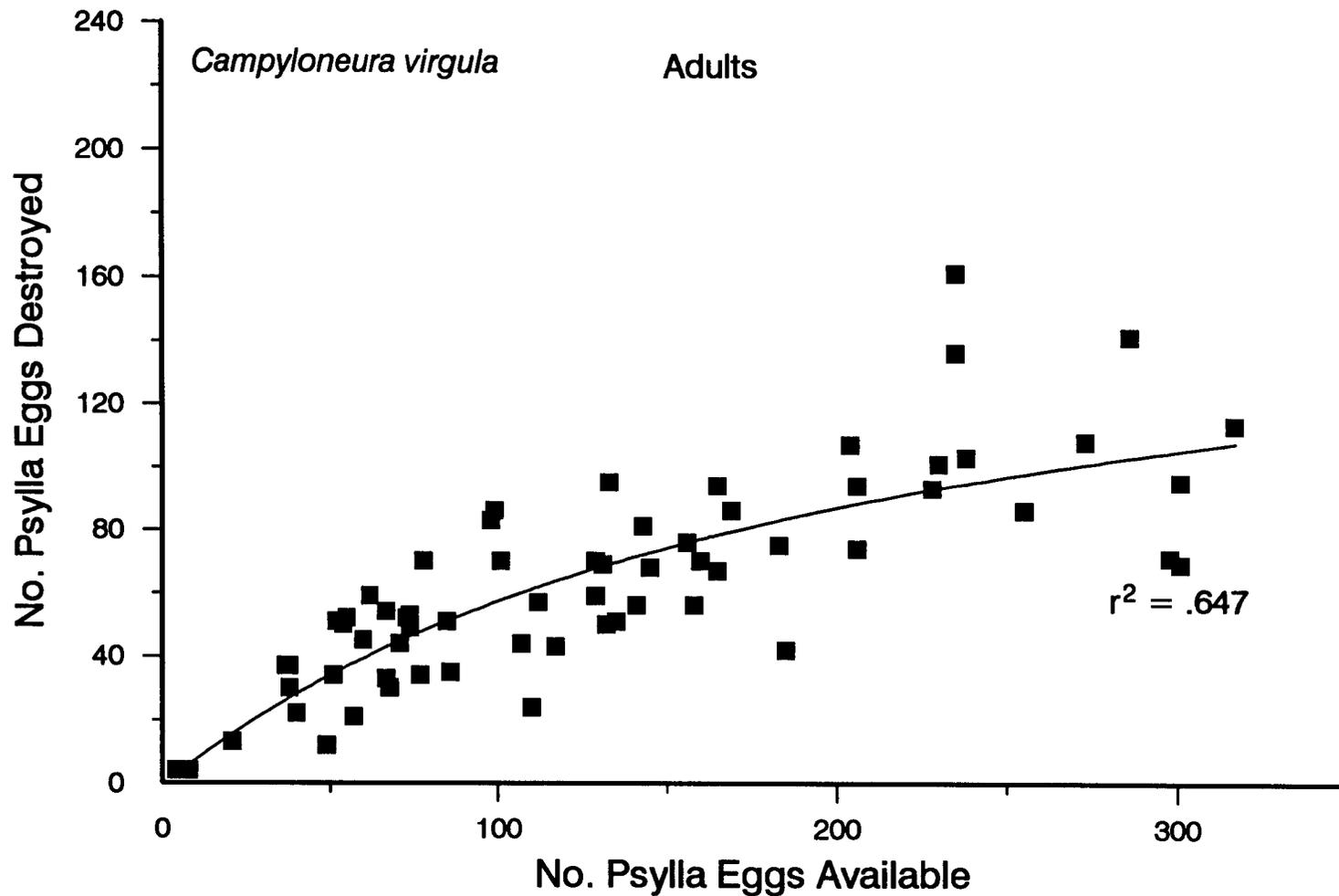


Figure V.8. The type II functional response (solid line) of *Campyloneura virgula* (Herrick.Schaeffer) adults to eggs of the pear psylla, *Cacopsylla pyricola* Förster, under standard laboratory conditions. Functional response equation and r^2 were calculated by non-linear regression of 66 observations (squares).

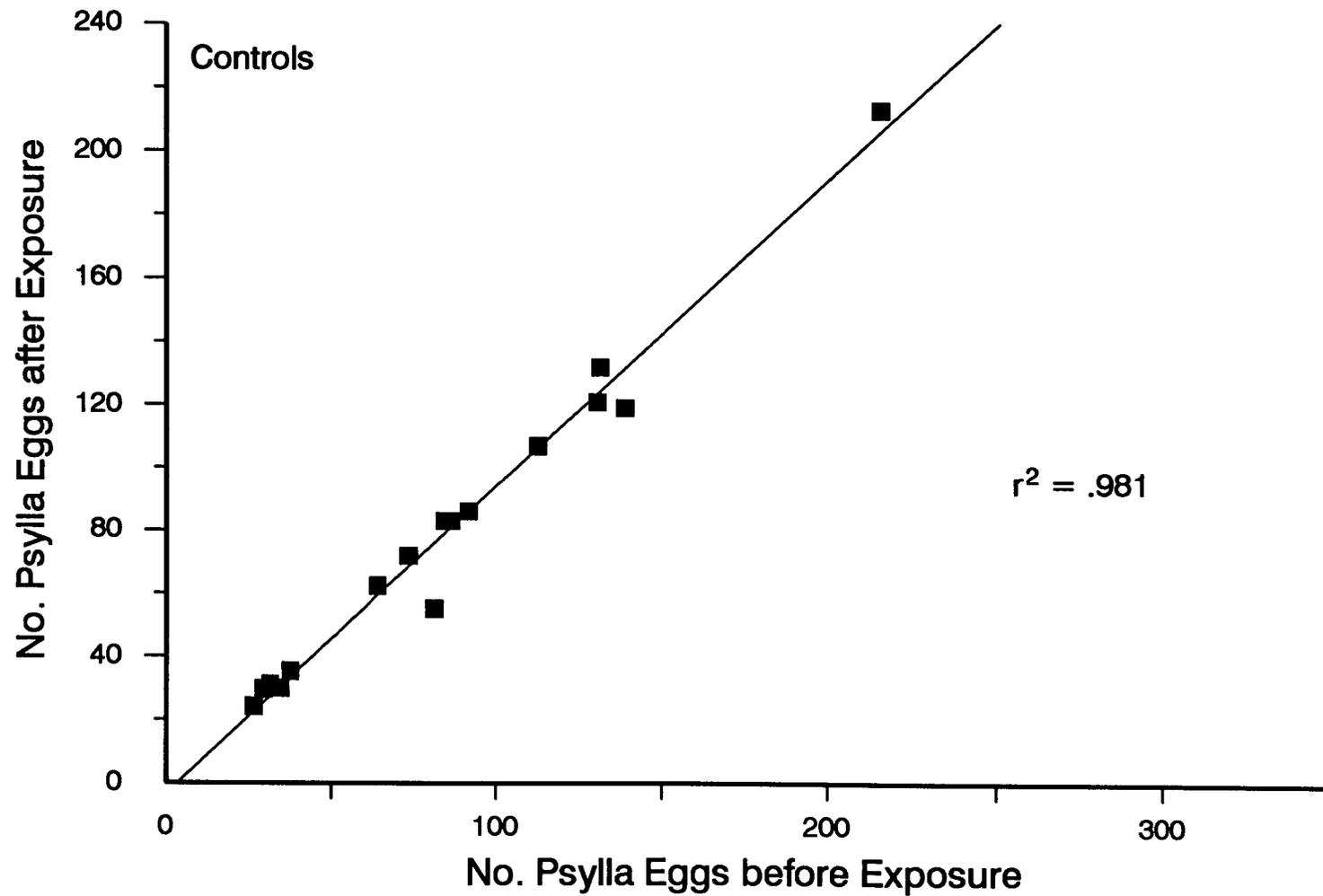


Figure V.9. Linear regression (solid line) of number of psylla eggs on control terminals before and after exposure to experimental conditions. 17 observations (squares) were made.

Table V.1. Functional response parameters and non-linear regression statistics of five predaceous mirids. N, number of observations, a , search constant, T_h , handling time (days⁻¹), F_{max} , predicted maximum number of psylla eggs consumed/day.

Species	Life Stage	N	r^2	a	T_h	F_{max}
<i>D. provancheri</i>	Adult	39	.532	0.765	0.0025	399
<i>P. perplexus</i>	Adult	48	.516	1.075	0.0039	258
<i>P. perplexus</i>	5th Instar	26	.493	1.329	0.0050	198
<i>P. fraterculus</i>	Adult	22	.469	0.838	0.0044	228
<i>D. brevis</i>	Adult	33	.555	1.064	0.0041	226
<i>D. brevis</i>	5th Instar	28	.558	0.602	$7 \cdot 10^{-10}$	---
<i>D. brevis</i>	4th Instar	26	.583	0.943	0.0049	205
<i>C. virgula</i>	Adult	66	.647	0.854	0.0056	179

Discussion

In these tests, numbers of eggs destroyed/day was somewhat higher than those measured elsewhere for these species. Nelson (1985) measured *C. virgula* adults consuming psylla immatures in petri dishes, but the prey were presented in mixed life stages so results are difficult to compare with those from other investigations. Still, a single individual devoured 21 psylla eggs in one hour (Nelson 1985). *Deraeocoris brevis* fourth-instar, fifth-instar, and adult life-stages consumed an average of 64, 44, and 54 psylla eggs/day, respectively, inside small plastic "wafers" Fye (1985, unpublished), but the number of psylla eggs presented during these trials were not reported. Brunner (1975) calculated maximum consumption rates from the functional response of *D. brevis* 5th instar nymphs and adults (F_{max}) as 175 and 225 psylla immatures/day, respectively.

Brunner's (1975) functional response methodology differed substantially from that presented here. His experimental arena was larger, allowing both more searching area for test insects and greater prey availability. Because mixed life-stages of psylla immatures were presented, his results are not wholly comparable to those presented here. Brunner also estimated the functional response line by linear transformation, which frequently underestimates actual functional response parameters (Williams and Juliano 1985).

Methodology presented here tended to promote, rather than restrict predator consumption of pear psylla eggs. The arena more closely resembled a mirid's natural habitat than those used in other functional response experiments, yet still probably severely restricted foraging range. The densities of psylla eggs presented to the test animal were substantially larger than those normally found in the field. Animals were starved prior to each trial and placed under constant warm temperatures.

These methods also account for some of the differences observed among functional response curves. The number of psylla eggs available during each trial varied, sometimes considerably, among the test insects. Had more highly infested terminal shoots been presented to *D. brevis* fifth instar nymphs (Figure V.6), the predicted type II curve would have undoubtedly been more curvilinear. The number of observations of each test insect also varied considerably (Table V.1). Larger sample sizes during all trials would probably have

raised r^2 values of each regression and allowed a more accurate determination of the functional response.

Moderate r^2 values may also be due to differential number of eggs/leaf within each terminal shoot. That is, species may have foraged differently among the five terminal leaves in response to both egg densities and leaf position. The preference of each test insect for leaves of differing position within the experimental arena is available from this data set, but these results will be presented elsewhere.

In summary, all test insects destroyed large numbers of psylla eggs under these experimental conditions. Results also indicate that the experimental protocol influenced the shape of the functional response.

VI. EXPERIMENTAL DIRECTIONS FOR THE IMPLEMENTATION OF BIOLOGICAL CONTROL OF THE PEAR PSYLLA IN THE HOOD RIVER VALLEY

Introduction

Despite observations at several orchards in the Hood River Valley, natural enemies effectively suppressed the pear psylla in a minority of cases (Chs. II, III). General reasons for ineffective pear psylla biological control include low numbers and diversity of both natural enemies as well as arboreal vegetation adjacent to orchards (Ch. II). The potential of natural enemies to suppress pear psylla in commercial orchards was hindered by the lack of truly selective psyllacides (Ch. III). In some cases, early season prey densities in pear orchards may have been too low to promote natural enemy immigration (Ch. IV).

Aside from the selective programs, particular tactics to enhance the potential for biological psylla control were not directly addressed in these studies. Nevertheless, two general strategies for the promotion of biological control of psylla are apparent from these studies: (1) modify the non-pear vegetation and its arthropod fauna (species pool) adjacent to the target orchard, and (2) modify the orchard habitat to encourage both natural enemy colonization and permanent complex development.

This section describes further experimental approaches to implement biological control of the pear psylla in the Hood River Valley. Rather than detailed proposals of specific experiments, ideas are broad in nature and applied in approach. Although categorized into one or the other of the two general strategies listed above, most tactics involve both. Successful biological control may be best enhanced if several tactics were implemented together. In any case, small scale trials should be conducted prior to full implementation.

Augment natural enemies on non-pear vegetation

Plant hedgerows

Ground cover cultivation and manipulation is a frequently cited methodology to enhance the biological control of orchard pests (Altieri and Schmidt 1986, Bugg and Dutcher 1989). Fye (1983) reported that major psylla predators colonized small grain cover crops in orchards in the Yakima Valley of Washington, but his study failed to measure the impact of these predators on psylla control. However, because most of the important psylla natural enemies in the Hood River Valley are arboreal (Ch II), ground covers will not support a large and diverse assemblage of natural enemies.

Because most psylla natural enemies are arboreal, suitable hedgerows rather than ground covers should act as reservoirs for the development of pear psylla natural enemies. In particular, trees which host large densities of monophagous prey which develop early in the season are the best candidates. Filbert and willow are discussed below. Many of the same arthropod generalist predators which feed on pear psylla are also important natural enemies of the filbert aphid, *Myzocallis coryli* (Messing 1982). In the Hood River Valley, native filbert and its monophagous pest the filbert aphid provided alternate host plants and prey for many psylla natural enemies (Ch. II). These included *Deraeocoris brevis*, *Diaphnocoris provancheri*, and *Pilophorus perplexus*. Because filbert cultivars support higher densities of the filbert aphid than the native tree (Messing 1982), planted hedgerows may attract and maintain a large and diverse assemblage of arthropod generalist predators. Unfortunately, filbert hosts leafroller species (AliNiasee 1980) which are also pests of pear.

Although the fauna of both phytophagous and predaceous arthropods on willow is relatively sparse in the Hood River Valley (Booth unpublished data, Ch. II), populations of non-pear psyllids have been sampled on willow southern Oregon (Westgard personal communication), British Columbia (Booth unpublished data), and Washington State (Fields and Bierne 1973). Two species hosted the pear psylla predator *Anthocoris nemoralis* at the latter site (Fields and Bierne 1973). The planting of willow hedgerows followed by the introduction of suitable prey species offers a possible avenue to enhance pear psylla biological control in the Hood River Valley.

Tactics to encourage natural dispersal from non-pear hosts into pear orchards have not been investigated. Defoliation of the hedgerow at opportune times could conceivably stimulate natural enemy immigration to pear without destroying hedgerows. If natural enemies are very abundant, their capture and release directly into psylla-infested orchards could be feasible. Further research is needed to evaluate these tactics.

Cultivate snakeflies

Woglum and McGregor (1958), noting large numbers of the snakefly *Agulla bractea* feeding on black scale and residing in a California orange orchard, recommended the continued study of the predatory potential of snakeflies. Although snakeflies have been listed as psylla natural enemies in both southern Oregon and France (Westigard et al. 1986, Herard 1986), methods to increase snakefly populations have not been documented.

These generalist predators seem especially amenable to cultivation. In a small rearing study, *Agulla sp.* females were mated in the laboratory and produced over 400 eggs apiece (Woglum and McGregor 1958). Snakeflies probably emerged from rotting pear bins near the Gale mini-orchard (Ch IV). Rotting wood should not be a difficult habitat to cultivate.

Introduce *A. nemoralis*

Anthocoris spp. are among the more important psylla natural enemies in other pear growing regions (Anderson 1962a, Atger and Fauvel 1981, Herard and Chen 1986, Grbic 1989). The European species *A. nemoralis* and *A. nemorum* were introduced near Summerland, British Columbia in 1963 (Brunner and Burts 1975), and have replaced *A. antevolens* and *A. melanocerus* as the most common anthocorids in most Okanagan and Yakima Valley pear orchards (Fields and Bierne 1973, Brunner and Burts 1975). In the Medford area, *A. antevolens* was documented as an important psylla predator in 1968 (Westigard et. al 1968), but no members of the genus were listed in Gut's exhaustive (1985) species list from that area. Recently, *A. nemoralis* was reported in the San Francisco Bay area of California and may have replaced *A. antevolens* as a dominant anthocorid (Hagen and Dreistadt 1991). Species of *Anthocoris* collected during these studies in the Hood River Valley included only *A. antevolens* and *A. melanocerus*.

Modify orchard cultural practices

Adjust early season psylla densities

In these studies (Ch. II, Ch. III) low densities of psylla immatures often failed to attract and maintain a sufficient number of arthropod generalist predators to suppress pear psylla over the course of the growing season, whereas high psylla densities were never suppressed despite an abundant and diverse natural enemy complex (Ch IV). As Brunner (1975) hypothesized, it may be possible to encourage natural enemies to colonize and develop in pear orchards by allowing slightly higher early-season psylla densities. These goals might be accomplished by decreasing the number of delayed dormant and pink sprays. The latter tactic may also help slow the development of pyrethroid resistance in *C. pyricola*.

Use a more effective selective psyllacide

A more selective psyllacide could greatly aid pear psylla control in the Hood River Valley (Ch III). Besides diflubenzuron, other insect growth regulators showing selective properties are under registered in Europe (e.g., teflubenzuron, (Larguier 1990)), but different marketing strategies and difficult registration procedures have slowed their implementation in the United States.

Juvenile hormone analogs (JHA) such as fenoxycarb (Insegar[®], Maag Agrochemicals, Inc.) offer another selective chemical with the demonstrated potential to aid in pear psylla control during the foliar period (Stäubli 1985). In addition, reversals in *C. pyricola* dormancy development after fenoxycarb applications suggest opportunities for fall or winter control (Krysan 1990). Single-tree replicates of fenoxycarb and fenoxycarb with oil were included in field trials in Medford (Westigard personal communication). Results suggest adequate psylla and codling moth suppression, but the effect of fenoxycarb on natural enemies is not well documented.

Although pre-harvest tree-washes failed to effectively suppress late-season psylla densities in selective trials in the Wenatchee Valley (Burts 1983), applications earlier in the season may be more effective against psylla without harming many natural enemies. More effective soaps are currently under investigation (Westigard personal communication). In Italian pear orchards, early-season applications of unregistered detergents effectively reduced

the proportion of psylla-infested shoots without harming anthocorids and "other beneficials" (Briolini et al. 1990).

Augment populations of resident natural enemy populations in pear

In addition to enhancing psylla natural enemies on hedgerows or non-cultivated vegetation, populations resident within orchard blocks should also be enhanced. Aside from the appropriate chemical regime, long-term development of the natural enemy complex depends on suitable overwintering habitat (Ch. II). Recommendations include the addition of artificial overwintering structures as well as changes in cultural practices.

Fye (1985) used fiberboard traps to assess spatial preferences of overwintering psylla natural enemies. Similar traps placed in the Quince selective block during winter 1987/1988 collected only a small fraction of the high late-fall densities of adult *D. brevis* (Booth unpublished data). Spring densities of natural enemies among pear blocks with and without overwintering traps have not been compared. Other types of trunk traps, used to survey overwintering predators in pecan orchards (Mizell and Schiffhauer 1987), may be more effective. Appropriate trap construction, placement, and density would have to be investigated to enhance psylla biological control.

Many predaceous mirids overwinter in orchards as eggs inserted in recent terminal growth (Sanford 1964). Current pruning practices hinder the establishment of resident populations of *C. virgula*, *D. provancheri*, and *Phytocoris* spp. Recommendations to enhance overwintering egg survival include alternating pruning location and time, leaving clipped terminals in the orchard, and providing alternate (artificial) oviposition sites.

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