AN ABSTRACT OF THE THESIS OF

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Title: The Biology and Seasonality of the Imported Parasitoid Trioxys pallidus Haliday in Western Oregon.

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Seasonal synchrony between the filbert aphid, Myzocallis coryli (Goetze) and its newly introduced parasitoid Trioxys pallidus Haliday was examined in the field to evaluate the effectiveness of parasitoid based biological control in filbert orchards of Oregon. Field-emergence observations showed that 50% eclosion of the aphid occurred 14 days before that of the parasitoid. Winter mortality of the parasitoid was 61.6% in 1986, and 55.3% in 1987. Host depression by the parasitoid was limited in early spring and steadily increased throughout the season. A post release study showed that aphid numbers diminished by greater that 62% during the peak point of the pest season.

Time from ovipostion to 50% eclosion for nondiapause T. pallidus in the field ranged from 248.0 to 373.6 degree days above a base temperature of 6.0°C. Time from oviposition to mummy formation represents 64% of the time to adult eclosion. Four generations of T. pallidus were

produced in a controlled field experiment in one growing season although based on heat unit calculations it would be possible to produce 6 generations in the field. The parasitoid population declined during the summer months accounting for fewer generations in the season.

Diapause type individuals are present in the *T. pallidus* population throughout the filbert growing season but are not dominant until October-November. Diapause development continued as winter progressed as demonstrated by the decrease in the number of days to eclosion.

In 1987 a total of 2,645 adult and 1,900 mummy *T. pallidus* were released in western Oregon filbert orchards. A 1988 survey of 12 of the 13 release sites showed 4 of the sites to have established populations that survived the winter.

The Biology and Seasonality of the Parasitoid *Trioxys pallidus* Haliday in Western Oregon.

by

Judy L. Cohn

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THE BIOLOGY AND SEASONALITY OF THE IMPORTED PARASITOID *Trioxys pallidus* HALIDAY IN WESTERN OREGON.

I. INTRODUCTION

Filbert (hazelnuts) trees, *Corylus avellana* L. (Betulaceae) were brought into the U.S. in 1871 from Europe (Lagerstedt, 1975). The Willamette Valley of western Oregon is the largest producer of filbert nuts in the United States growing 95% of the crop (Baron and Stebbins, 1981). Between 1979 and 1983 the filbert crop contributed from $12.3 to $38.3 million annually to Oregon's economy.

Filbert trees have a complex of pests that feed on or infest the leaves, nuts, or bark (AliNiazee, 1983a and 1985). Of the guild of arthropod pests, the filbert aphid, *Myzocallis coryli* (Goetze) ranks below the filbertworm, *Melissopus laetifereanus* (Walsingham) (Lepidoptera), presently the major insect pest on filbert (AliNiazee, 1980). In secondary importance along with the filbert aphid are the leafroller, *Archips rosanus* (L.), and the bud mites, *Phytoptus avellanae* (Nalepa) and *Cecidophypsis vermiformis* (Nal.).

The filbert aphid was imported into the U.S. along with filbert seedlings from Europe but did not become a pest until the 1920's (Smith and Parron, 1978; AliNiazee, 1983a).

M. coryli is specific to *Corylus* species, *C. avellana* L. the cultivated filbert and *C. cornuta* a species of filbert native to the northwestern U.S. (Richards, 1968; Messing, 1982). A major increase in the filbert aphids pest status has been correlated with increased pesticide usage in filbert orchards which kills many of it's natural enemies (AliNiazee, 1983b; Messing and AliNiazee, 1985). Pesticide use has also promoted resistance in the aphid to insecticides (Katunda and AliNiazee, 1989).

M. coryli belongs to the Callaphidini tribe of Aphididae, a group of small aphids that feed on the leaves of a wide variety of plants (Richards, 1968). *M. coryli* is holocyclic having parthenogenic reproduction throughout the growing season and sexual reproduction in the fall. The aphid overwinters in the egg stage, which are laid from September to December in the bark of filbert trees (El Haidari, 1959). The eggs overwinter in a state of diapause (arrested development). The aphid is phenologically synchronous with it's host plant, egg hatch occurs from March through April, the time of bud break in the filbert trees. The alate parthenogenic fundatrix females that hatch give birth to alate parthenogenic viviparous forms. There are 8 to 10 generations per year (Messing, 1986). Sexual forms are produced in the population from October through November. Sexual females are apterous and mate with alate males.

The filbert aphid, a phloem feeder, feeds directly on the undersides of the leaves. Feeding on the leaves reduces photosynthetic area and promotes early leaf senescence. Aphids excrete honeydew onto the tree providing a substrate for the growth of sooty mold, and soils nuts and farm equipment. The effect of feeding on nut quality and yield is unclear but appears to have an impact on nut size and kernel fill (Painter and Jones, 1960).

In 1984 a biotype of the parasitoid, Trioxys pallidus Haliday was imported to western Oregon from France as a classical biological control agent of the filbert aphid. T. pallidus belongs to order Hymenoptera, family Aphidiidae, and the tribe Trioxini (Mackauer and Stary, 1967). Morphologically Trioxys species can be identified by reduced wing venation and spines on the last sternites which help hold the aphid during oviposition (Stary, 1966). T.pallidus has a list of 10 aphid hosts that various biotypes parasitize (Stary, 1970). T.pallidus is a solitary ahrennotokus endoparasitoid of Aphididae. The biotype of T.pallidus studied here is a monophagous primary parasitoid of M. coryli.

A biotype of T. pallidus is also a parasitoid of the walnut aphid Chromaphis juglandicola (Kaltenbach) (Schlinger et al., 1960). In the walnut agroecosystem it has proven to be a relatively successful biological control agent of the aphid (van den Bosch, 1970; van den Bosch et al., 1979). In an effort to control the walnut aphid in both the coastal regions and the dry central valley of California, 2 different ecotypes were imported. The ability of T. pallidus to successfully control the walnut aphid is largely due to temporal synchronization between the host and the parasitoid. T. pallidus emerges from hibernal diapause in early spring when the walnut aphid is most active. The parasitoid also goes through an aestival diapause during the period of summer heat when the aphid is at a low population level. In the fall when the aphid populations rise again, the parasitoid emerges from aestival diapause, and parasitizes the aphid population (Nowierski, 1979). This classical biological control program saves the California walnut industry at least $0.5 to 1.0 million annually (van den Bosch, 1979).

There are other examples of classical biological control within the genus Trioxys. These include: the spotted alfalfa aphid Therioaphis maculata (Buckton) parasitized by Trioxys complanatus (Quilis); the elm aphid, Tinocallis platani (Kaltenbach) parasitized by Trioxys tenuicaudus (Stary); and the linden aphid, Eucallipterous tilia (L.) parasitized by Trioxys curvicaudus (Mackauer).

T. complanatus is one of a guild of parasitoids that was introduced into California for spotted alfalfa aphid control. It has become the dominant species of the guild having a high reproductive rate over a wide range of temperatures and does not have a diapause, therefore is active year round, producing 24 generations in a year (Schlinger and Hall, 1959 and 1961; Force and Messenger 1964, 1965, 1968).

T. tenuicaudus and T. curvicaudus were imported into California and established in the Berkeley area in an effort to control ornamental tree aphids (Olkowski et al., 1976 and 1982). These parasitoids have made a significant contribution to aphid control. T. tenuicaudus has spread more slowly (Olkowski et al., 1984).

The goal of this study was to examine various aspects of the biology, seasonality, impact, and establishment of T. pallidus on M. coryli in western Oregon.

T.pallidus winter mortality and synchrony in emergence with M. coryli from overwintering are examined in the Chapter 1. Also examined is the impact the parasitoid is making on the aphid 3 years after initial introduction.

Diapause, often an important factor in host-parasitoid synchrony was examined (Chapter 2). Field induction and development of diapause was assessed in a natural situation (a commercial filbert orchard) and in a manipulated field experiment on filbert trees. Also examined was the potential number of generations and degree day requirements of *T. pallidus* under Willamette Valley, Oregon conditions.

A mass rearing and release program was conducted in an effort to augment establishment of *T. pallidus*. Chapter 3 describes the releases made and documents establishment within the release year and one year following.

II: SEASONAL SYNCHRONY BETWEEN THE INTRODUCED PARASITOID, *Trioxys pallidus* HALIDAY AND THE HOST, *Myzocallis coryli* (GOETZE) ON FILBERT TREES IN WESTERN OREGON.

ABSTRACT

Seasonal synchrony between the filbert aphid, *Myzocallis coryli* (Goetze) and its newly introduced parasitoid *Trioxys pallidus* Haliday was examined in the field to evaluate the effectiveness of parasitoid based biological control in filbert orchards of Oregon. Field-emergence observations showed that 50% eclosion of the aphid occurred 14 days before that of the parasitoid. Winter mortality of the parasitoid was 61.6% in 1986, and 55.3% in 1987. Host depression by the parasitoid was limited in early spring and steadily increased throughout the season. A post release study showed that aphid numbers diminished by greater that 62% aphids/leaf during the peak point of the pest season.

INTRODUCTION

Host-parasitoid phenology involves the interaction of three trophic levels--plant, pest, and parasitoid--and the many biotic and abiotic factors affecting all three. Phenological synchrony between parasitoid and host is essential for successful introduction, propagation, and release of biological control agents (Huffaker, 1971; Huffaker and Messenger, 1976). Seasonal synchrony is a complex adaptation including seasonal coincidence of host and parasitoid populations and overlapping life-cycles. Temperature requirements, photoperiodic stimulation, and food and host availability are a few of the many factors that influence seasonal synchrony (Tauber et al, 1986).

In the summer of 1984, a biotype of *Trioxys pallidus* Haliday was imported from France to western Oregon, where 95% of the filberts are grown in the United States (Baron and Stebbins, 1981). The parasitoid was brought as a potential biological control agent of *Myzocallis coryli* (Goetze), an exotic pest of filbert, *Coryllus avellana* L. (Messing, 1986). *T. pallidus*, a solitary endoparasitoid, is slowly becoming established in western Oregon, and its impact is still being evaluated. This paper deals with studies conducted in 1986 and 1987 examining seasonal synchrony between the introduced parasitoid, *T. pallidus* , and the aphid host, *M. coryli*, on filbert trees. The patterns of synchrony or asynchrony were studied by examining the winter mortality of *T. pallidus*, pattern of springtime emergence, impact on the aphid populations, and the occurrence of non-diapause (light colored) and diapause (dark colored) mummies throughout the season.

MATERIALS AND METHODS

The four experiments examining seasonal synchrony between T. pallidus and M. coryli are outlined separately. These experiments were conducted from September 1986 through March 1988.

Winter mortality

Mummified aphids (mummies) were collected from filbert orchards where the parasitoid had been established for two winters. The mummies were brought to the laboratory and the coloration identified (29 October to 18 December 1986). A total of 923 mummies were collected--42 light in color and 881 dark. In 1987 mummies were collected from 28 September to 27 December from another field experiment. A total of 1052 mummies were collected--330 light and 722 dark. Mummies were taped ventrally to qualitative #1 filter paper and placed in 160-ml polystyrene cups with lids. Every cup had two 4-by-4-cm organdy windows glued to the top and bottom. Each cup contained from 2 to 50 mummies. The cups were hung in mature filbert trees on a northeast or northwest limb 2 m from the ground, at the trunk crotch 1 m from the ground, or directly on the ground. Winter mortality of T. pallidus was assessed by counting mummies in early spring from which either hyperparasitoids or no parasitoids emerged. In 1987 there were no hyperparasitoids because the mummies were from a controlled field experiment that excluded hyperparasitoids.

Percent mortality was compared between light and dark colored mummies, as well as between aerial and ground sample locations in 1986. In 1987 location was not documented because there did not appear to be any significant effect of location in 1986. Hyperparasitism was quantified in two ways: as a percentage of total number of hyperparasites emerged from dark mummies; and as a fraction of total parasites emerged.

Springtime emergence

Emergence was followed in 1986 using the cups of mummies prepared as outlined above. In addition, aphid hatch was determined using field-collected twigs of filbert limb with a heavy concentration of aphid eggs, placed in separate cups. Emergence curves were fitted to heat-unit accumulations, based on a lower threshold of 7.4°C for *T. pallidus* and 3.3°C for *M. coryli* (Messing, 1986). Air temperatures were measured at the Hyslop weather station near Corvallis, Oregon.

Impact

Percent parasitism was followed at a commercial filbert orchard 4 km NE of Corvallis, Oregon in 1986. This orchard was chosen because it had the greatest establishment and proliferation of T. pallidus of any orchard of the previous year's releases (personal observation). Sampling was conducted every 7 to 10 days from 2 April to 9 June; then, samples were taken on around the 20th day of each month, except for July when samples were taken on the 1st. Sampling in early spring was destructive (leaves were picked from the trees), but such measures were eliminated after 29 May. Ten leaves per tree were sampled from 12 trees. All leaves sampled were penultimate to the outer end of the limb and always on the periphery of the tree canopy. On each leaf, the following were counted: total number of aphids; alate aphids; fourth-instar aphids; and light and dark mummies. Also recorded were whether mummies were still developing, had emerged, or had been killed by fungi or predators. From 2 April to 19 May, no mummies had formed in the field; therefore, third and fourth instars were dissected to determine if parasitism had occurred.

Percent parasitism was based on the number of winged and fourth-instar aphids that were mummified. Parasitism based on this part of the aphid population provided an indication for the general level of parasitism in the population, since the mummification occurs only during the fourth or fifth instar. Although dissection showed third-instar aphids may be occasionally parasitized, this instar was too difficult to count in the field and therefore, left out of the calculation.

The orchard studied (Twedt's orchard) was one of the original release sites of T. pallidus by Messing (1986). Because documentation of this site exists, I compared the number of aphids per leaf in 1987 to the pre and post release data in 1985. I used the same sampling technique as Messing (1986).

RESULTS

Winter mortality

Winter mortality is defined as failure of T. pallidus to emerge from overwintering mummies, resulting from hyperparasitism or other mortality factors. In 1986 (Table 1) over 38% of dark mummies produced adult parasitoids, and whereas no T. pallidus or hyperparasitoids emerged from light-colored mummies indicating no survival of the light-colored mummies during the winter months. Out of the 62% dark colored mummies that did not produce adult parasitoids nearly 13% were parasitized by three different hyperparasitoids, Asaphes sp. (Pteromalidae), Alloxistinae sp. (Cynipidae), and an unidentified species of Encyrtidae. The remaining mummies were dead.

In 1987 (Table 1) similar results to 1986 were observed. In some of the light colored mummies (3%) adult T. pallidus did successfully emerge. Of the dark colored mummies 55% did not produce adult parasitoids; these mummies were obtained from an exclusion cage where no hyperparasitoids could have reached the host.

Spring time emergence

Figure 1 illustrates the sequence of field emergence for M. coryli, T. pallidus, and the hyperparasitoids. Data are presented as cumulative percentage emergence over time to more clearly illustrate the relationship among the different insects. Based on their respective lower developmental thresholds, 50-percent emergence of M. coryli and T. pallidus was at 82.2 (base temperature of 3.3°C (Messing, 1986) starting at 1 January) and 272.2 (base temperature of 7.4°C) and degree days, respectively, which were 14 days apart under field conditions (Table 2). Filbert leaves at this experimental site started to open within the same week that M. coryli began to emerge.

Impact

Mummification of M. coryli (Table 2 and Figure 3) did not occur until 19 May, when dissections also showed that parasitism had occurred. The dissections did not show parasitism earlier in the season, perhaps because T. pallidus larvae were too small to see in the aphid body. Figure 3 shows the percentage of the aphid population in the fourth instar larvae or adult stage; these older aphid instars were used for calculating percent mummification (parasitism) in Table 2.

Figure 4 illustrates that there is a depression in the number of aphids per leaf at the commercial orchard in 1987 as compared to both the pre and post release periods in 1985. At the height of the season, late June to early July, aphid populations in 1985 averaged 100 aphids/leaf, while in 1987 they were only 38 aphids/leaf. The natural phenology of the aphid population throughout the year is relatively the same in the years compared. The aphids start to appear in the orchard in April, have a small peak in late May, then a high peak in early July, and from mid August until October or November remain below 10 aphids/leaf.

DISCUSSION

Successful emergence from overwintering only occurred in the dark mummies of T. pallidus. Cocoon coloration in Aphidiidae has been correlated with the diapause characteristic of the individual. Praon palitans, an internal parasitoid of Therioaphis maculata (Buckton) is known to have 2 color types, white and dark brown (Schlinger and Hall, 1960). Both color types may have some diapausing and some nondiapausing type individuals, but in general, the brown P. palitans are mostly diapausing whereas the white ones are nondiapausing. Aphidius sonche Marshall also is generally brown as a diapause type individual and white as nondiapause (Liu and Carver, 1985). Diapause coloration has been mentioned in passing for the genus Trioxys but has not been clearly documented (Van den Bosch, et al, 1962; Sluss, 1967; Singh and Sinha, 1980). Based on the emergence from overwintering cocoons (Table 3), it is clear that T. pallidus also diapauses as brown cocoons. Minimal or lack of spring emergence from light mummies clearly illustrates that they were unable to survive winter conditions and therefore are susceptible to adverse environmental conditions, typical of a nondiapause stage. It appears that a very small proportion of white mummies may either be in diapause or capable of survival through milder winters without going into diapause as documented by the 3%

emergence of light colored mummies in 1988.

Winter mortality of dark mummies due to factors other than hyperparasitism was high in both years. Many factors might account for this mortality, but none were specifically identified. The most obvious causes are environmental, although pathogens may have also caused mortality.

Hyperparasitism of T. pallidus has been documented on filbert by Messing (1986) and on walnut by Nowierski (1979). The hyperparasitoid species that emerged from the dark mummies are known to be native, which have apparently moved from their native hosts to these introduced populations. For hyperparasitoids to show less host specificity than primary parasitoids (Gordh, 1981) is common, which generally reduces the effectiveness of new primary parasitoids like T. pallidus.

Greater than 50% of the dark mummies did not emerge in both years indicating that some factor is damaging the overwintering population. Fungal hyphae were seen developing on many of the overwintering mummies. Although cause and effect were not identified it is likely that overwintering mummies which predominantly reside on the soil surface on rotting leaves are exposed to many pathogens be they obligate or facultative. Percent mortality between the

2 years was not significantly different and although minimum temperature varied between the years (January 1986, -10.3°C; January 1987, -13.6°C), it is doubtful that mortality was specific to the climate of each year. The *T. pallidus* population in Oregon, although collected from similar climatic regions in Europe, was started from a narrow gene pool (only 268 individuals, 146 females and 122 males). Western Oregon may not have ideally suitable winter climate for *T. pallidus*.

The emergence curves (Figure 1) show an ideal association between a plant, a host, and a parasitoid for successful biological pest control but are confounded by the close synchrony of the hyperparasitoids. The relationship of emergence of *T. pallidus* to that of *M. coryli* is still unclear: although the relation is close (14 days apart), it still may not be optimal for maximum *T. pallidus* reproduction in the spring. Messing (1986) documented that the diapause of *T. pallidus* is shallower than that of *M. coryli* and suggested that the emergence of *T. pallidus* can be altered. His laboratory experiments measuring emergence from overwintering only accounted for the influence of temperature. The mean temperature in early spring 1987 was warmer than average (+1.9 to +6.3 C above long term average), and parasitoid emergence followed the emergence of prey by about 14 days, thus providing a highly desirable phenological synchrony.

Data (Figure 3) suggested a limited impact of _T. pallidus_ in the early spring. When mummies first appeared in the field (May 12) there was an average of 15 aphids per leaf. Although this number is much below the treatment threshold of 30 aphids per leaf set for May (Calkin et al, 1983), the number of aphids were still able to double by the end of June. Based on data from the same orchard, aphid counts in June 1985 were 80 per leaf compared to less than 35 per leaf in 1987. The parasitism rate increased to about 20% or greater by mid July, suggesting that the activity of _T. pallidus_ is highly density-dependent, the percentage of parasitism increasing with increased aphid density. High winter mortality is probably also a contributing factor to limiting biological control by reducing the number of potentially reproducing females in early spring. In spite of these limitations, it appears that _T. pallidus_ is capable of reducing aphid populations in a commercial hazelnut orchard as documented by dramatic reduction of aphids in during 1987.

Table II. 1. Percent field emergence of <u>Trioxys pallidus</u> from mummies collected in fall 1986 and 1987.

Mummy Color	N	% Parasitoid Emerged	% Hyperparasitized Emerged	% Unemerged (dead)
1986				
Light	40	0.0	NA	100.0
Dark	588	38.4	12.8 (N=75)	48.8
1987				
Light	330	3.0	0[1]	97.0
Dark	722	44.7	0[1]	55.3

[1]In 1987 there were no hyperparasitoids because mummies were collected from an experiment that excluded them.

Table II. 2. Progression of percent mummification of *Myzocallis coryli* by *Trioxys pallidus* in the field, Corvallis, Oregon, 1987.

Date Sampled	Percent Mummification[1]	Dissection Parasitism[2]
2 April	0.0	no
10 April	0.0	no
20 April	0.0	no
28 April	0.0	no
5 May	0.0	no
12 May	1.1	no
20 May	8.5	yes
29 May	2.8	yes
9 June	4.1	-
19 June	5.0	-
1 July	21.4	-
20 August	27.7	-
18 September	6.7	-
20 October	14.7	-
20 November	54.1	-

[1]Percent mummification was calculated as the number of mummies that still had developing *T. pallidus*, divided by the number of winged plus the fourth instar *M. coryli*, and then multiplied by 100.

[2]*M. coryli* was dissected in the laboratory to detect *T. pallidus* larvae.

Table II. 3. Emergence of *Myzocallis coryli* and *Trioxys pallidus* overwintering populations, 1987.

Species	N	Emergence dates First	50%	Last	Duration (days)
M. coryli	882				
julian date		63	80	101	38
degree days[1]		23.0	272.2	399.3	
T. pallidus	226				
julian date		73	94	118	45
degree days[2]		45.7	82.2	172.8	

[1]degree days measured starting 1 Jan. 1987, >3.3°C

[2]degree days >7.4°C

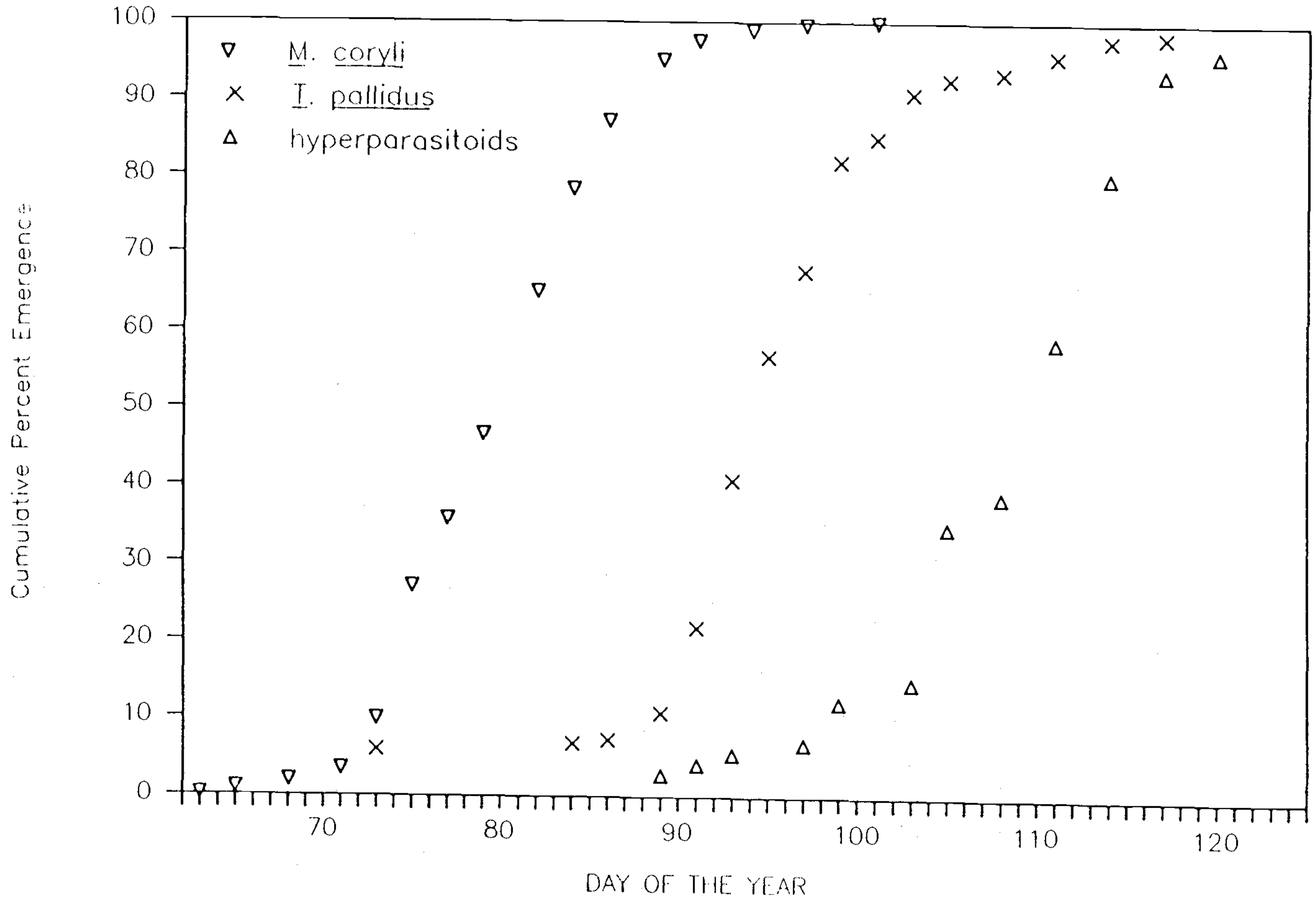


Figure II. 1. Spring emergence of Myzocallis coryli, Trioxys pallidus, and hyperparasitoids in western Oregon, 1987.

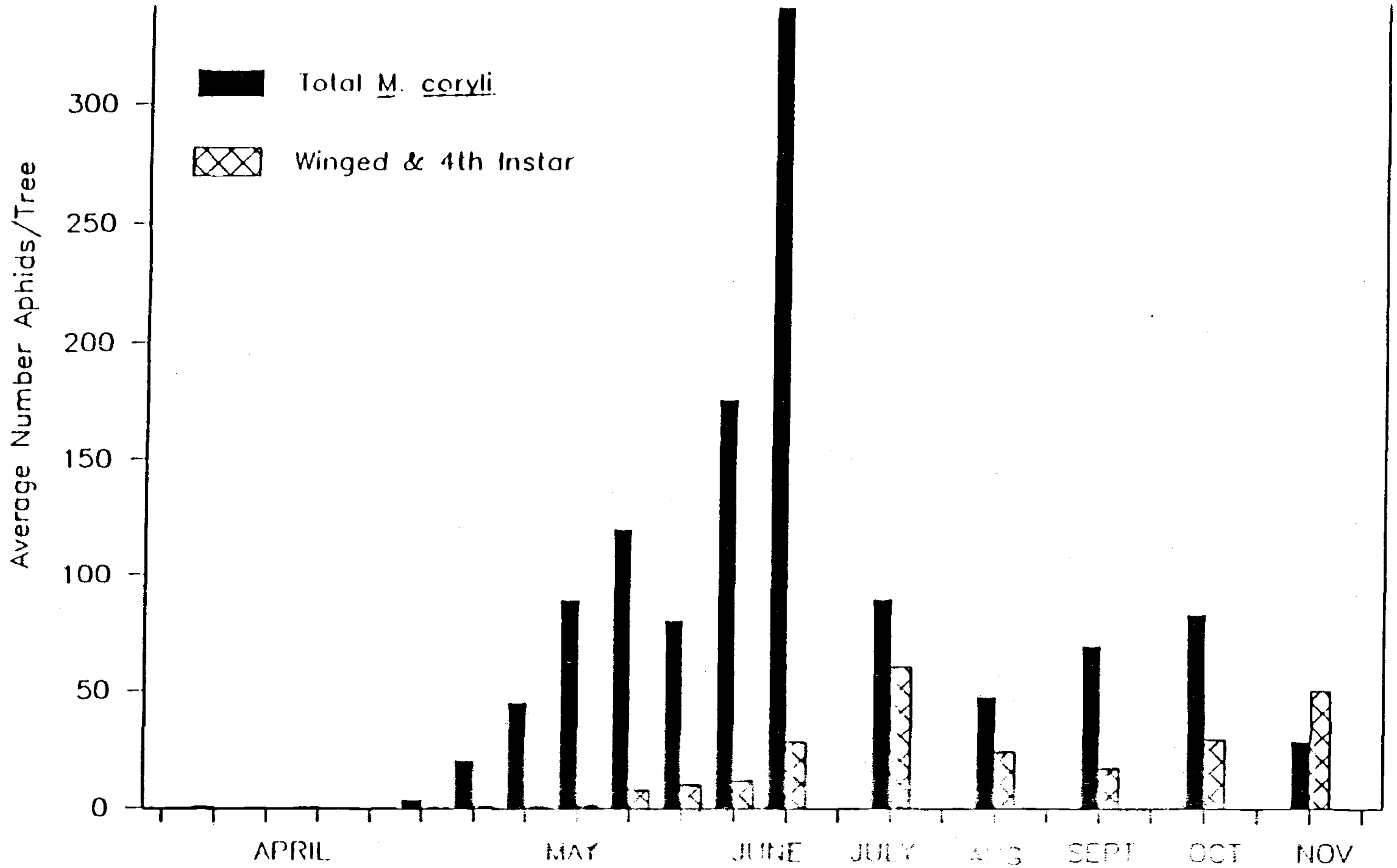


Figure II. 2. Instar class distribution of Myzocallis coryli at a commercial filbert orchard, 1987.

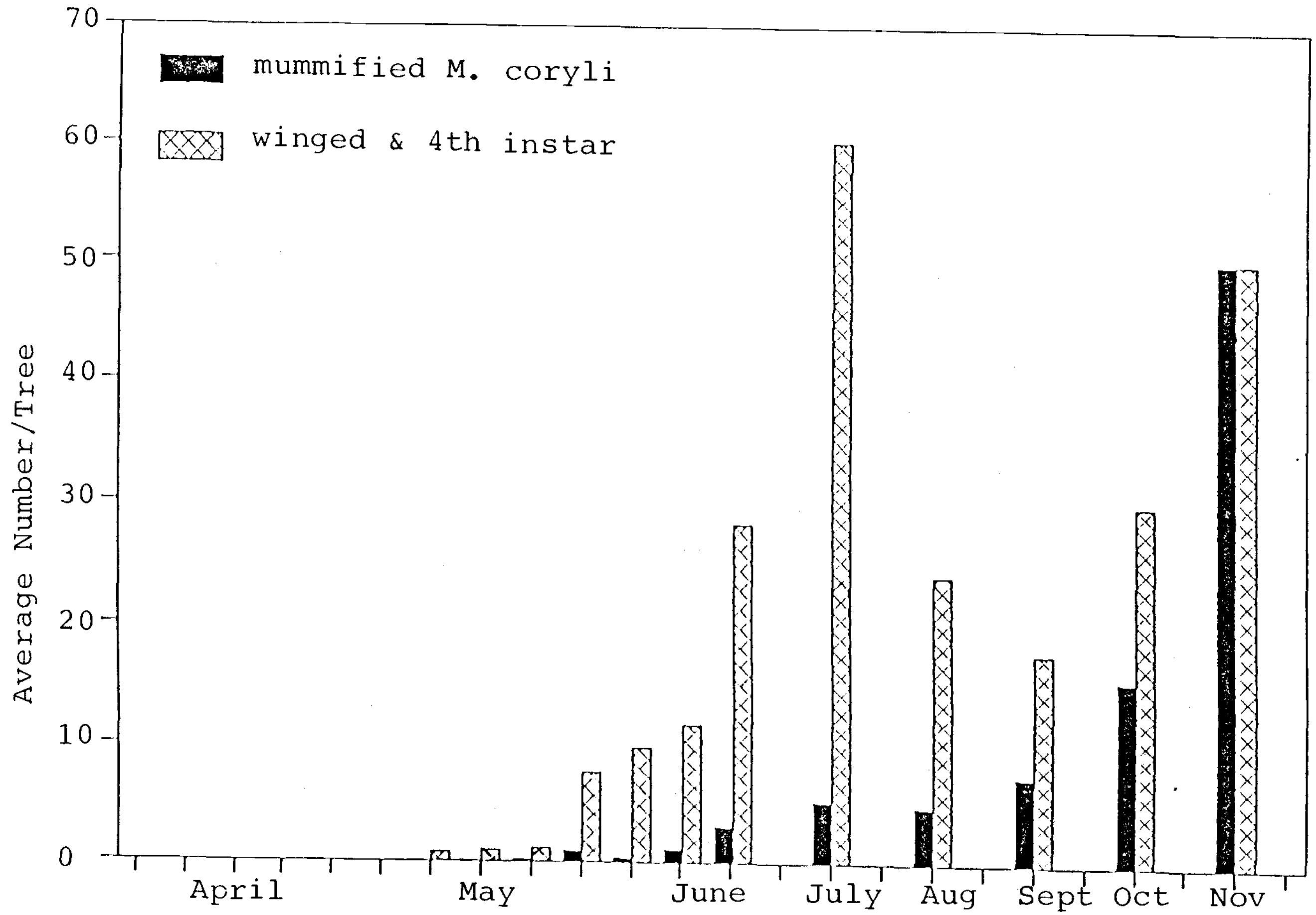


Figure II. 3. Parasitism of <u>Myzocallis coryli</u> at a commercial filbert orchard, 1987.

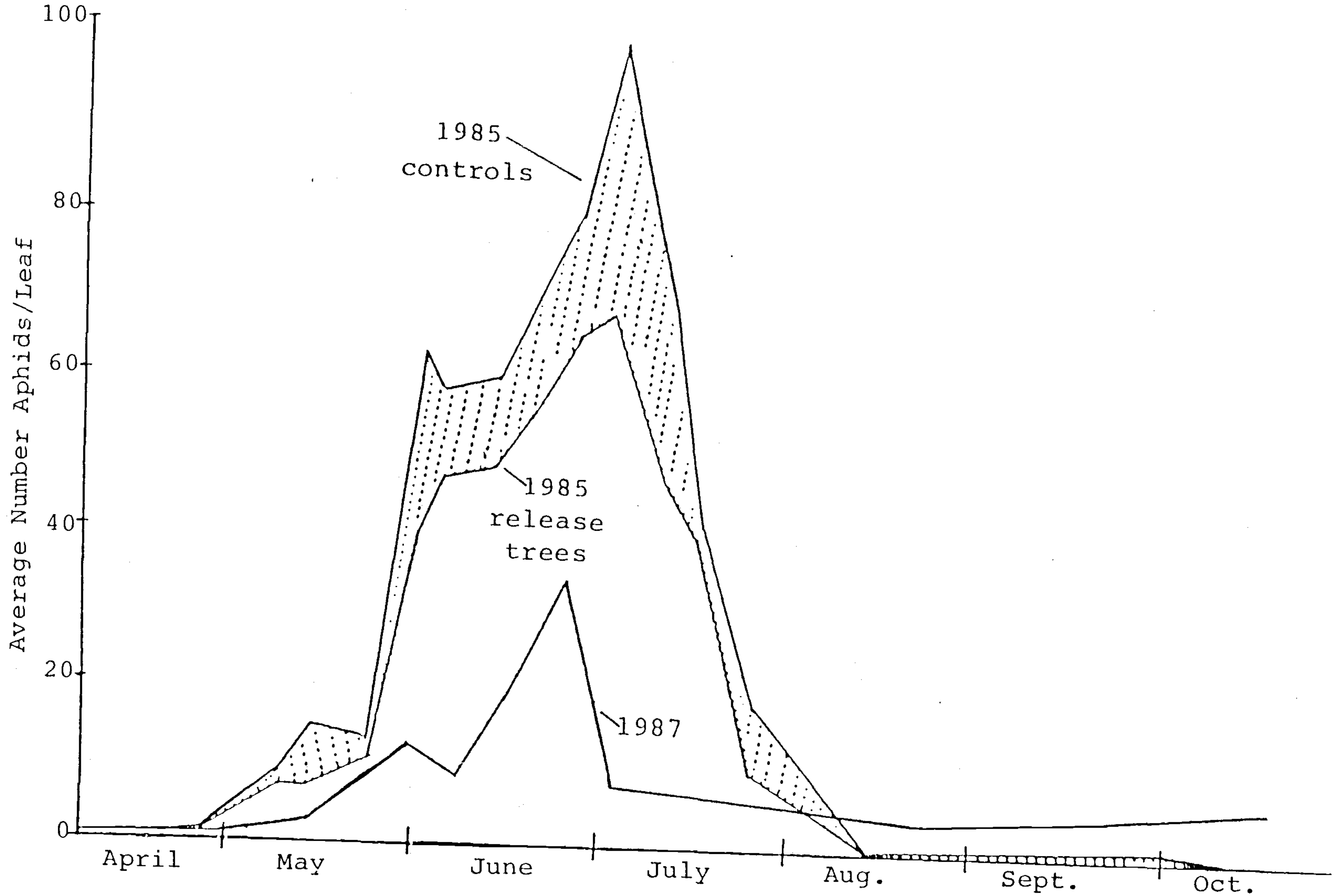


Figure II. 4. Myzocallis coryli population densities at a commercial filbert orchard, 1985 and 1987.

III. FIELD DEVELOPMENTAL TIME, DIAPAUSE INDUCTION AND DIAPAUSE DEVELOPMENT IN *Trioxys pallidus* HALIDAY UNDER WILLAMETTE VALLEY CONDITIONS.

ABSTRACT

Time from ovipostion to 50% eclosion for nondiapause *T. pallidus* in the field ranged from 248.0 to 373.6 degree days (6.0^{o}C lower threshold from mean inoculation date). The time from oviposition to mummy formation represents 64% of the time to adult eclosion. Four generations of *T. pallidus* were produced in one growing season during a controlled field experiment although, based on heat unit calculations, it would be possible to produce 6 generations. The parasitoid population declined in experiments during the summer months accounting for fewer generations in the season.

Diapause type individuals were produced in *T. pallidus* population throughout the filbert growing season but were not dominant until October-November. The incidence of diapause largely occurred when there were less than 13 hours of light per day. Diapause development continued as winter progressed as demonstrated by a decrease in days to eclosion with each successive winter sample date.

INTRODUCTION

Seasonal synchrony between a parasitoid and it's host is very important in assessing success in a biological control system (van den Bosch et al., 1959; Schlinger, 1960). Success of a classical biological control program can often depend on the species or biotype of natural enemy imported (Huffaker, 1971). Important aspects of synchrony in classical biological control include the occurrence of diapause, seasonal activity, and survival of the natural enemy in the new environment.

Diapause, a dynamic state of arrested development that anticipates nature, is an important aspect of classical biological pest control, for it's occurrence can influence the survival in a new environment and phenological synchrony with the new host (Tauber et al., 1983). The timing of it's different stages are an important factor in an organism's successful adaptation to its environment. Examining diapause helps to elucidate synchrony between host and parasitoid, estimate geographic limitation of parasitoid survival, and identify efficient mass-culturing techniques. Diapause can act as an equilibrator between host and parasitoid lifecycles by slowing down insect development and allowing them to be active at relatively similar times. Parasitoid survival is often greatly aided by a diapause state through protecting survival at times which may be stressful, or when host activity is limited. This low metabolic state of growth allows insects to overwinter and withstand extreme summer conditions with limited mortality.

Trioxys pallidus Haliday is known to pass through a winter diapause stage enabling survival through adverse winter conditions. In the filbert aphid population of *T.*

pallidus, winter dormancy appears to be more prevalent and critical in developing spring synchrony with available aphid hosts, particularly because aphid eclosion occurs in early spring (Chapter 1). In the present study I attempted to evaluate the dynamics of diapause of T. pallidus, a parasitoid of the filbert aphid, Myzocallis coryli (Goetze) in Oregon. The proportions of diapause occurrence in a field population during the entire growing season was assessed and diapause development characteristics were evaluated. The degree days per generation of T.pallidus that can occur in the filbert growing season were also investigated.

MATERIALS AND METHODS

Diapause induction under field conditions and degree days per generation

Filbert tree limbs were covered with mesh bags (measuring 45 cm x 25 cm) in early January-before bud break, and prior to aphid hatch and parasitoid eclosion. Each bagged limb measured approximately 30 cm. long. Four filbert trees (Barcelona variety) were used with each tree representing a replicate. Before bagging, the limbs were hand cleaned of predators, parasitoid mummies, other insect eggs, moss, and lichen. Pieces of filbert twigs that were covered with aphid eggs were also placed in the bags to insure plenty of hosts for the parasitoids. On 27 March, when it was observed in another experiment (Chapter 1) that 95% aphids had hatched in the field, 100 first and second instar aphids from the laboratory were placed in each mesh bag as further insurance of having enough hosts for the parasitoids.

During the growing season parasitoids were inoculated into a bag on each of the 4 trees (replicates). A total of 5 of these experiments were conducted throughout the growing season. Timing of inoculation and the number of parasitoids put into each bag varied due to availability and problems encountered in the field. Many attempts were made to continue the parasitoid generations throughout the summer failed. As a result the experiment did not continue until the September inoculation date (9/3-9/12). These summer attempts failed due to a diminished aphid population in the bagged limbs. The adults used to inoculate the bags in September were from a greenhouse culture kept at 22^{o}C, 16L:8D. Table 1 lists the inoculation dates and other information pertaining to the set-up of this experiment.

The percent diapause versus nondiapause mummies was assessed throughout the season. The diapause (dark) mummies were identified as those which were light to dark brown in color, whereas the nondiapause (light) mummies were white to light tan. As explained and investigated in Chapter 1 the difference between these types of mummies is in their ability to survive winter conditions. Outdoor temperatures were monitored at Hyslop Weather Station, approximately 3 km from the experimental site. Degree day accumulations were calculated by adding the maximum and the minimum daily temperatures and dividing by 2. Degree day requirements were calculated for mummy formation period and time to eclosion in the field generation experiment from the mean inoculation date at each generation. The number of degree days accumulated were calculated by adding the daily maximum and the minimum temperatures and dividing by 2. A lower development threshold of 6.0°C for nondiapause individuals was used as determined by Messing (1986).

Diapause development under field conditions

T. pallidus diapause (dark colored) mummies were brought in from the field from 31 October 1986 to 30 December 1986 at 2 week to 1 month intervals. The mummies were separated into replicates of 10 and taped ventrally to qualitative #1 filter paper and placed in 9 cm diameter covered plastic petri dishes. Three to five replicates of dishes containing mummies were placed in small wooden boxes (Table 4). The boxes measured 50 cm. x 67 cm. x 45 cm. and were provided with a timer to control the light source. Illumination in the box was supplied by a 15W bulb and temperature was controlled within 1°C. The light intensity was maintained at 31 LUX per m^2 per second. The light source was set at 8 hours light, 16 hours dark at 22°C. Petri dishes were checked daily for parasitoid emergence and the filter paper was moistened with water. A tray of water was also placed in each box to maintain humidity in the photoperiod box.

Data were collected daily on the time of emergence, sex of the parasitoid, and hyperparasitoids. Degree days to eclosion were calculated using a base temperature for diapause mummies of 7.4°C (Messing, 1986) accumulated over the days since October 31, the first sample date from the field.

RESULTS AND DISCUSSION

Diapause induction under field conditions and degree days per generation

In the first generation (mummy formation period 1), no comparison was possible as no mummies were found at this early date at the commercial orchard (Table 1). It is notable that at this early date in the controlled experiment 12.0% dark mummies were found indicating the presence of a diapause inducing factor. Only 12 (16.7%) of these diapause mummies eclosed, of these, 50% eclosed 2 weeks later than the nondiapause mummies.

During period 2 (5/5-5/8), 100% were nondiapause mummies. At the same time at the commercial orchard the number of mummies found was less than 8/leaf. Although the Twedt's sample was small, there were a few (N=3) diapause mummies found indicating a diapause inducing stimulus early in the season.

At period 3 in July, a predominance of nondiapause mummies occurred again in both the experiment and at the commercial orchard, 100.0% versus 93.3% to 94.4% respectively. At this time in the orchard samples were showing a trend, although small, towards diapause mummy production which continued as fall and winter approached (Figure 1).

It was not possible to continue the parasitoid summer generations in the controlled experiment after the July sample dates. It has been documented (El Haidari, 1959; Messing, 1982; Chapter 1) that the aphid population naturally declines at this time of year, presumably due to high temperatures. *T. pallidus* is also known to decline during the heat of the summer which is in synchrony with declining host populations. The number of viable mummies (Figure 1) at the commercial orchard was low (average of 6.3/leaf).

In September results are skewed due to the problems explained in the methods. The result of 100% mummies being nondiapause may have been due to the source of the parents (greenhouse) of those mummies and not due to field conditions. This is particularly evident because at the commercial orchard on 18 September there were 74.0% nondiapause mummies and on October 20 the number dropped to 29.7% nondiapause, showing the field trend to diapause type individuals.

In November and December, the last sample dates both the controlled experiment and the orchard showed a predominance of diapause mummies. In the experiment the results were dramatic with 7.8% nondiapause and 92.2% diapause. At the orchard 12.2% were nondiapause and 87.8% were diapause. Coupled with results from other experiments (Chapter 1) it is clear that the overwintering form of this parasitoid is in a diapause mummy, and the natural occurrence of more dark colored mummies as winter approaches is expected.

Photoperiod is the main stimulating factor promoting induction of diapause in many insects (Tauber et al., 1983; Beck, 1980; Saunders, 1982) with other factors such as temperature often acting as modifiers (Maslennikova, 1958; Ryan, 1965). The photoperiod at both the beginning of the growing season (April-May) and at the end (October-November) ranged from 12:45 to 11:35 hours light compared to a season maximum of 15:34 hours in June. The incidence of diapause occurred when there were less than 13 hours light per day as exhibited by the first mummy formation period when 12.1% of the mummies were in diapause and there were 12:45 hours. Also at mummy formation period five (11/10-12/27) when there were 11:35 hours the incidence of diapause was 92.2% in the experimental bags and 87.8% at the orchard. At the orchard during October and November there was a steady rise in the incidence of diapause at a time when light hours were declining from 13:10 hours light. The temperature at this time of year also reached an average monthly low of -5.73°C.

Adult eclosion (50%) from nondiapause mummies in field generations averaged 322.1 degree days (6.0°C lower threshold) from the inoculation date (Table 3) with a range of 248.0 to 373.6. As the season progressed, it took more heat units for the parasitoids to eclose although the number of days to eclosion was similar, 35 to 40 days. Messing (1986) documented in the laboratory that the parasitoid requires 265 degree days from oviposition to adult eclosion as opposed to the 322.2 demonstrated in this field experiment. The difference between these 2 experiments is 57.1 degree days which represents 29.4% of the average time until the first mummies appeared in the field. The difference in the heat units required from oviposition to eclosion may represent preoviposition time, a time for initial feeding and mating.

Although the total number of degree days required per generation in this field experiment differ from Messing's (1986) data, oviposition to mummy formation represents 64% of the time to adult eclosion in both experiments. This validates the growing season developmental threshold of 6.0°C for _T. pallidus_.

Messing also projected that within the filbert growing season the parasitoid could have 8 generations (2025 DD/season:265 DD/*T.pallidus* generation=7.6 generations). Based on the heat unit requirements required in this field study this estimate appears liberal. In this experiment 2025 DD/season:322 DD/*T.pallidus* generation=6.3 generations. As mentioned previously it was not possible to continue the parasitoid generations into the summer months, the reasons for this difficulty have not been precisely documented but it appears that the high temperatures in summer limits *T. pallidus* activity in filberts as it does in the walnut agroecosystem (Nowierski, 1979). The drop in parasitoid activity closely follows a decline in the host population at this time of year. This is a limitation in *T. pallidus* producing 8 generations per season. If the April generations from the experiment are grouped together, because they closely overlap in time, it was possible to get at least 4 generations of *T. pallidus* in the growing season and quite possibly more but the potential for 8 generations is questionable due to limited summer activity and the longer generation time calculated.

Diapause development under field conditions

Results of this experiment are inconclusive due to the small sample size of many of the treatments. General trends can be seen with respect to date that the sample was brought in from the field.

The first date, 31 October (excluding 3 December sample due to unexplainable biological reasons), had the lowest total number of emerging parasitoids, indicating that diapause development had not occurred and physiological requirements were not met when brought into the lab.

However, as the winter progressed the number of parasitoids emerging increased with each sample date (Table 4 and Figure 2). The 3 December sample date had extremely low numbers of T. pallidus emerging. One account for this was that hyperparasitism was greater than 50% on this date. There could also be other reasons but they were unclear.

Table 4, showing degree days to eclosion clearly demonstrates the effect of winter chill on developing T. pallidus. On almost all sample dates the degree days to 50% eclosion decreased as winter progressed, at this time of year no heat units accumulated above the development threshold of 7.4^{o}C (Hyslop Farm Weather Data). Further analysis (Figure 3) illustrates a high correlation between sample date and mean number of days to 50% eclosion (r^2=0.6), thus diapause development conditions are being met in the field as would be expected at this time of year for a diapausing insect.

Analysis of the time to 50% eclosion (Table 5) demonstrates that, as the season progressed, T. pallidus had varying levels of diapause development (Fisher's LSD at p=.05). For example, 31 October and 5 November took significantly more days to eclose, therefore not having enough time in the field to complete diapause development. The 19 November sample exhibited partial diapause development with 21 days to eclosion. The samples taken on 26 November, and 3 December, and 30 December ranging from 9 to 16 days to 50% eclosion had more fully completed diapause development. Mean number of T. pallidus eclosed on each sample date (Figure 2) further demonstrates the effect of winter conditions for promoting diapause development, as the sample date was delayed the number of T. pallidus emerged increases.

Table III. 1. Percent diapause (dark) versus nondiapause (light) type mummy of _Trioxys pallidus_ per generation.

Mummy Formation Period (Date)	N	Percent Light Mummies	Percent Dark Mummies	Photoperiod hours light[1]
1. 5/5 - 5/8	599	88.9%	12.1%	12:45
orchard[2] 5/6[3]		-	-	
2. 5/8 - 5/18	742	99.6%	0.4%	13:28
orchard 5/12[4]				
3. 6/1 - 6/22	205	100.0%	0.0%	14:40
orchard 6/9	18	93.3%	6.7%	
orchard 6/19	40	94.4%	5.6%	
orchard 7/1	83	94.3%	5.7%	
4. 9/28 - 10/28[5]	308	100.0%	0.0%	13:10
orchard 9/18	74	74.0%	26.0%	
orchard 10/20	132	29.7%	70.3%	
5. 11/10 - 12/27	691	7.8%	92.2%	11:35
orchard 11/20	204	12.2%	87.8%	

[1] The hours of sunlight at the inoculation date.
[2] Twedt's commercial filbert orchard, Corvallis, Oregon.
[3] No mummies had formed in the commercial orchard yet.
[4] Sample size less than 8 mummies.
[5] These results may be biased because the source of the parent population was the greenhouse.

Table III. 2. Trioxys pallidus mummy formation period in field generations, 1987.

Inoculation Date	Mummy Formation Period[1,2]					
	1st mummy		50% mummy		last mummy	
	days	DD	days	DD	days	DD
April 1-4						
light mummies	33	183.7	33	183.7	36	232.6
dark mummies	33	183.7	33	183.7	36	232.6
April 14-24	20	168.5	20	168.5	30	267.4
May 11-14	28	224.8	32	263.3	39	335.4
Sept. 3-12	22	220.7	22	220.7	52	472.4
Oct. 4-18						
light mummies	30	173.3	34	193.8	38	199.2
dark mummies	30	173.3	32	182.4	77	240.7

[1]Days since mean inoculation date.

[2]Degree days above a lower threshold of 6.0°C since mean inoculation date.

Table III. 3. *Trioxys pallidus* mean 50% eclosion from non-diapause type mummies in field generations.

Inoculation Date	*T. pallidus* Eclosion Time from inoculation date: days	from inoculation date: DD[1]	from 50% mummy formation date: days	from 50% mummy formation date: DD
April 1-4	37	248.0	5	70.2
April 14-24	38	317.7	17	133.8
May 11-14	40	349.2	9	96.6
Sept. 3-12	35	373.6	12	139.5

[1]Degree days above a lower threshold of 6.0°C.

Table III. 4. Diapause development of Trioxys pallidus under laboratory conditions (8 hours light, 16 hours dark at 22°C) collected from the field successively through the season, 1986.

Sample Date	N	% Completed[1] Development	Time Required for[2] Completion of Development	
			Days	Degree Days[3]
31 Oct.	40	27.5%	52	759.2
5 Nov.	37	37.8%	58	467.2
19 Nov.	40	52.5%	24	350.4
26 Nov.	42	42.9%	18	262.8
3 Dec.	40	17.5%[4]	11	160.6
30 Dec.	28	71.4%	12	175.2

[1]The number of Trioxys pallidus that eclosed from the total sample (N) less hyperparasitoids that also eclosed.

[2]Time to 50% eclosion of Trioxys pallidus.

[3]Degree days accumulated above 7.4°C.

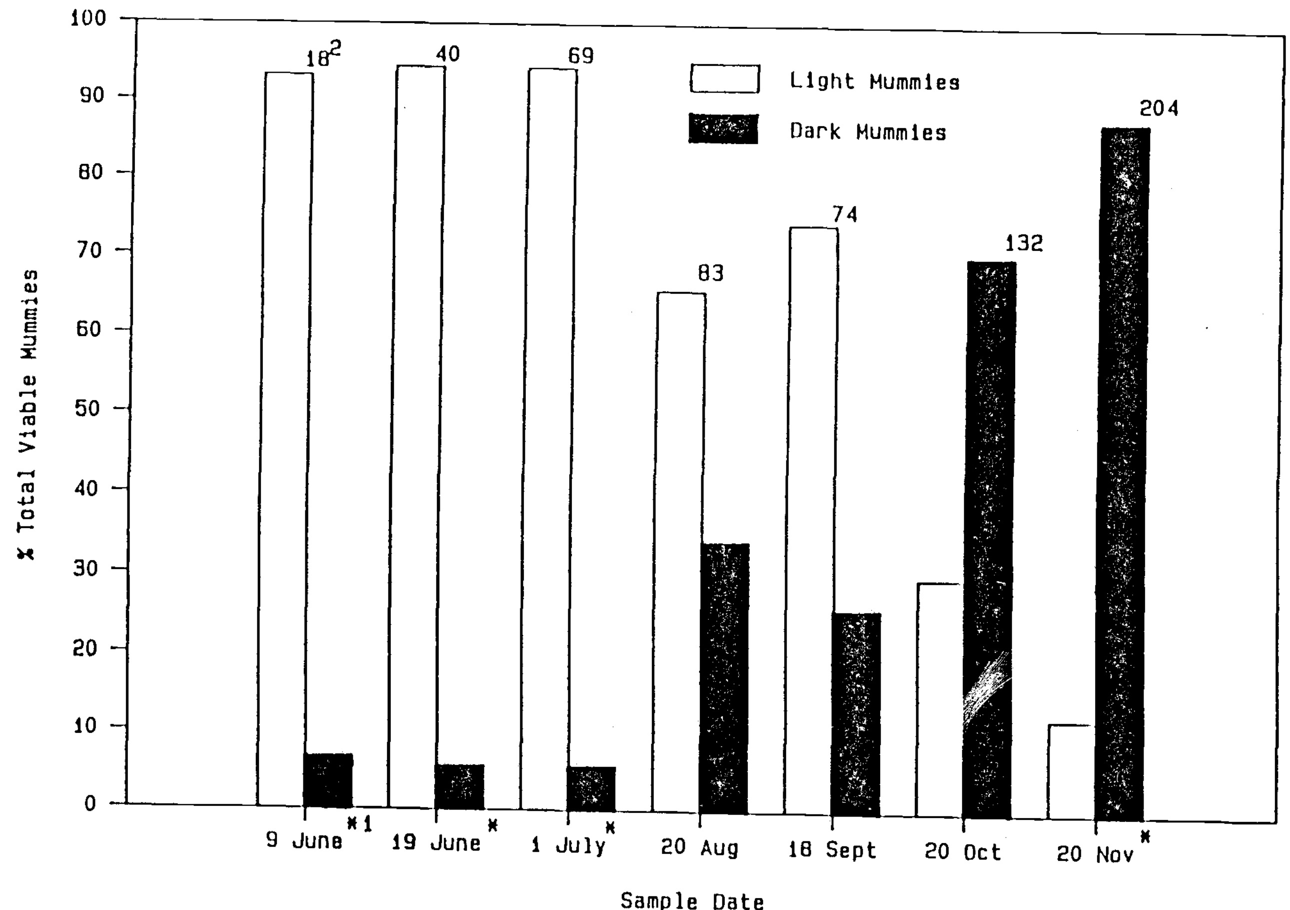
[4]Percent hyperparasitism unusually high on this sample date which partially explains the low percent that completed development.

Table III. 5. Influence of field conditions on diapause development of *Trioxys pallidus*.

Sample Date	Time to Emergence (Days)	
31 Oct	54.5 ± 4.5	d[1,2]
5 Nov	62.0 ± 3.7	d
19 Nov	21.7 ± 3.7	bc
26 Nov	16.8 ± 3.2	abc
3 Dec	9.3 ± 3.7	ab
30 Dec	12.0 ± 3.7	abc

[1]Mean days to emergence followed by the same letters are not significantly different. Fisher's LSD at p=.05.

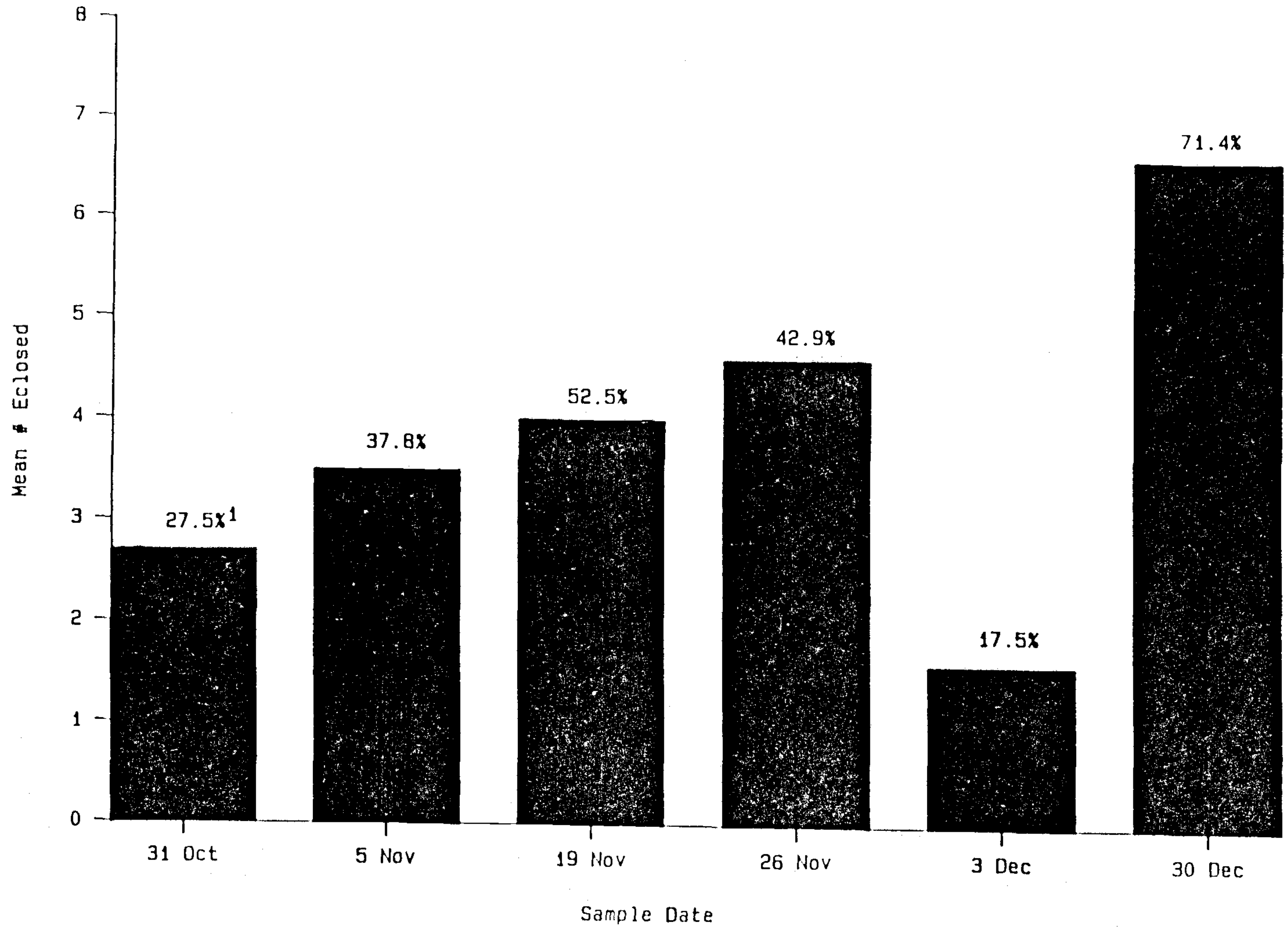
[2]Analysis run for samples that had greater than 1 *T. pallidus* eclosed per replicate.



[1] *Mummy colors significantly different on that sample date. ANOVA $p<.05$

[2] Sample size (N)

Figure III. 1. Percent viable <u>Trioxys pallidus</u> mummies found at the commercial filbert orchard, 1987.



[1]Percent of total number per sample date that eclosed.

Figure III. 2. Mean number of Trioxys pallidus eclosed on each sample date in the laboratory at 8 hours light, 16 hours dark, and 22°C.

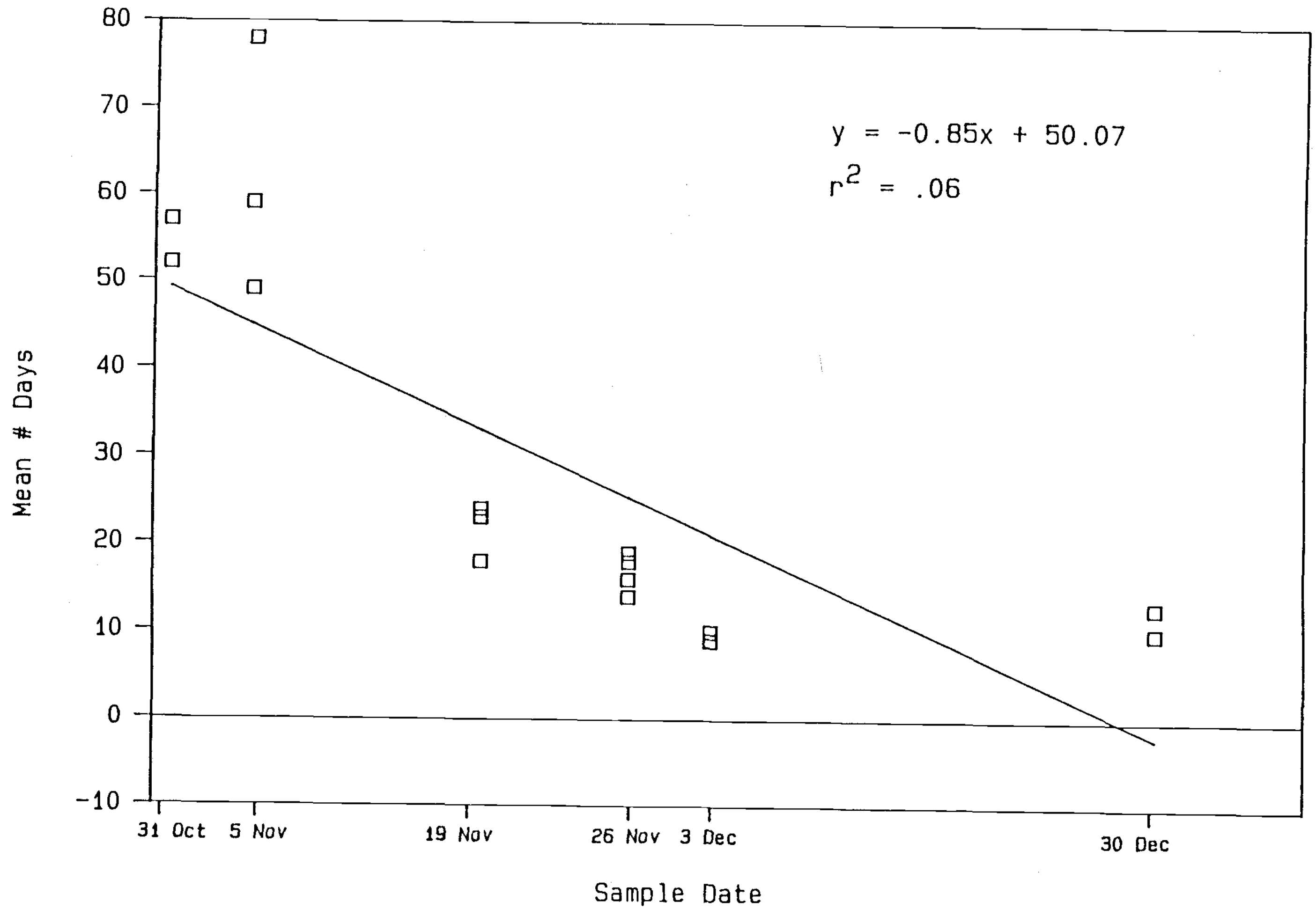


Figure III. 3. Comparison of the mean number of days to 50% eclosion of _Trioxys pallidus_ in the laboratory at 8 hours light, 16 hours dark, and 22°C.

IV. MASS CULTURING AND RELEASE OF *Trioxys pallidus* HALIDAY IN FILBERT ORCHARDS OF OREGON.

ABSTRACT

In 1987 a total of 2,645 adult and 1,900 mummy *T. pallidus* were released in western Oregon filbert orchards. A 1988 survey of 12 of the 13 release sites showed 4 of the sites to have established populations that survived the winter.

INTRODUCTION

The filbert aphid, *Myzocallis coryli* (Goetze) is an important pest of hazelnut in Oregon (Calkin et al., 1983). An aphidiid parasitoid, *Trioxys pallidus* Haliday, was imported from Europe in 1984 and released in small numbers (146 females and 122 males) during 1985 and 1986 to control *M. coryli* (Messing, 1986). This mass culturing and field release program was continued in 1987 to expand the areas of *T. pallidus* establishment further throughout western Oregon. Preliminary evaluation of establishment of the 1987 releases were made in 1987 and 1988.

MATERIALS AND METHODS

Culturing

A mass culturing and release program of Trioxys pallidus was continued from what was set up by Messing (1986). Briefly, individually potted filbert seedlings were maintained in greenhouses that were kept at 22°C, 16L:8D photoperiod. In December, 1986, filbert branches that were covered with aphid eggs were collected from the field and spread among the seedlings in the greenhouses. Aphids eclosed within 2 weeks and were allowed to establish for 1 month before parasitoids were manually released in the room. An effort was made to wait for the aphids to establish in high numbers on the plants before releasing parasitoids in the greenhouse but the parasitoids inoculated themselves before the scheduled first release, although other releases were subsequently made into the rooms. The parasitoids released were from another on going culture that was maintained at 22°C, 16L:8D photoperiod.

The same problems discussed by Messing (1986) were encountered with the culturing program. Trophic interactions beyond the plant-aphid host-primary parasitoid were a continual battle in this system. Maintaining healthy plants was particularly difficult when aphid densities exceeded 100 per leaf. At these high aphid densities the leaves continually senesced and sooty mold accumulated to levels that further inhibited maximum plant growth. An outbreak of the whitefly, Trialeurodes vaporum (Westwood) occurred but was kept in check using yellow sticky traps for monitoring and trapping, and with a release of Encarsia formosa Gahan when the potential outbreak was noticed.

Predation and hyperparasitism occurred continually. The predators were mainly Cecidomyiidae, Hemerobius sp., Syrphids, and spiders which preyed upon both parasitized and non-parasitized aphids at random. However hyperparasitism was more of a threat to the mass culture and release program than the predators for not only did they directly impact the number of potential T. pallidus to field release but once in the culture they would be field released when the time came. Hyperparasitism was only noticeable in the culture late in the season.

Method of Release

Because of the problems encountered in culturing, the number of adults available for release during the growing season was limited. Due to this limitation and the fragility of adults, releases of both adult parasitoids and mummified aphids were made at each release site. By releasing mummies, it was expected that there would be a small reservoir of parasitoids in the field that may spread the risk of losses over time. Releases were made successively at most of the sites throughout the season in an effort to better promote establishment. In general, putting mummies in the field was satisfactory other than the probability of releasing hyperparasitoids along with the primary parasitoids.

Adults were collected with an aspirator that had a tissue in it for the parasitoids to sit on and to collect any moisture accumulation in the vial. The vial was then capped and placed in a cooler with an ice pack, care was taken not to freeze the parasitoids. Mummies were collected by clipping leaves from the culture seedlings that were covered with mummies and aphids. There was no concern of releasing added aphids to the field for it was clear that many would develop in to mummies, also the sites were large enough that the number of aphids being released was inconsequential.

Release sites were chosen based on grower cooperation and aims to get the parasitoid spread further northward in the Willamette Valley (Table 1; Figure 1). The growers agreed to leave the release trees unsprayed for the 1987 growing season. The release tree sites within an orchard were chosen to avoid prevailing winds towards the trees so that when spraying was conducted these trees had less possibility of exposure to pesticides. The goal to spread the parasitoid northward largely led me to Yamhill County, one of the main filbert growing regions of Oregon.

In 1987 after the first releases were made, the establishment was checked at each release tree at different time interval. Non-destructive searching for parasitized aphids was conducted on each tree for 5 minutes.

In August 1988, another survey of establishment was made using the same searching methods as in 1987.

Site Descriptions

The release sites are briefly described below and the number of parasitoids released per site can be found on Table 2. All releases were made in 1987.

Turner, Dayton: Two acres of 3 year old trees. To be left unsprayed for 1987. This site is isolated, and no other filbert orchards were found in the immediate vicinity. Releases were made on 22 April and 19 June. On both dates there were many aphids on the leaves, greater than 20/leaf.

Huffman, Newberg: Two acres of abandoned trees next to a managed filbert orchard. Releases were made 4 times on 22

April, 19 June, 3 July, and 23 September. Throughout the season the aphid numbers at this site were low, less than 5/leaf.

Bestwick, Newberg: One acre of abandoned trees adjacent to a managed orchard. Three releases were made on 22 April, 19 June, and, 23 September. Aphid numbers were low to nonexistent throughout the season.

Pierce, Newberg: A one acre nursery planting within 4 acres of managed orchard. Four releases were made, 22 April, 15 May, 19 June, and 23 September. Aphid numbers were always less than 5/leaf.

Skene, Dundee: Five old abandoned trees next to a managed orchard. Aphid numbers were less than 5/leaf throughout the growing season.

McDonald, Wilsonville: 53 acres of filberts. Releases made in the northeast corner of the orchard and the 4 rows of trees adjacent were to be left unsprayed. Three releases were made, 22 April, 17 July, and 23 September. At the first and second release dates there were less than 5 aphids/leaf, but on the last release date there were between 10 and 15 aphids/leaf.

Mitchell, Newberg: Trees 8 years old. Releases made on the southwest corner of the orchard. This orchard is next to another managed orchard. Four releases were made, 1 May, 15 May, 3 July, and, 23 September. On the second release date the aphids numbered greater than 20/leaf, but on all the other dates the aphid numbers were very low.

Duncan, Sherwood: Releases were made on abandoned trees next to a managed orchard. Only one release was made.

Gingerich, Canby: Fifty acres of 8 year old trees. Two releases were made, 1 May and 17 July. On the first release date it was raining and hailing. Aphids were generally 10 to 15/leaf.

Jorgensen, Dever Conner: Two abandoned trees in a backyard. Although in a backyard this house is located in an area of many filbert orchards.

Nofziger, Dever Conner: A managed orchard of 20 acres. Two releases were made, 26 May and 27 July.

Hornaday, Bellfountain: One unmanaged trees in a backyard. Aphid numbers were less than 5/leaf throughout the season. One release made on 9 July.

Smith,Monroe: One third of an acre of abandoned trees located from a managed orchard with greater than 20 aphids/leaf. One release made on 10 July.

RESULTS AND DISCUSSION

In 1987 *T. pallidus* was established at six of the thirteen release sites (Table 3 and Fig. 3). Of the sites showing parasitoid reproduction in the release season, four of the sites had relatively high numbers of aphids/leaf (greater then 20) on most release dates. Of the two remaining sites, one had no data on the number of aphids/leaf (Nofziger) because the releases were not made by me. The remaining site had relatively low numbers (less than 5/leaf) but because the release trees were large (old) and were located close to a larger orchard a reservoir of aphids may have existed that was not noticed at sampling time. Of all of the sites where aphids numbers stayed above 10/leaf establishment was evident in 1987.

In 1988 a survey of twelve of the release sites showed four of the sites to be establishing (Fig. 3). Of the establishing sites one had showed signs of establishment in 1987 (Smith); one site was not surveyed in 1987 (Duncan); and 2 sites showed establishment in 1988 but it was not evident in 1987 (Hornaday and Nofziger). The number of aphids at the establishing sites in 1987 (other than Smith) was low in the release year. There is no consistent pattern of establishment relating to the number of adult or mummies of *T. pallidus* released. The number of individuals released at the establishing sites ranged from 80 to 520.

There does not appear to be a relationship between multiple releases and greater establishment. Three of the establishing sites only had one release. There were sites that had 3 or 4 releases made over the season but no establishment was evident in 1988.

The main similarity amongst the establishing sites was a greater abundance of aphids during the season. In all but one of the sites (Hornaday) that were showing establishment in 1987 or 1988 the number of aphids/leaf was greater that ten. It appears that the parasitoid responds in a density dependent way, the more hosts the greater the possibility for oviposition and therefore the greater chance of parasitoid establishment. It has also been observed that when mummies are found on leaves they are usually clustered together on a leaf rather than spread evenly throughout the tree canopy.

Because T. pallidus responds in a density dependent manner it would be the most beneficial in future releases to encourage reservoirs of aphids for the parasitoid to attack. To insure more aphid hosts, limbs of filbert trees should be caged and inoculated with aphids, followed by parasitoid introduction. Another technique would be to increase aphid numbers with an additional application of a nitrogen fertilizer to certain release trees. The number of aphids available at a site should be maximized for increased probability of parasitoid establishment.

Table IV. 1. Trioxys pallidus release site location list, 1987.

Site Name	Location
1.Turner	Dayton
2.Huffman	Newberg
3.Bestwick	Newberg
4.Pierce	Newberg
5.Skene	Dundee
6.McDonald	Wilsonville
7.Mitchell	Newberg
8.Duncan	Sherwood
9.Gingerich	Canby
10.Jorgensen	Dever Conner
11.Nofziger	Dever Conner
12.Hornaday	Bellfountain
13.Smith	Monroe

Table IV. 2. Trioxys pallidus individuals released and initial recovery in western Oregon, 1987.

Site	Release Date	# Adults	# Mummies[1]	Recovery 1987
1.Turner	4/22	60	300	
	6/19	110	50	yes
Total		170	350	
2.Huffman	4/22	60	100	
	6/19	75	50	
	7/3	300	50	
	9/23		60	
Total		435	260	
3.Bestwick	4/22	60	100	
	6/19	75		
	9/23	110	60	
Total		245	160	
4.Pierce	4/22	70	100	
	5/15	60		
	6/19	75		
	9/23	150	60	
Total		355	160	
5.Skene	4/22	65	100	
	5/15	30		yes
Total		95	100	
6.McDonald	4/22	100	200	
	7/17	65	100	
	9/23	20	60	yes
Total		185	360	

Table IV. 2 (continued). Total Trioxys pallidus released in western Oregon, 1987.

Site	Release Date	# Adults	# Mummies[1]	Recovery 1987
7.Mitchell	5/1	70	100	
	5/15	30		
	7/3	135	50	
	9/23		60	
Total		235	210	
8.Duncan	5/1	70	100	
Total		70	100	
9.Gingerich	5/1	100	25	
	7/17	40	50	yes
Total		140	75	
10.Jorgensen	5/26	35		
	6/27	150	25	yes
Total		185	25	
11.Nofziger	5/26	50		
	6/27	200	100	
Total		250	100	
12.Hornaday	7/9	80		
Total		80		
13.Smith	7/10	200		yes
Total		200		

Grand Total: 2,645 Adults 1,900 Mummies[1] = 4,545 individuals

[1]Number of mummies released is an approximation.

Table IV. 3. Evaluation of <u>Trioxys pallidus</u> establishment from 1987 releases.

Location # sites	Total # Released	Initial Establishment	1988 Evaluation
Wilsonville - 1 site	545	yes	
Sherwood - 1 site	170		yes
Canby - 1 site	215	yes	
Newberg - 4 sites	2,160		
Dayton - 1 site	520	yes	
Dundee - 1 site	195	yes	
Dever Conner - 2 sites	560	yes-1 site	yes-1 site
Monroe - 2 sites	280	yes-1 site	yes-2 sites

13 release sites
4,545 individuals released
6 sites establishing as of 1987
4 sites establishing of 12 checked in 1988

1. Turner
2. Huffman
3. Bestwick
4. Pierce
5. Skene
6. McDonald
7. Mitchell
8. Duncan
9. Gingerich
10. Jorgensen
11. Mofziger
12. Hornaday
13. Smith

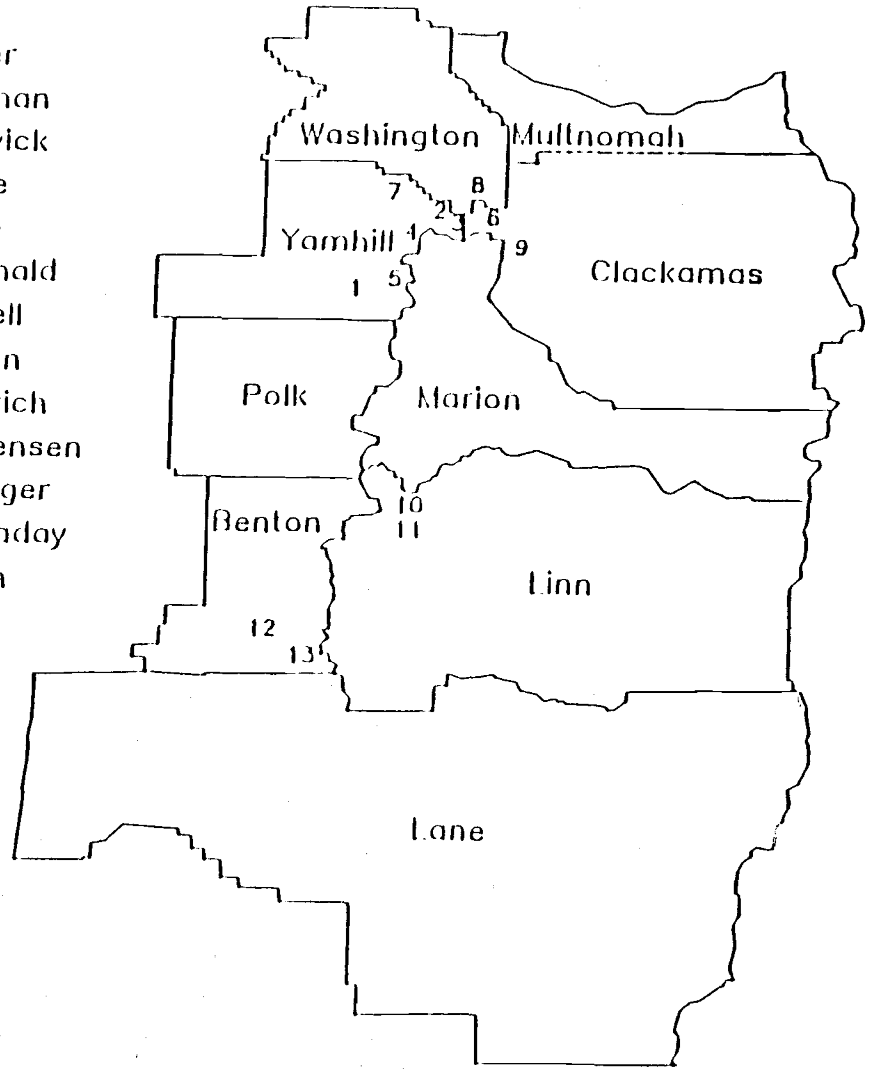


Figure IV. 1. Field releases of <u>Trioxys pallidus</u> in western Oregon counties, 1987.

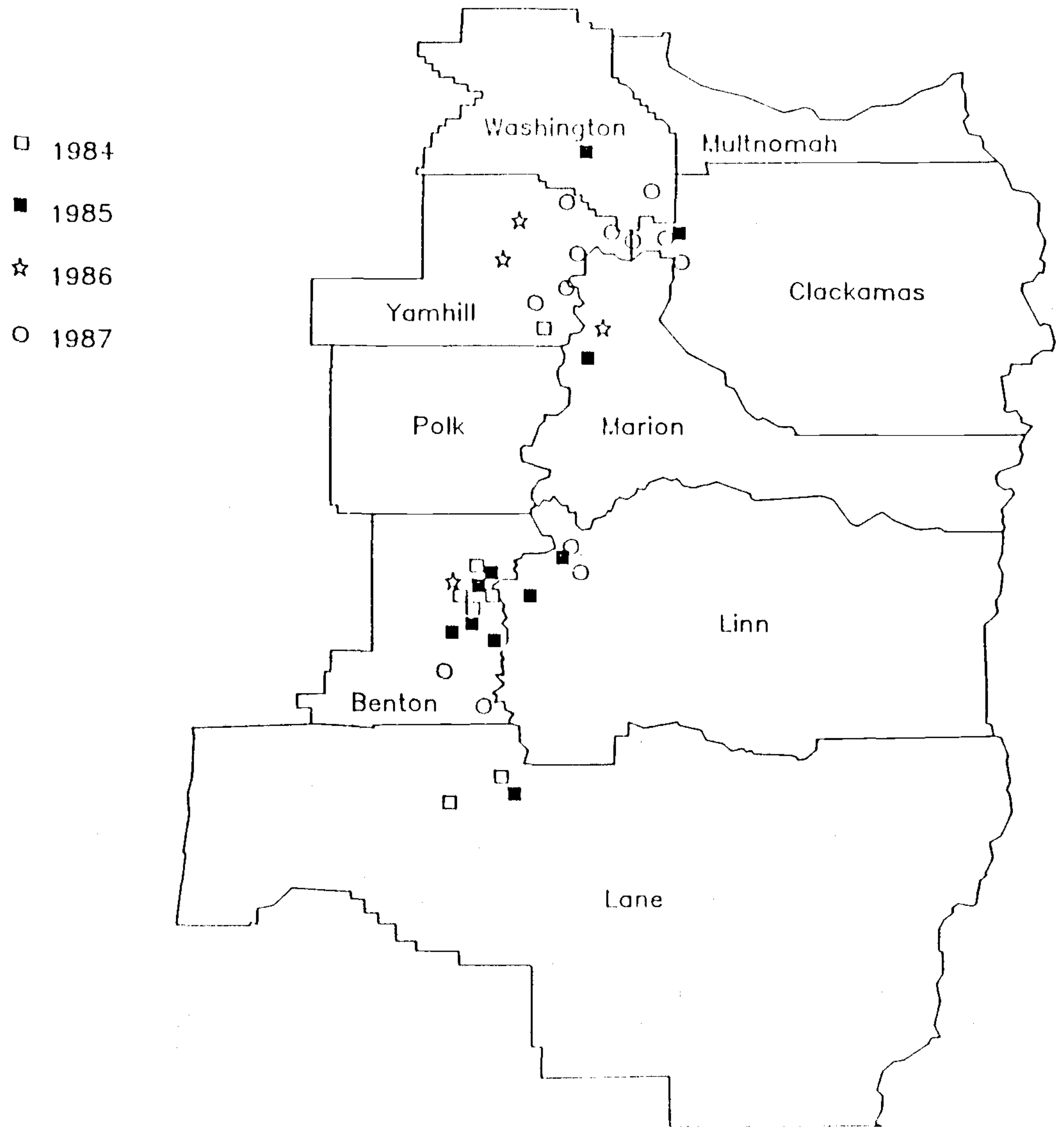


Figure IV. 2. Field releases of Trioxys pallidus in western Oregon counties, 1984-1988.

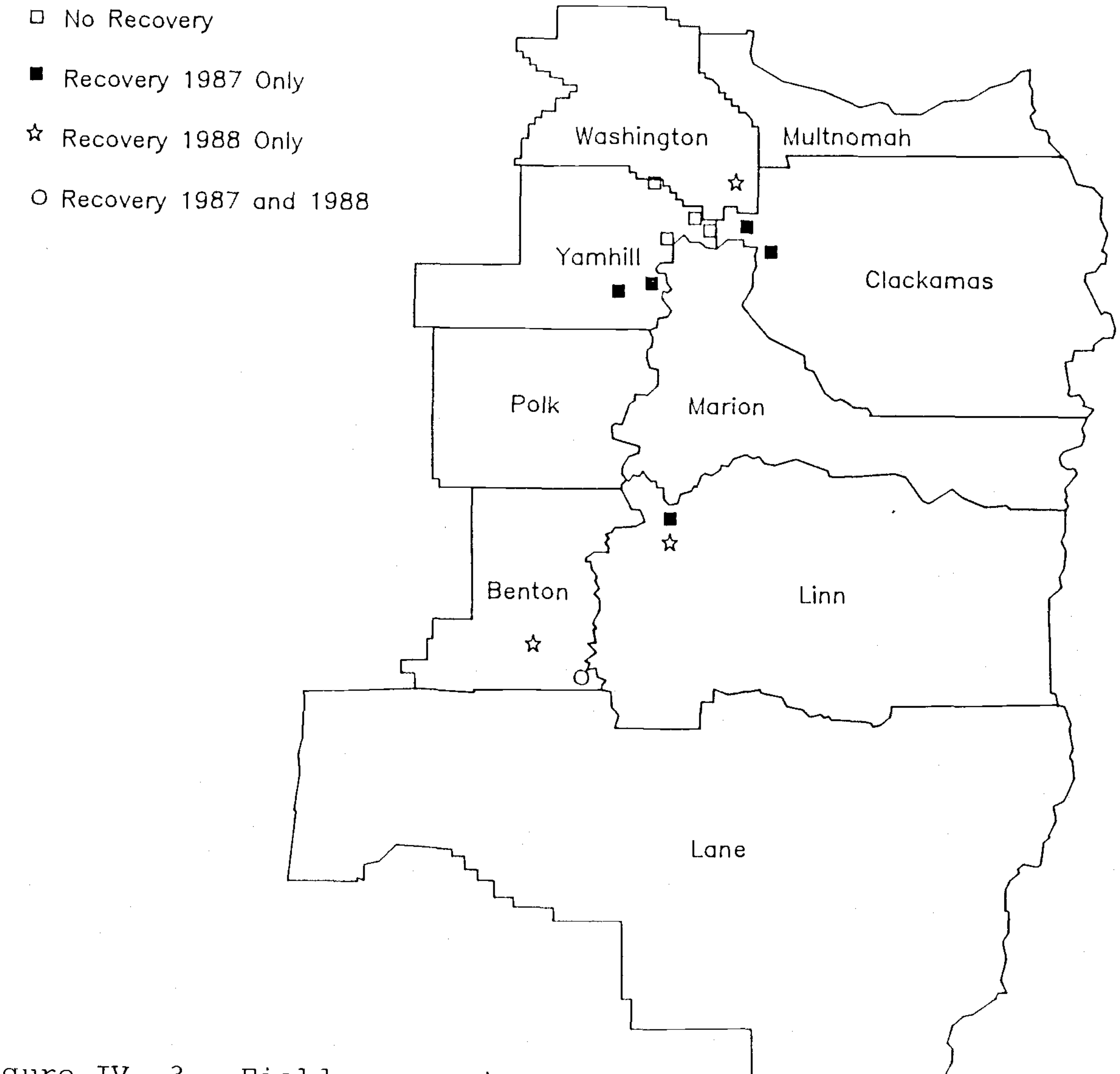


Figure IV. 3. Field recoveries of Trioxys pallidus offspring in western Oregon counties, 1987-1988.

V.CONCLUSION

Introduction and establishment of a natural enemy involves many aspects of evaluation. Assessment of basic biological parameters aids in determining present and potential outcome and helps in determining good management practices in the agroecosystem. Survival in a new environment, synchrony with the host, and ability to reproduce are important parameters to assess in a classical biological pest control program. The goal of this study was to examine the dynamics and occurrence of diapause, impact on and seasonal synchrony with the host, and promote the spread of the biotype of T. pallidus imported to control M. coryli in filbert orchards of western Oregon.

T. pallidus is establishing in western Oregon and seems to reduce populations of M. coryli in some orchards. A good synchrony of emergence from overwintering between the host and the parasitoid was observed which could be attributed to diapause in both insects. Although early season aphid depression is limited, impact throughout the season is positive. Biological control of M. coryli appears promising after only 3 years since initial introduction of the parasitoid.

The biotype of T. pallidus introduced exhibits a true diapause and overwinters in this state as does the aphid host. Diapause type mummies are produced throughout the filbert growing season but are not dominant in the population until October-November, a time of short daylength and low temperatures. Diapause appears to develop in the field at least through December.

Nondiapause adult parasitoids develop and eclose in the field in 322.1 degree days from the mean inoculation date of the parent (above a base temperature of 6.0°C). The time required in the field is 57.1 degree days longer than the developmental period of oviposition to eclosion documented by Messing in the laboratory, indicating a preoviposition time in the field. The time in the field from oviposition to mummification took 64% of the total generation time.

Seasonal appearance of T.pallidus and M. coryli generations appears synchronous with respect to the occurrence of a summer decline and winter diapause that allows survival after the summer heat and during the below freezing winter months of the Willamette Valley. The occurrence of a diapause type mummy in the early spring, although at a low percentage, is generally a wasted resource for very few of these individuals emerged.

It appears that T. pallidus responds to host availability in a density dependent manner, and this may influence its establishment in filbert orchards. For maximal establishment of the parasitoid, future releases should be made in orchards with a high aphid density throughout the season of release, or an effort should be made to increase the number of aphids at the release sites.

In 1987 a total of 2,645 adult and 1,900 mummy T. pallidus equalling 4,545 individuals were released in western Oregon filbert orchards. A 1988 survey of 12 of the 13 release sites showed 4 of the sites to be definitively establishing, having survived the winter. The goal of spreading the parasitoid throughout western Oregon is being met through greenhouse rearing of T. pallidus followed by field release.

Due to seasonal synchrony, the presence of diapause to survive the winter, and the establishment documented, the newly imported biotype of *T. pallidus* appears to be of great benefit to filbert pest management.

VI.BIBLIOGRAPHY

AliNiazee, M. T. 1980. Filbert insect and mite pests. Exp. Sta. Bull. 643. Oregon State Univ. Corvallis, OR.

AliNiazee, M. T. 1983a. Pest status of filbert (hazelnut) insects: a ten year study. Can. Entomol. 115: 1155-1162.

AliNiazee, M. T. 1983b. Carbaryl resistance in the filbert aphid (Homoptera: Aphididae). J. Econ. Entomol. 76: 1162.

AliNiazee, M. T. 1985. Pests of hazelnuts in North America. A review of their bionomics and ecology. Proc. Intern. Congress of hazelnuts, Avellino, Italy. Sept. 1983, pp. 463-476.

Askew R.R. 1971. Parasitic insects. American Elsevier Publ. Comp. New York. 834 pp.

Baron, L. C., and R. Stebbins. 1981. Growing filberts in Oregon. Ext. Bull. Oregon St. Univ. 628.

Beck, S. D. 1980. Insect photoperiodism. Academic Press, New York. 387 pp.

Calkin, J., M. T. AliNiazee, and G. C. Fisher. 1985. Hazelnut integrated pest management. Proc. Intern. Congress of Hazelnuts. Avellino, Italy. pp. 477-483.

Clausen, C.P. (ed.). 1978. Introduced parasites and predators of arthropod pests and weeds: a world review. USDA-ARS Agric. Handbook 480. 545 pp.

Danilevskii, A. S. 1965. Photoperiodism and seasonal development of insects. Oliver and Boyd, Edinburgh and London. 283 pp.

El-Haidari, H. 1959. The biology of the filbert aphid, Myzocallis coryli in the Central Willamette Valley. Ph.D. thesis, Oregon State Univ., Corvallis.

Flanders, S. E. 1944. Diapause in the parasitic hymenoptera. J. Econ. Entom. 37(3): 408-411.

Force, D. C., and P.S. Messenger. 1964. Duration of development, generation time, and longevity of three Hymenopterous parasites of Therioaphis maculata reared at various constant temperatures. Ann. Entomol. Soc. Am. 57: 405-413.

Force, D. C., and P.S. Messenger. 1964. Fecundity, reproductive rates, and innate capacity for increase of three parasites of _Therioaphis_ _maculata_ (buckton) Ecology, Vol. 45(4): 706-715.

Force, D. C., and P.S. Messenger. 1965. The use of laboratory studies of three hymenopterous parasites to evaluate their field potential. J. Econ. Entomol. 61: 1374-1378.

Frazer, D. C., and R. van den Bosch. 1973. Biological control of the Walnut aphid in California: The interrelationship of the aphid and its parasite. Environ. Entomol. 2: 561-567.

Gruys, P. and F. Vaal. 1984. _Colpoclypeus_ _florus_, an eulophid parasite of tortricids in orchards: Rearing, biology and use in biological control. Entom. Exp. Appl. 35: 31-35.

Hagen K. S. and R. van den Bosch. 1968. Impact of pathogens, parasites, and predators of aphids. Ann. Rev. Entomol. 13. 325-384.

Hagen, K. S., J. K. Holloway, F. E. Skinner, and G. L. Finney. 1958. Aphid parasites established. Calif. Agric. 12:(3) 15 pp.

Hodek, I. 1966. Ecology of aphidophagous insects. Academia, Prague. 366 pp.

Huffaker, C. B., and P. S. Messenger (eds.). 1976. Theory and practice of biological control. Academic Press. 788 pp.

Huffaker, C. B. (ed.). 1971. Biological control. Plenum-Rosetta Press. 511 pp.

Katunda, J., and M.T. AliNiazee 1989. Status, distribution and seasonal variations of filbert aphid. Resistance to selected insecticides in the Willamette Valley, Oregon. J. Econ. Entomol. In press.

Lagerstedt, H. B. 1975. Filberts. _In_: J. Janick and J.N. Moore (eds), Advances in fruit breeding. Purdue University Press, West Lafayette, Indiana.

Lees, A. D. 1955. The Physiology of diapause in arthropods. Cambridge Univ. Press. London. 151 pp.

Liu, S.S. and M. Carver. 1985. Studies on the biology of Aphidius sonchi Marshall (Hymenoptera:Aphidiidae), a parasite of the sowthistle aphid, Hyperomyzus lactucae (L.) (Hemiptera: Aphididae). Bull. Ent. Res. 75: 199-208.

Mackauer, M., and P. Stary. 1967. Hym. Ichneumonoidea. World Aphidiidae. In: V. Delucci and G. Remaaudiere (eds), Index of entomophagous insects. Paris, 195 pp.

Maslennikova, V. A. 1958. The conditions determining diapause in the parasitic hymenopteron Apanteles glomeratus L. (Hymenoptera;Braconidae) and Pteromalus puparum L. (Hymenoptera,Chalcidae). Ent. Obozr. 37:538-545.

McNeil, J. N. and R. L. Rabb. 1973. Physical and physiological factors in diapause initiation of two hyperparasites of the tobacco hornworm, Manduca sexta. J. Insect Physiol. 19: 2107-2118.

Messing, R. H. 1985. Parasites of the filbert aphid imported from Europe. Proc. Oreg. Wash. and B.C. Nut Growers Soc. 70: 96-100.

Messing, R. H. and M. T. AliNiazee. 1985. Natural enemies of Myzocallis coryli (Homoptera: Aphididae) in Oregon hazelnut orchards. J. Entomol. Soc. B. C. 82: 14-18.

Messing, R. H. 1986. Classical biological control of the filbert aphid, Myzocallis coryli (Goetze), in western Oregon. Ph.D. thesis, Oregon State Univ. 127 pp.

Nowierski, R. M. 1979. The field ecology of the walnut aphid Chromaphis juglandicola (Homoptera: Aphididae) and its introduced parasite, Trioxys pallidus (Hymenoptera: Aphidiidae)--a qualitative and quantitative assessment of population regulation. Ph.D. thesis, Univ. Cal., Berkeley. 231 pp.

Olkowski, W., H. Olkowski, R. van den Bosch and R. Hom. 1976. Ecosystem management: a framework for urban pest control. Bioscience. 26: 384-389.

Olkowski, W., H. Olkowski, R. van den Bosch and R. Hom. 1982. The parasitoid Trioxys tenuicaudus stary (Hymenoptera: Aphidiidae) established on the elm aphid Tinocallis platani Kaltenbach (Homoptera: Aphididae) in Berkeley, Calif. Pan Pac. Entomol. 58: 59-63.

Olkowski, W., H. Olkowski, R. van den Bosch. 1982. Linden aphid parasite establishment. Environ. Entomol. 11: 1023-1025.

Painter, J. H., and S.C. Jones. 1960. Effect of aphid control on quality and yield of filberts in 1960. Proc. Oregon and Washington Nut Growers Soc. 46: 23-24.

Richards, W.R. 1968. The Callaphidini of Canada (Homoptera: Aphididae). Mem. Entomol. Soc. Can. 68.

Ryan, R. B. 1965. Maternal influence on diapause in a parasitic insect, Coeloides brunneri Vier. (Hymenoptera:Braconidae). J. Insect Physiol. 11:1331-1336.

Saunders, D. S. 1966. Larval diapause of maternal origin-III. The effect of host shortage on Nasonia vitripennis. J. Insect Physiol. 12: 899-908.

Schlinger, E. T. and J. C. Hall. 1960. The biology, behavior, and morphology of Praon palitans Muesebeck, an internal parasite of the spotted alfalfa aphid, Theriioaphis maculata (Buckton) (Hymenoptera: Braconidae: Aphidiinae). Ann. Ent. Soc. Am. 53:144-160.

Schlinger, E. I., and J.C. Hall. 1961. The biology, behavior and morphology of Trioxys utilis, an internal parasite of the spotted alfalfa aphid, Therioaphis maculata (Hymenoptera: Braconidae, Aphidiinae). Ann. Entomol. Soc. Am. 54: 34-45.

Schlinger, E. T. and J. C. Hall. 1960. The biology, behavior, and morphology of Trioxys (Trioxys) utilis, an internal parasite of the spotted alfalfa aphid, Therioaphis maculata (Hymenoptera: Braconidae, Aphidinae). Ann. Ent. Soc. Am. 54: 34-45.

Schlinger, E. T. and J. C. Hall. 1959. A synopsis of the biologies of three imported parasites of the spotted alfalfa aphid. J. Econ. Ent. 52:154-157.

Schlinger, E. I., K. S. Hagen, and R. van den Bosch. 1960. Imported French parasite of walnut aphid established in California. Calif. Agric. 14: 3-4.

Singh, R. and T.B. Sinha. 1980. Bionomics of Trioxys (Binodoxys) indicus Subba Roa and Sharma, an aphidiid parasitoid of Aphis craccivora Koch. VI. Occurrence of non-productive mummies in the field population. Z. Ang. Ent. 90: 233-237.

Sluss, R.R. 1967. Population dynamics of the walnut aphid, Chromaphis juglandicola (Kalt.) in northern California. Ecology 48(1): 41-58.

Smith, C. F. and C. S. Parron. 1978. An annotated list of Aphididae (Homoptera) of North America. Bull. 255, North Carolina Ag. Exp. Sta.

Smith, R. F., and K. S. Hagen. 1959. Integrated control programs in the future of biological control. J. Econ. Ent. 55: 5-11.

Stary, P. 1966. Aphid parasites of Czechoslovakia. A review of the Czechoslovak Aphidiidae (Hymenoptera). The Hague:Junk. 242 pp.

Stary, P. 1970. Biology of aphid parasites with respect to integrated control. Series Entomophaga 6: 643 pp. Dr. W.Junk, Hague.

Stary, P. 1972. Host life-cycle and adaptation of parasites of Periphyllus-aphids. Acta. Ent. Bohemoslov. 69: 89-96.

Tauber, M. J., C. A. Tauber and S. Masaki. 1986 Seasonal adaptations of insects. Oxford Univ. Press. N. Y. 411 pp.

Tauber, M.J., C. A. Tauber, J. R. Nechols and J. J. Obrycki. 1983. Seasonal activity of parasitoids: Control by external, internal and genetic factors. In: Diapause and life cycle strategies in insects. Brown, V. K. and I. Hodek (Eds.). Dr. W. Junk Publ. Boston.

Tauber, M.J. and C. A. Tauber. 1976. Insect seasonality: Diapause maintenance, termination, and postdiapause development. Ann. Rev. Entomol. 21: 81-107.

van den Bosch, R., E.I. Schlinger, E.J. Dietrich, K. S. Hagen and J. K. Holloway. 1958. The colonization and establishment of imported parasites of the spotted alfalfa aphid in California. J. Econ. Entomol. 52: 136-141.

van den Bosch, R., B. D. Frazer, C. S. Davis, P.S. Messenger, and R. Hom. 1970. Trioxys pallidus, an effective new walnut aphid parasite from Iran. Calif. Agric. 24: 8-10.

van den Bosch, R., R. Matteson, B. D. Frazer, P.S. Messenger, and C. S. Davis. 1979. Biological control of the walnut aphid in California: impact of the parasite Trioxy pallidus. Hilgardia. 47: 1-13.

van den Bosch, R., E. J. Schlinger, and K. S. Hagen. 1962. Initial field observations in California on Trioxys pallidus (Haliday) a recently introduced parasite of the walnut aphid. J. Econ. Entomol. 55(6): 857-862.

van den Bosch, R., E. J. Schlinger, and J.M. Hall. 1959. The role of imported parasites in the biological control of the spotted alfalfa aphid in South California in 1957. J. Econ. Entomol. 52(1): 142-157.