

BIONOMICS OF THE ANTHOCORID, ORIU INSIDIOSUS

(SAY) IN VIRGINIA APPLE ORCHARDS

by

Joseph Peter McCaffrey

Dissertation submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Entomology

APPROVED:

Dr. R. L. Horsburgh, Chairman

Dr. R. L. Pienkowski

Dr. J. L. Eaton

Dr. W. A. Allen

Dr. J. A. Barden

July, 1981

Blacksburg, Virginia

This dissertation is dedicated,
with love, to my parents:

and

ACKNOWLEDGEMENTS

I would like to thank Dr. Robert L. Horsburgh for serving as my advisor. His guidance has been crucial to my development as a scientist and I will always appreciate his friendship. Drs. Robert L. Pienkowski, William A. Allen, John L. Eaton, and John A. Barden were very helpful during all stages of my graduate program. I sincerely appreciate their assistance and support.

My friend and former colleague, _____, provided considerable input into my research program. His enthusiasm, diligence, and productivity served to stimulate me. His friendship lightened the rigors of graduate student life.

Special thanks go to _____, _____, _____, and all the staff of the Shenandoah Valley Res. Sta. for their help during my stays at Steeles Tavern.

Many people, including _____, _____, _____, _____, _____, and _____ provided support and friendship, particularly at crucial times. I thank them all.

Finally, I again thank _____ for her friendship during the past six years that I have been here in Virginia. It's been fun.

TABLE OF CONTENTS

	Page
DEDICATION	ii
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	vii
LIST OF FIGURES	ix
 Section	
I. INTRODUCTION	1
II. GENERAL LITERATURE REVIEW	5
The Genus <u>Orius</u> Wolff in North America	6
Anthocorids in biological control	8
III. BIOLOGY OF <u>ORIOUS INSIDIOSUS</u> (SAY) IN VIRGINIA APPLE ORCHARDS	13
Introduction	14
Methods and Materials	15
Description of Egg and Nymphal Instars	15
Egg and Nymphal Development at Different Temperatures	17
Determination of Lower Thermal Threshold (base) Temperatures and Degree-day Requirements for Egg and Nymphal Development	18
Nymphal Development with Different Food Sources	18
Prey and Predator Records	19
Host Plant Records	20

Section	Page
Results and Discussion.	20
Description of Egg and Nymphal Instars	20
Egg and Nymphal Development at Different Temperatures	29
Determination of Lower Thermal Threshold (base) Temperatures and Degree-day Requirements for Egg and Nymphal Development	29
Nymphal Development with Different Food Sources	35
Prey and Predator Records	36
Host Plant Records	40
General Discussion	43
IV. <u>ORIU</u> <u>INSIDIOSUS</u> (SAY) TOLERANCE OF <u>SELECTED ORCHARD PESTICIDES</u>	46
Introduction	47
Methods and Materials	48
Adult Tolerance of Pesticides	48
Ovicidal Effects of Methomyl (Lannate 1.8 L [®])	50
Results and Discussion	50
Adult Tolerance of Pesticides	50
Ovicidal Effects of Methomyl (Lannate 1.8 L [®])	52
General Discussion	53
V. <u>POPULATION TRENDS OF ORIU</u> <u>INSIDIOSUS</u> <u>(SAY) IN VIRGINIA APPLE ORCHARDS</u>	55
Introduction	56

Section	Page
Methods and Materials	56
Results and Discussion	58
VI. <u>FUNCTIONAL RESPONSES OF <u>ORIVS INSIDIOSUS</u></u> <u>(SAY) TO THE EUROPEAN RED MITE AT DIFFERENT</u> <u>CONSTANT TEMPERATURES</u>	70
Introduction	71
Methods and Materials	72
Results and Discussion	73
VII. <u>INTERSPECIFIC INTERACTIONS BETWEEN</u> <u><u>ORIVS INSIDIOSUS</u> (SAY) AND <u>LEPTOTHRIPS</u></u> <u><u>MALI</u> (FITCH)</u>	84
Introduction	85
Methods and Materials	85
General Procedures	85
Description of Major Behavioral Elements	88
Results and Discussion	89
VIII. LITERATURE CITED	98
VITA	109
ABSTRACT	

LIST OF TABLES

Table	Page
1. Measurements (\bar{X} mm + SE) of <u>O. insidiosus</u> nymphs	23
2. Days (\bar{X} + SE) required for <u>O. insidiosus</u> to complete developmental stages	30
3. Linear regression models (development rate vs temp.) and lower thermal threshold (base) temperatures for <u>O. insidiosus</u> development	31
4. Calculated degree-day requirements using base temperatures estimated by two different techniques: linear regression and the Standard Error Method	33
5. Orchard insect and mite pests recorded as prey for <u>O. insidiosus</u> in Virginia	37
6. Orchard insect and mite beneficials recorded as prey for <u>O. insidiosus</u> in Virginia	39
7. Orchard insects and arachnids recorded as predators of <u>O. insidiosus</u> in Virginia	41
8. Cultivated and non-cultivated plant host for <u>O. insidiosus</u> that occur in or adjacent to apple orchards in Virginia	42
9. Toxicity of selected orchard pesticides to adult <u>O. insidiosus</u>	51
10. Occurrence of mite predators in orchards under different pesticide programs	66
11. Functional response of <u>O. insidiosus</u> to densities of <u>P. ulmi</u> at four constant temperatures	74

Table	Page
12. Functional response of <u>O. insidiosus</u> to the European red mite, <u>P. ulmi</u> , at four constant temperatures: Comparison of models	76
13. The effects of temperature on the rate of successful search and handling time of <u>O. insidiosus</u>	80
14. Three-way ANOVA of factors affecting consumption of <u>P. ulmi</u> by <u>O. insidiosus</u> (Model 1--fixed factors)	82

LIST OF FIGURES

Figure	Page
1. Adult male (A) and female (B) <u>O. insidiosus</u>	7
2. Rearing cage for constant temperature development studies. A) 100-mesh stain- less steel screening, B) 9 dram plastic vial, C) plastic vial cap, D) 9 dram plastic vial filled with water, E) apple leaf, F) cotton wrapped around leaf petiole	16
3. Eggs of <u>O. insidiosus</u> imbedded in a green bean pod. Note the operculum (A) and the red eye spots of the de- veloping nymph (B) (ca.40X)	21
4. 1st instar <u>O. insidiosus</u> feeding on an adult spider mite, <u>Tetranychus</u> <u>urticae</u> (ca.25X)	24
5. 2nd instar <u>O. insidiosus</u> feeding on an adult spider mite, <u>Tetranychus</u> <u>urticae</u> (ca.25X)	25
6. 3rd instar <u>O. insidiosus</u> feeding on an adult spider mite, <u>Tetranychus</u> <u>urticae</u> (ca.25X)	26
7. 4th instar <u>O. insidiosus</u> (ca.25X)	27
8. 5th instar <u>O. insidiosus</u> (ca.25X)	28
9. Development rate vs temperature for 5th instar <u>O. insidiosus</u>	35
10. Population trends of selected pest and beneficial species in Block-A, 1977	60
11. Population trends of selected pest and beneficial species in Block-A, 1978	61

Figure	Page
12. Population trends of selected pest and beneficial species in Block-B, 1977	62
13. Population trends of selected pest and beneficial species in Block-B, 1978	63
14. Population trends of selected pest and beneficial species in Block-C, 1977	64
15. Population trends of selected pest and beneficial species in Block-C, 1978	65
16. Functional response (type-2 model) of <u>O. insidiosus</u> to <u>P. ulmi</u> at four constant temperatures	78
17. Interaction arena: A) 6 cm diam. X 2 cm deep petri dish, B) 2.4 cm diam. plastic disk	84
18. Kinematic graph of predatory behavior exhibited by satiated <u>O. insidiosus</u> towards the thrips, <u>L. mali</u> . The circle area represents the relative frequency of occurrence for that behavioral element: TACT=tactual perception, VIS=visual perception, DIS=discontinue, ORI=orient, PRO=probe, ATT=attack, S=successful attack, US=unsuccessful attack; width of arrows represents the relative proportion of the time that the transition occurred in that direction	88
19. Kinematic graph of predatory behavior exhibited by starved <u>O. insidiosus</u> towards the thrips, <u>L. mali</u> . See Fig. 18 for legend	89

I. INTRODUCTION

Apple producers, particularly those in the eastern United States, must deal with a complex of serious pest problems. These include arthropods, diseases, weeds, nematodes, and vertebrates. This, coupled with the severe restraints on fruit quality imposed upon the growers by the government and the consumer has led to heavy reliance by the grower on pesticides. In the past, pesticides provided economical pest control. However, serious problems have developed as a consequence of this unilateral chemical pest management strategy. Resistance by pest species to pesticides has increased dramatically, outbreaks of secondarily induced pests such as mites are widespread, and concerns over environmental contamination are mounting. If this were not enough, the monetary costs and limited availability of pesticides are now serious concerns to the grower. As a consequence of these problems, there has been increased research and development of alternative pest control strategies. This is exemplified by several successful integrated pest management (IPM) programs recently developed for the nonchemical or selective chemical control of phytophagous orchard mites (Croft 1975). Since there is a substantial complex of pests and natural enemies associated with the orchard ecosystem (Oatman et al. 1964), further IPM control strategies could benefit from a broader consideration of

the entire pest fauna, including aphids, tortricid moths, and scale insects.

In a study of the population dynamics of pest and beneficial arthropod species in Virginia orchards (Parrella et al. 1981a) the following complex of predatory insects was noted: Orius insidiosus (Say), (Heteroptera: Anthracoridae); Leptothrips mali (Fitch) and Haplothrips submillissimus Haliday (Thysanoptera: Phlaeothripidae); Stethorus punctum (LeConte), (Coleoptera: Coccinellidae); Deraeocoris nebulosus (Uhler), (Heteroptera: Miridae); and Chrysopa spp. (Neuroptera: Chrysopidae). With the exception of S. punctum, these are general predators that feed on a number of pest and beneficial species.

Stethorus punctum has received considerable attention in Pennsylvania and is the major predator in the Penn State IPM program for European red mite control (Colburn and Asquith 1971; Mowery et al. 1975). Leptothrips mali was the most abundant predator found in Virginia orchards. Parrella (1980) recently completed a detailed study of its biology and importance in Virginia's developing IPM programs. The remaining three predator species have not yet been evaluated in this context.

Orius insidiosus is probably the most ubiquitous of all the aforementioned predators. It is an important predator

in a number of agroecosystems (See Ryerson and Stone 1979) and is commonly found on many species of noncultivated flowering plants (Kelton 1978).

Despite its potential importance to a number of crops, there have been few studies on its biology. The research presented in this dissertation was undertaken to evaluate O. insidiosus with respect to its role and importance in Virginia apple orchards. The objectives were to: 1) provide information on its biology, especially the relationship between temperature and egg and nymphal development; 2) evaluate its tolerance to common orchard pesticides; 3) note its numerical response to various pest-prey densities; 4) study its functional response to an important pest, the European red mite; and 5) study its interspecific interactions with another important orchard predator, the thrips, Leptothrips mali. Information from all the above mentioned studies will provide a strong data base on which predictive biological models can be built.

II. GENERAL LITERATURE REVIEW

The Genus *Orius* Wolff in North America

The Holarctic genus *Orius* Wolff is represented by five species in the Nearctic region. They are *Orius insidiosus* (Say), *O. tristicolor* (White), *O. minutus* (L), *O. diespeter* Herring, and *O. pumilio* (Champion) (Kelton 1963, 1978; Herring 1966). *O. insidiosus* and *O. tristicolor* are widely distributed in the United States and Canada, but *O. insidiosus* is more common in the eastern states than is *O. tristicolor*. *O. minutus*, the largest species of the genus found in the Nearctic region, is a common species in Western Europe and has been introduced into Western North America. *O. diespeter* has been described from British Columbia. *O. pumilio* is a southern species found in Florida. These five species are distinguished by differences in color pattern, size, and the left genital clasper of the male (Kelton 1963, 1978; Herring 1966). In particular, *O. insidiosus* (Fig. 1) can be distinguished from *O. tristicolor* by its pale clavus and the lack of a long curving bristle on the genital clasper (see Kelton 1963, p. 633, Figs. 2-3).

O. insidiosus and *O. tristicolor* have received considerable attention due to their presence and importance as predators in a wide variety of agricultural crops. No attempt will be made here to summarize all of the literature; instead, the reader is referred to a recent



Fig. 1. Adult male (A) and female (B) O. insidiosus.

comprehensive bibliography by Ryerson and Stone (1979) that deals specifically with these two species.

Anthocorids in Biological Control

Predaceous Heteroptera often take a prominent part in the biological control of many insect and mite pests. However, the value of many of the smaller predators, such as the anthocorids has been underestimated. Unlike the larger members of the Heteroptera, anthocorids are aggressive and very active (Carayon 1961).

The genus Orius, Anthocoris Fallen, and Xylocoris Dufour have received the most attention with regard to biological control and crop protection. Orius spp. and the somewhat larger Anthocoris spp. exhibit very similar behavior and have similar ecological roles. Members of both genera are common to trees and herbaceous plants where they feed on a wide variety of soft-bodied insects and mites. Orius spp. are important predators in a number of crops including corn (Barber 1936), cotton (Whitcomb and Bell 1964; van den Bosch and Hagen 1966; Ehler and van den Bosch 1974), soybeans (Isenhour and Marston 1981), alfalfa (Wheeler 1977), apples (Horsburgh and Asquith 1968; Holdsworth 1968, 1970; Parrella et al. 1981a) and grapes (Jubb et al. 1980). Anthocoris spp. have been indicated as important predators particularly in fruit crops such as

apples (Lord 1949), and pears (Madsen 1961). Xylocoris spp. have quite different habits and are found primarily in leaf litter, under bark, and in stored grain. Like Orius spp. and Anthocoris spp., Xylocoris spp. are polyphagous. Xylocoris flavipes (Reuter) has shown great promise as a biological control agent of a number of stored grain pests (Arbogast 1976; Press et al. 1975; LeCato et al. 1976).

Anthocorids have many characteristics of an ideal biological control agent as defined by Hassell and Rogers (1972). These attributes include high searching efficiency, an ability to increase more rapidly when food is abundant, a density-dependent decrease in fecundity resulting from interference, and the ability to aggregate in regions of high prey density (Evans 1976a). Factors which have been characterized as limiting the efficiency of these predators include large, unpredictable variations in abundance in time and space, polyphagy, cannibalism, high overwintering mortality, and low fecundity relative to that of their prey (Carayon 1961). To best evaluate such attributes, and the importance of anthocorids in biological control, consideration should be given to properties of these natural enemies that suit them to the temporal dimensions of the habitat (Ehler and van den Bosch 1974). Such properties include the ecological strategies exhibited by these natural enemies and their associated pest-prey. The theory of r- and K-selection

has recently been considered in this context (Force 1972; Conway 1976; Ehler and Miller 1978).

A r-selected species has a relatively high reproductive capacity, superior dispersal ability, and is a relatively inferior competitor. A K-selected species exhibits a lower reproductive potential, but is a superior competitor (MacArthur and Wilson 1967; Pianka 1970; Force 1974; Ehler and Miller 1978). Generally, r-selected species are dominant in newly available or disrupted habitats (Ehler and Miller 1978). It should be noted that the r-K-strategies occur in a continuum. Pest or beneficial species can exhibit strict r- or K- strategies or intermediate strategies that incorporate characteristics of both (Conway 1976). Conway (1976) suggests that effective control measures for a pest species should correspond to the ecological strategy of the pest. Insecticides usually would be required for r-pests, while biological control or cultural control would be effective for intermediate pests; K-pests would be best controlled by insecticides, cultural control, host resistance, and sterile mating techniques. Ehler and Miller (1978) generally support these claims, but further suggest that r-pests could be controlled by natural enemies if the natural enemies themselves were r-strategist. This conclusion was based on studies of the natural enemies of the

cabbage looper (r-strategist) on cotton in California. The major predators were Orius tristicolor, Nabis americanoferus Carayon, and Chrysopa carnea Stephans. These predators were characterized as polyphagous, colonizing species that exhibited an extreme r-strategy (Ehler 1977; Ehler and Miller 1978). While it is questionable whether or not these species particularly O. tristicolor, have a high capacity for increase relative to their prey, their ability to colonize and exploit pest-prey populations is well documented (see Ehler 1977).

All the aforementioned predator species are polyphagous. Ehler (1977) reviewed the importance of general predators. Since anthocorids for the most part fall into this category, this is of special interest. In his review, Ehler (1977) concluded that the belief that host-specific natural enemies are highly desirable in biological control is a questionable assumption. He supports the supposition that the lack of prey specificity may be an advantage in an environment where prey populations are often unstable (i.e., agroecosystems). He further emphasizes that the complex of general predators is the important biotic factor in insect control. Thus, in evaluating a predator, consideration must be given not only to its individual role, but also its interactions, whether complementary or antagonistic, with other predators that form the complex.

There have been some experimental introductions of anthocorids resulting in partial biological control of several pest species (see Evans 1976a for a short review). A common feature to many of the successes was a relatively slow rate of increase of the prey. This allowed the predator to multiply sufficiently to prevent harmful pest outbreaks. Evans (1976a) concluded that anthocorids may be effective biological control agents against pest-prey with a potentially high rate of increase only if they act in conjunction with other mortality factors, such as other predators, or if high predator numbers are present when prey numbers are already declining.

III. BIOLOGY OF ORIOUS INSIDIOSUS (SAY) IN
VIRGINIA APPLE ORCHARDS

Introduction

Orius insidiosus (Say) is a common predaceous insect found on a variety of vegetation, including trees, shrubs, field crops, vegetables, and many wild plants (Barber 1936). Parrella et al. (1981a) showed the O. insidiosus was a potentially important predator in Virginia apple orchards. O. insidiosus has previously been reported as a predator of orchard mites (Garman and Townsend 1939; Lord 1949; Clancy and Pollard 1952; Thomas et al. 1959; Putman and Herne 1966; Horsburgh and Asquith 1968; Holdsworth 1968; Meyer 1974; Childers and Enns 1975), aphids (Holdsworth 1970), and the codling moth (eggs and larvae) (MacLellan 1963).

Despite the predatory nature and potential importance of O. insidiosus to Integrated Pest Management (IPM) programs in apples, grapes (Jubb et al. 1979), corn (Barber 1936), cotton (Whitcomb and Bell 1964), soybeans (Isenhour and Marston 1981), and alfalfa (Wheeler 1977), there have been few definitive studies on the biology, ecology, and behavior of this insect species.

The study of Isenhour and Yeargan (1981) on the effects of temperature on O. insidiosus development is the most comprehensive to date regarding egg and nymphal development. Barber (1936) reported on various aspects of the life history and behavior of O. insidiosus in corn. Other notes on

O. insidiosus biology include those of Garman and Jewett (1914), Marshall (1930), Inglinsky and Rainwater (1950), and Simpson and Burkhardt (1960).

The series of laboratory and field studies presented here were undertaken to provide information on egg and nymphal development, prey relationships, and other aspects of the biology of O. insidiosus in Virginia orchards.

Methods and Materials

Description of Egg and Nymphal Instars

Eggs: Several adult female O. insidiosus were confined for 12 h with a whole green bean pod in a 50 dram plastic vial with one end covered with 100-mesh stainless steel screening. The adult bugs were removed and the bean pods placed in an environmental chamber set at 23°C and a 15L:9D photoperiod for 24 hours. Several eggs that were carefully dissected away from the bean tissue were measured using a stereomicroscope fitted with an ocular micrometer.

Nymphs: Newly emerged (<12 h) first instar nymphs were individually confined with field-collected apple leaves infested with the European red mite, Panonychus ulmi (Koch), in a 9 dram plastic vial cage that had one end covered with 100-mesh stainless steel screening (Fig. 2). The leaf

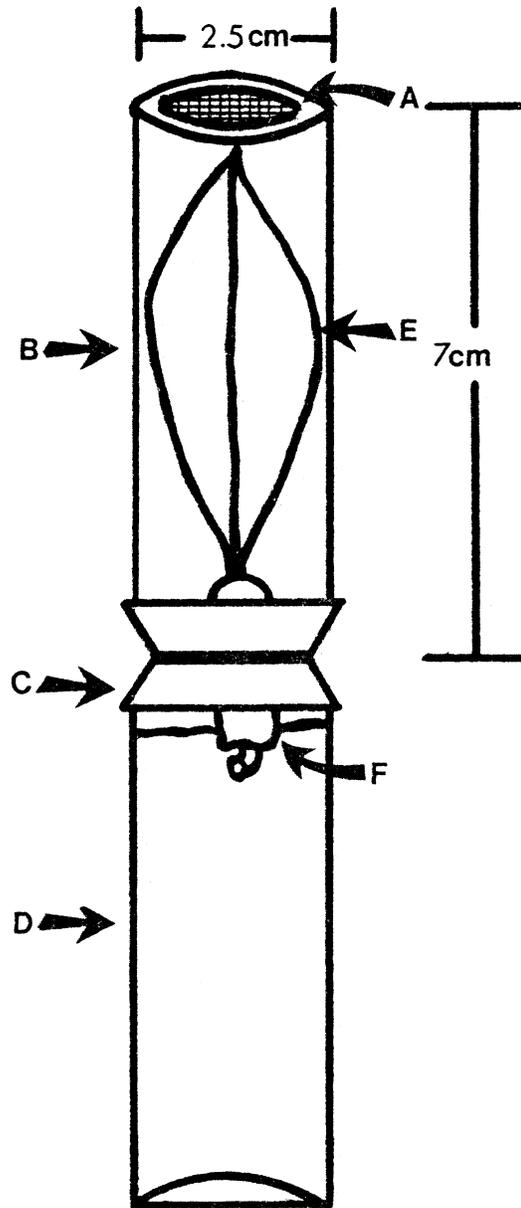


Fig. 2. Rearing cage for constant temperature development studies: A) 100-mesh stainless steel screening, B) 9 dram plastic vial, C) plastic vial cap, D) 9 dram plastic vial filled with water, E) apple leaf, F) cotton wrapped around leaf petiole.

petiole was wrapped in cotton and maintained in water in another 9 dram vial below. The bugs were maintained at 23°C and a 15L:9D photoperiod. Representative specimens of all instars were collected and preserved in 70% ETOH. All bugs collected were at least 24 h into a stadium and had fed on mites. Measurements of various morphological structures were made at a later date using a stereomicroscope fitted with an ocular micrometer.

Egg and Nymphal Development at Different Temperatures

Eggs: Eggs oviposited in green bean pods were maintained in environmental chambers set at 17°, 23°, 29°, and 35° ± 1.0°C, and a 15L:9D photoperiod. Hatching was recorded every 24 h until no further hatching took place.

Nymphs: Methods used to rear nymphs were similar to those described in the previous section (description of egg and nymphal instars), but in this case, nymphs were maintained at 17°, 23°, 29°, or 35° ± 1.0°C and a 15L:9D photoperiod. Nymphs were checked every 24 h and the presence of exuviae was noted. Leaves and mites were changed every other day for 17° and 23°C and daily for 29° and 35°C. A surplus of mites was present at all times.

Determination of Lower Thermal Threshold
(base) Temperatures and Degree-Day Requirements
for Egg and Nymphal Development

Linear regression method (Arnold 1959): Linear regressions were performed using temperature as the independent variable (x) and development rate (1/days) as the dependent variable (y). The base temperature for development was determined by solving the linear model $y=mx+b$ with $y=0$.

Standard error technique (Casagrande 1971; Ravlin 1980): Degree day (DD) accumulations were determined using base temperatures ranging from 1-20°C and developmental data for each rearing temperature. Standard errors were then calculated for each assumed base (1-20°C) over the range of rearing temperatures. The base temperature which minimized the standard error of the DD determinations provided the best fit for the data.

For comparative purposes, DDs were calculated using base temperatures calculated with linear regression and the standard error technique.

Nymphal Development with Different Food Sources

Ten newly emerged (<12 h) first instar nymphs were maintained singly in a plastic leaf cage previously described by Parrella (1980). The cage is circular (4.1 cm

diam. x 2.0 cm deep) and has a plastic lid with a 2 cm diam. hole covered with 100-mesh stainless steel screening for ventilation. The following food sources were provided: 1) nymphal and apterous adult aphids, Aphis sp.; 2) common mullein pollen, Verbascum thapsus L.; and 3) Red Delicious apple leaves (no other food source). Leaves and food were changed every other day; nymphs were checked daily. All treatments were maintained at 23°C with a 15L:9D photoperiod.

Prey and Predator Records

Laboratory studies: Individual adult or third-fifth instar O. insidiosus were confined with a potential prey or natural enemy in a covered 6 cm diam. x 2 cm deep plastic petri dish for 24 h and the presence or absence of feeding recorded. Each test was replicated 2-3 times. The prey tested included pest insects and mites (Table 4) and beneficial species (Table 5). The potential natural enemies of O. insidiosus evaluated were other general predators commonly found in Virginia orchards (Table 6).

Field observations: Periodic observations of O. insidiosus in individual trees were made over a three year period. Species observed preying on or serving as prey for O. insidiosus were recorded.

Host Plant Records

This survey was conducted during the 1978 and 1979 growing seasons. The purpose of the survey was to identify host plants that harbored populations of O. insidiosus. Emphasis was given to those plants commonly found in and adjacent to orchards. Both non-cultivated and cultivated plants were surveyed. Direct visual observation and sweep net sampling were the survey methods utilized.

Results and Discussion

Description of Egg and Nymphal Instars

Eggs: The egg length was 0.470 ± 0.015 mm ($\bar{X} \pm$ S.E.) (N=5); opercular diameter was 0.100 ± 0.000 mm (N=5); and egg width was 0.190 ± 0.006 mm (N=5). These values conform well to those obtained by Garman and Jewett (1914), Barber (1936), and Isenhour and Yeargan (1981). The egg of O. insidiosus has been described in detail by Garman and Jewett (1914) and Isenhour and Yeargan (1981); therefore, only a brief description is given. The egg is elongate and clear to milky white when first laid. As the embryo develops, the red eyes of the bugs are often visible through the chorion and plant tissue (Fig. 3-B). Occasionally a small portion of the chorion extends beyond the plant tissue; the operculum is always exposed (Fig. 3-A).

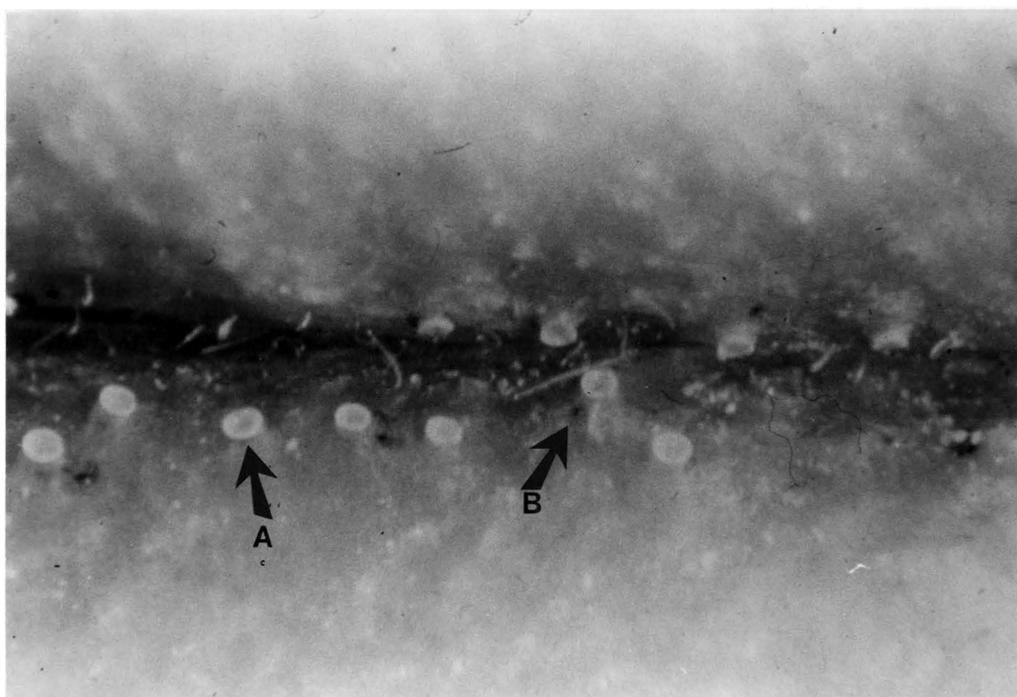


Fig. 3. Eggs of *O. insidiosus* imbedded in green bean pod. Note the operculum (A) and the red eye spots of the developing nymph (B). (ca. 40X).

Nymphs: Measurements of a number of morphological characters for each instar are presented in Table 1. Isenhour and Yeargan (1981) recently described the nymphal instars and provided measurements of body length and interocular distance. My measurements of interocular distance and body length are similar to theirs, but I found first instars to be somewhat larger than the 0.4-0.5 mm range that they purported. Such discrepancies in length measurements are not unusual considering that factors such as the age and feeding history of the bug within the instar can influence such measurements. Interocular distance provides more precise measurements since it is less likely to be affected by such factors.

As Isenhour and Yeargan (1981) note, first, second, and third instar nymphs (Figs. 4-6) are yellowish and have distinct orange scent glands on the third, fourth, and fifth dorsal segments. Wing pads are not present on first instars; second instars have only metathoracic wing pads; and third instars have both mesothoracic and metathoracic wing pads. Fourth and fifth instar nymphs (Figs. 7-8) are tan to dark brown and the scent glands are less prominent. The tips of the mesothoracic wing pads extend to those of the metathoracic in the fifth, but not the fourth instars (Isenhour and Yeargan 1981). Developing ocelli, evidenced as red spots near the eyes, are present in fifth instars.

Table 1. Measurements (\bar{X} mm \pm SE) of *Orius insidiosus* Nymphs

Character	Instar				
	1st (N=6)	2nd (N=10)	3rd (N=10)	4th (N=10)	5th (N=10)
Transocular width	0.175 \pm 0.000	0.200 \pm 0.003	0.239 \pm 0.004	0.280 \pm 0.005	0.328 \pm 0.006
Interocular width	0.125 \pm 0.000	0.157 \pm 0.003	0.189 \pm 0.004	0.205 \pm 0.005	0.218 \pm 0.004
Body length ^a	0.613 \pm 0.009	0.790 \pm 0.008	1.013 \pm 0.020	1.378 \pm 0.028	1.653 \pm 0.024
Body width ^b	0.204 \pm 0.005	0.283 \pm 0.017	0.325 \pm 0.012	0.475 \pm 0.026	0.768 \pm 0.011
Pronotal length	0.071 \pm 0.003	0.100 \pm 0.003	0.138 \pm 0.006	0.228 \pm 0.009	0.255 \pm 0.005
Pronotal width	0.192 \pm 0.005	0.245 \pm 0.004	0.285 \pm 0.004	0.315 \pm 0.016	0.558 \pm 0.011
Antenna I ^c	0.025 \pm 0.000	0.036 \pm 0.000	0.044 \pm 0.003	0.050 \pm 0.000	0.063 \pm 0.003
II	0.075 \pm 0.000	0.080 \pm 0.003	0.089 \pm 0.003	0.125 \pm 0.000	0.163 \pm 0.004
III	0.050 \pm 0.000	0.067 \pm 0.003	0.087 \pm 0.003	0.115 \pm 0.004	0.138 \pm 0.004
IV	0.125 \pm 0.000	0.126 \pm 0.000	0.148 \pm 0.003	0.165 \pm 0.004	0.175 \pm 0.000
Total	0.275 \pm 0.000	0.308 \pm 0.005	0.367 \pm 0.005	0.453 \pm 0.006	0.538 \pm 0.005
Rostrum	0.200 \pm 0.000	0.267 \pm 0.002	0.313 \pm 0.003	0.354 \pm 0.004	0.428 \pm 0.002

^a/ Measured from tylus to end of the abdomen.

^b/ Measured at widest part of abdomen.

^c/ I-IV refers to antennal segments; Total refers to total antennal length.



Fig. 4. 1st instar O. insidiosus feeding on an adult spider mite, Tetranychus urticae. (ca. 25X).



Fig. 5. 2nd instar O. insidiosus feeding on an adult spider mite, Tetranychus urticae. (ca. 25X).



Fig. 6. 3rd instar O. insidiosus feeding on an adult spider mite, Tetranychus urticae. (ca. 25X).



Fig. 7. 4th instar O. insidiosus. (ca. 25X).



Fig. 8. 5th instar O. insidiosus. (ca. 25X).

Egg and Nymphal Development at
Different Temperatures

The duration for the egg and nymphal instars at each temperature is given in Table 2. The duration for egg development decreased significantly ($p < .05$) with increasing temperature. There were significant ($p < .05$) reductions in the duration of the stadia for the first, third, fourth, fifth instars, and total nymphal development up to 29°. The duration of stadia at 29° did not differ significantly ($p > .05$) from those of 35°. The stadia duration for second instars at 23°, 29°, and 35° were significantly shorter ($p < .05$) than at 17°, but were not significantly different ($p > .05$) from one another.

Determination of Lower Thermal Threshold
(base) Temperatures and Degree-Day Requirements
for Egg and Nymphal Development

Linear regression models and lower thermal threshold (base) temperatures calculated from the linear regression models and by the standard error method are presented in Table 3. Note that the base temperatures calculated from the linear regression models were lower than those calculated by the standard error method. There was a significant inverse correlation ($r = -.94$, $p < .001$ Spearman Rank) between

Table 2. Days ($\bar{X} \pm SE$) Required for *O. insidiosus* to Complete Developmental Stages

Temp. (C°)	Stage ¹							Total ²
	Egg	First	Second	Third	Fourth	Fifth		
17	\bar{X} 11.6 ^a \pm 0.2	5.9 ^a \pm 0.3	5.2 ^a \pm 0.3	5.6 ^a \pm 0.3	6.6 ^a \pm 0.2	11.0 ^a \pm 0.2	34.0 ^a \pm 0.8	
	N 7	14	14	12	11	10	10	
23	\bar{X} 5.8 ^b \pm 0.1	3.2 ^b \pm 0.1	1.9 ^b \pm 0.1	2.0 ^b \pm 0.1	2.7 ^b \pm 0.1	4.2 ^b \pm 0.3	13.9 ^b \pm 0.5	
	N 20	14	14	14	13	13	13	
29	\bar{X} 3.9 ^c \pm 0.1	2.0 ^c \pm 0.0	1.6 ^b \pm 0.2	1.2 ^c \pm 0.1	1.6 ^c \pm 0.2	3.2 ^c \pm 0.1	9.5 ^c \pm 0.2	
	N 15	13	11	11	11	11	11	
35	\bar{X} 3.1 ^d \pm 0.1	1.8 ^c \pm 0.2	1.4 ^b \pm 0.2	1.2 ^c \pm 0.1	1.3 ^c \pm 0.1	2.6 ^c \pm 0.2	8.3 ^c \pm 0.3	
	N 15	13	12	11	11	11	11	

^{1/} Means in a column followed by the same letter are not significantly different ($p > .05$);
Duncan NMRT.

^{2/} Eclosion to adult.

Table 3. Linear Regression Models (Development Rate vs Temp.) and Lower Thermal Threshold (Base) Temperatures for O. insidiosus Development

Stage	Data Base ^A	Linear Regression Model	R ²	Calculated Lower Thermal Threshold Temp. (C°)		Diff.
				Linear Regression Method	Standard Error Method	
Egg	M	Y=0.0132X - 0.1343	0.99	10.2	11.0	0.8
	IY	Y=0.0144X - 0.1618	0.96	11.2	13.0	1.8
Nymph ^B						
1	M	Y=0.0224X - 0.1987	0.96	8.9	10.0	1.1
	IY	Y=0.0216X - 0.1729	0.73	8.0	12.0	4.0
2	M	Y=0.0277X - 0.2069	0.89	7.5	11.0	3.5
	IY	Y=0.0439X - 0.6301	0.89	14.4	15.0	0.6
3	M	Y=0.0383X - 0.4093	0.89	10.7	13.0	2.3
	IY	Y=0.0525X - 0.5420	0.94	13.4	14.0	0.6
4	M	Y=0.0351X - 0.4343	0.99	12.4	13.0	0.6
	IY	Y=0.0405X - 0.5420	0.94	13.4	14.0	0.6
5	M	Y=0.0159X - 0.1575	0.96	9.9	12.0	2.1
	IY	Y=0.0248X - 0.3660	0.95	14.7	16.0	1.3
1-5	M	Y=0.0051X - 0.0511	0.96	10.0	12.0	2.0
	IY	Y=0.0069X - 0.0945	0.91	13.7	15.0	1.3

^{A/} Data base; M=McCaffrey, IY=Isenhour and Yeargan (1981).

^{B/} Numbers refer to respective instars.

the R^2 value for the linear regression model and the difference between the two calculated base temperatures. In other words, the better the data fit the linear model, the closer the base temperature calculated by the linear regression method was to that calculated by the standard error method and therefore the less the variation in the DD determinations. This is evident in Table 4, where DD requirements for egg and nymphal development determined with base temperatures estimated by both methods are presented.

The results of this study differ somewhat from those of Isenhour and Yeargan (1981). They did not report base temperatures or DD requirements for development, but my analysis of their data gives considerably higher (2-4°C) base temperatures when using either the linear regression or standard error method (Table 3). Also, note that fewer DDs were needed for development when using their data base (Table 4).

A number of factors could account for the differences between this study and that of Isenhour and Yeargan (1981). First, they used a different food source (frozen eggs of Heliothis virescens (Fabr.)) and a 16L:8D photoperiod. There is some evidence that this food source allows faster development than tetranychid mites (Isenhour 1977). This would account for the larger slopes for the regression

Table 4. Calculated Degree-Day Requirements Using Base Temperatures Estimated by Two Different Techniques: Linear Regression and the Standard Error Method.

Stage	Data Base ^a	$\bar{X} \pm$ SE No. degree-days required to complete development	
		Linear Regression Method	Standard Error Method
Egg	M	75.8 + 1.3 (10.2) ^b	71.0 + 1.2 (11.0) ^b
	IY	70.3 + 3.0 (11.2)	60.7 + 2.2 (13.0)
Nymph ^b			
1	M	45.0 + 1.7 (8.9)	41.5 + 1.4 (10.0)
	IY	47.5 + 3.5 (8.0)	36.1 + 2.8 (12.0)
2	M	38.0 + 4.2 (7.5)	29.1 + 2.3 (11.0)
	IY	23.1 + 1.5 (14.4)	21.7 + 1.4 (15.0)
3	M	27.8 + 2.9 (10.7)	22.0 + 1.6 (13.0)
	IY	19.4 + 1.1 (15.2)	19.8 + 1.2 (15.0)
4	M	28.8 + 0.8 (12.4)	26.8 + 0.7 (13.0)
	IY	24.9 + 1.1 (13.4)	23.5 + 1.1 (14.0)
5	M	64.9 + 4.9 (9.9)	53.9 + 2.8 (12.0)
	IY	41.3 + 2.2 (14.7)	35.4 + 1.6 (16.0)
1-5	M	201.7 + 13.7 (10.0)	168.8 + 8.1 (12.0)
	IY	147.9 + 7.9 (13.7)	129.4 + 7.1 (15.0)

^a/M=McCaffrey; IY=Isenhour and Yeargan (1981).

^b/Numbers in parentheses represent base temp. used in determining degree days.

^c/Numerals designate respective instars.

equations of development rate vs temperature obtained with their data (Table 3). Isenhour and Yeargan (1981) also used a more restricted temperature range; with their lowest temperature being 20° vs the 17° of this study. It was necessary, therefore, to extrapolate from a higher temperature to determine the base temperature (Fig. 9). While it is possible innate differences exist between the Kentucky (Isenhour and Yeargan 1981) and Virginia populations of O. insidiosus, it is probably not an important factor in this comparison.

Nymphal Development with Different Food Sources

The duration (\bar{X} days \pm S.E.) of total nymphal development was 19.0 \pm 0.0 (N=2) with aphids and 20.0 \pm 0.5 (N=3) with pollen. First instars survived 1.3 \pm 0.2 days (N=10) with leaves only. None survived to molt to second instar. The small sample size for the aphid and pollen studies reflected high mortality of the early instars. In the case of the aphid diet, early instar O. insidiosus could not effectively prey upon larger aphid nymphs and adults, and, therefore, the presence of early instar aphids was important. Smaller aphid nymphs were not always available during this study and this may have been responsible for considerable mortality. In the case of the pollen diet, those bugs that survived past the first and second instars did well.

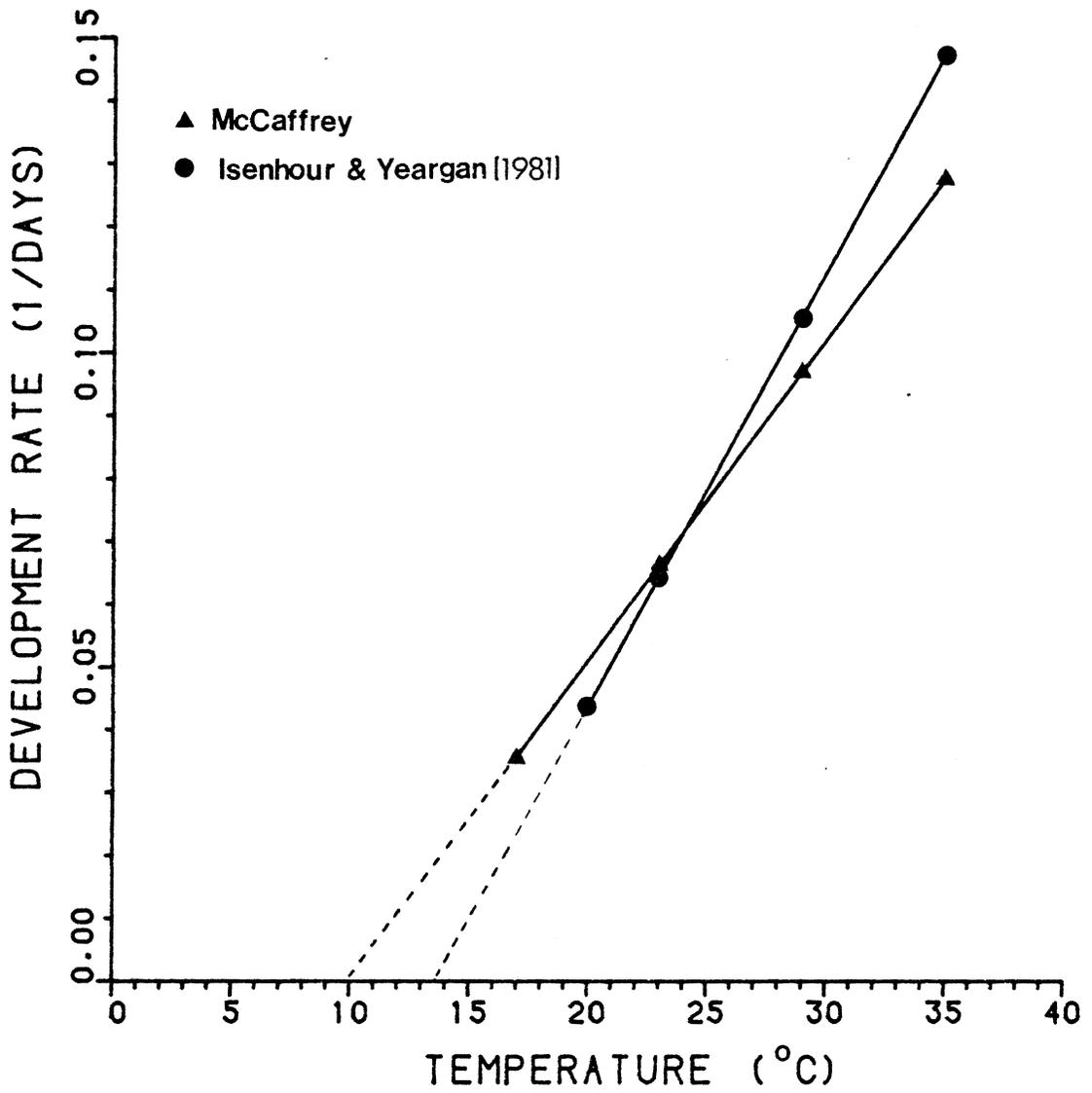


Fig. 9. Development rate vs temperature for 5th instar O. insidiosus.

Mortality after this point was due to handling when changing leaves and food.

Orius spp. are generally reported as predators, but many species also feed on plant tissue and pollen (Carayon and Steffan 1959). Salas-Aguilar and Ehler (1977) reported O. tristicolor (White) to be omnivorous and capable of surviving solely on plant food (green bean and pollen). Barber (1936) reported O. insidiosus to be closely associated with corn silks and able to complete development on this plant food. He also found that individuals which became adults without animal food were smaller and less vigorous.

The effects of diet on adult fecundity and longevity were not evaluated in this study, but Barber (1936) found that O. insidiosus would not oviposit if not supplied with animal food. He also noted increased longevity with animal food in the diet.

Prey and Predator Records

Insect and mite pests recorded as prey for O. insidiosus are presented in Table 5. Panonychus ulmi and aphids (primarily Aphis sp.) were the most important prey observed during this study. All stages of P. ulmi and all active stages of Aphis sp. were observed to be preyed upon by nymphal and adult bugs. Although O. insidiosus was

Table 5. Orchard Insect and Mite Pests¹ Recorded as Prey
for O. insidiosus in Virginia

Prey: Order, Family, Genus, Species	<u>O. insidiosus</u>	
	Adult	Nymph ²
Acarina		
Tetranychidae		
<u>Panonychus ulmi</u> (Koch)	*,F	*,F
<u>Tetranychus urticae</u> Koch	*,F	*,F
Eriophyidae		
<u>Aculus schlechtendali</u> (Nal.)	A,F	A,F
Tarsenomidae		
<u>Tarsenomus setifer</u> (Ewing)	A	-
Homoptera		
Aphididae		
<u>Aphis</u> sp.	N,A,F	N,A,F
<u>Dysaphis plantaginea</u> (Passer.)	N,A,F	N,A,F
Coccidae		
<u>Quadraspidiotus perniciosus</u> Coms.	N	N
Cicadellidae		
<u>Typhlocyba pomaria</u> McA.	N	-
Lepidoptera		
Olethreutidae		
<u>Laspeyresia pomonella</u> (L.)	E,L	E,L
Tortricidae		
<u>Platynota flavedana</u> (Clemens)	L	-

^{1/} *=all stages; A=adult; N=nymph; L=larva; E=egg;
F=Feeding observed in field; -=No info.

^{2/} 3rd-5th instar O. insidiosus.

observed to prey upon adult and nymphal Dysaphis plantaginea (Passerini), it was not usually present early enough in the season to be an important predator of this aphid species. Holdsworth (1970) found O. insidiosus associated with D. plantaginea but only in low numbers.

A number of beneficial insect and mite species were preyed upon by O. insidiosus (Table 6). Laboratory studies show that the phytoseiid mite, Amblyseius fallacis (Garman) and stigmatid mite, Zetzellia mali (Ewing) are potential prey for O. insidiosus. These two mite species are not common in Virginia orchards (Parrella et al., 1981a), so interference is probably minimal. It has been reported that O. minutus (L.) is an important predator of phytoseiid mites on fruit trees in Europe and reductions in numbers of phytoseiid mites are related to the presence of that insect predator (Kramer 1961).

Predaceous thrips are often found in association with O. insidiosus in mite infested trees. Since members of the genus Orius (Wolff) are natural enemies of thrips (Lewis 1973), the potential for interference is great. Recent studies, however, have shown that Leptothrips mali (Fitch) has a defensive behavior which reduces predation by O. insidiosus (Parrella et al. 1981b).

Table 6. Orchard Insect and Mite Beneficials Recorded as Prey for O. insidiosus in Virginia

Prey: Order, Family, Genus, Species	<u>O. insidiosus</u>	
	Adult	Nymph ²
Acarina		
Phytoseiidae		
<u>Amblyseius fallacis</u> (Garman)	*	*
Stigmatidae		
<u>Zetzellia mali</u> (Ewing)	L,N,A	L,N,A
Thysanoptera		
Phlaeothripidae		
<u>Leptothrips mali</u> (Fitch)	L,A,F	L,A,F
<u>Haplothrips subtilissimus</u> Hal.	L,A	L,A
Aeolothripidae		
<u>Aeolothrips melaleucus</u> Hal.	A	-
Diptera		
Cecidomyiidae		
<u>Aphidoletes aphidimyza</u> (Rond.)	L,F	L,F

^{1/}*=all stages; A=adult; N=nymph; L=larva; E=Egg; F=Feeding observed in field; -=No info.

^{2/}3rd-5th instar O. insidiosus.

The cecid, Aphidoletes aphidomyza (Rondani) is a potentially important aphid predator in Virginia apple orchards. O. insidiosus was observed in the field and laboratory to feed on early instar larvae. The significance of this predation should be studied in more detail. Adult and nymphal O. insidiosus were observed to probe or attack larval Chrysopa spp. and adult and larval Stethorus punctum (LeConte), but they never were observed to successfully capture these predators.

O. insidiosus itself falls prey to numerous other general predators. Spiders are probably the most important of these predators (Table 7). It is significant that even early instar spiderlings are capable of capturing and subduing adult bugs. Other predators include the mirid, Deraeocoris nebulosus (Uhler) and larval Chrysopa spp. Also, O. insidiosus was observed to be cannibalistic.

Host Plant Records

Numerous plant species were found to harbor populations of O. insidiosus. The most important are listed in Table 8. Corn and alfalfa were the most common cultivated crops adjacent to orchards. O. insidiosus was often abundant in these fields. Thistle, especially Carduus acanthoides L. (plumeless thistle) was a common weed in and around orchards, in fence rows, and in vacant pastures.

Table 7. Orchard Insects and Arachnids Recorded as Predators of Q. insidiosus in Virginia.

Predator: Order, Family, Genus, Species

Araneae

Philodromidae

Philodromus spp.

Thomisidae

Misumenops oblongus (Keys.)

M. asperatus (Hentz)

Misumenoides formesipes (Walck.)

Xysticus spp.

Salticidae

Metaphidippus galathea (Walck.)

Hentzia spp.

Phidippus audax (Hentz)

Araneidae

Araniella displicata (Hentz)

Dictynidae

Dictyna sublata (Hentz)

Theridiidae

Theridion albidum Banks

Theridion spp.

Heteroptera

Miridae

Deraeocoris nebulosus (Uhler)

Neuroptera

Chrysopidae

Chrysopa sp.

Table 8. Cultivated and Non-cultivated Plant Hosts for
O. insidiosus that Occur in or Adjacent to Apple
Orchards in Virginia.

Plant: Family, genus, species (Common Name)	Stage found on plant ¹	
	Adult	Nymph
Cultivated Plants		
Poaceae		
<u>Zea mays</u> L. (Corn)	X	X
Leguminosae		
<u>Medicago sativa</u> L. (alfalfa)	X	X
Rosaceae		
<u>Prunus persica</u> (L.) (peach)	X	X
Non-cultivated Plants		
Compositae		
<u>Verbascum thapsus</u> L. (common mullein)	X	X
<u>Carduus acanthoides</u> (Plumeless thistle)	X	X
<u>C. thoermeri</u> Wienmann (Musk thistle)	X	X
<u>Cirsium vulgare</u> (Savi) (Bull thistle)	X	X
<u>Taraxacum officinale</u> Weber (Dandelion)	X	-
<u>Erigeron</u> sp. (Fleabane)	X	-
Leguminosae		
<u>Trifolium pratense</u> L. (Red Clover)	X	-

¹/ X=present; -=absent.

Large populations of O. insidiosus were often associated with the flowers of these plants where they were observed to feed on thrips. Another weed, Verbascum thapsus L. also had large populations of adult and nymphal O. insidiosus associated with it. Most bugs were found in the flower stalk where they fed on thrips (Haplothrips verbasaci (Osborn)) and perhaps pollen. Although they did not identify specific weed species, Jubb et al. (1979) reported O. insidiosus to be found on weeds and in fence rows surrounding Concord grape vineyards. O. insidiosus was also the most common predator of P. ulmi in those vineyards.

General Discussion

Considering that ca. 1490 DDs (>10°C) are accumulated between June 1 and September 1 in central Virginia (Nelson Co., 1978) and that ca. 275 DDs (>10°C) are required for development from egg to adult, several generations of O. insidiosus are possible in the orchard ecosystem. The actual population densities and numbers of generations occurring in an orchard will depend on a number of factors, including the amount and type of prey available, the pesticide program utilized, and the surrounding weed species and crops that might offer suitable alternative prey and habitat.

O. tristicolor has been characterized as a competent disperser and colonizing species, preadapted by polyphagy and phytophagy to exploit prey populations in annual or temporal crops (Ehler 1977). This is apparently true for O. insidiosus as well. Isenhour (1977) purports the concept of a floating population of adult O. insidiosus, continually moving within and between crops and other vegetation during the season. While the orchard system is perennial, many pest outbreaks such as those of mites and aphids are ephemeral in nature. Thus, the ability of O. insidiosus to colonize favorable habitats and promptly exploit a number of prey species (as does O. tristicolor (Ehler 1977)), suggests that this predator is an important component of the orchard predator complex.

It has been indicated that O. insidiosus preys upon other natural enemies and vice versa. This is not necessarily an undesirable situation. Parrella et al. (1981b) point out that predator-predator contact between O. insidiosus and Leptothrips mali might stimulate predator movement to other leaves on the tree which would reduce thrips mortality and possibly promote more efficient control of mites at low prey densities. Also, consider the scenario where a complex of mite predators have responded numerically and functionally to a population of prey, and at some point, the prey population crashes due to predation or some other

pressure such as pesticides: predators, especially general predators such as O. insidiosus, would be able to subsist on the most abundant, readily available food. This might be other pest-prey, other predators (Huffaker et al. 1970), or pollen.

The importance of weed communities for the manipulation of insect populations in agroecosystems has been reviewed by Zandstau and Motooka (1978) and Altieri and Whitcomb (1979). Survival and activity of natural enemies of crop pests are enhanced by manipulation of the abundance and composition of weed populations within crop fields and along adjacent habitats. Care must be taken, however, not to promote other problems. For instance, ground cover encouraged as an alternative habitat for predators in orchards could lead to rodent problems. Furthermore, weeds can also serve as potential reservoirs for destructive insects such as Lygus spp. (Fye 1980).

Much more information is needed before we are able to manipulate and use O. insidiosus to our full advantage. Of special importance are the effects of orchard pesticides and management practices on O. insidiosus populations. How these factors influence migration and colonization of O. insidiosus in the orchard and surrounding ecosystems needs to be defined.

IV. ORIOUS INSIDIOSUS (SAY) TOLERANCE OF
SELECTED ORCHARD PESTICIDES

Introduction

There is a substantial pest complex associated with apple trees. Oatman et al. (1964) reported that more than 100 species of insects and mites attacked apple trees in Wisconsin orchards. Forty of these species were of economic importance; ten caused serious problems. High standards of fruit quality imposed on the fruit producers by the visual attractiveness of blemish-free fruit and laws regulating contamination of food products by animal parts has resulted in low economic threshold values for arthropod pest populations. This in turn has led to a heavy reliance by growers on chemical pest management programs (Office of Technology Assessment, 1979).

In spite of the dominance of pesticides in orchard insect and mite pest management, programs using reduced rates of properly timed pesticide applications were advocated as early as the late 1940s (Pickett et al. 1946; Lord 1949). It has only been in the past 10-15 years that this concept has been practiced, as illustrated by programs developed for European red mite (Panonychus ulmi (Koch)) control in Washington (Hoyt and Caltagirone 1971), Michigan (Dover et al. 1979), and Pennsylvania (Asquith and Colburn 1971). These programs provide an alternative to unilateral chemical pest control by using selective placement and

timing of pesticide applications or physiologically selective pesticides for key pest problems, and biological control for the European red mite (Croft 1975).

These integrated pest management (IPM) programs dictate that a careful evaluation be made of the effects of pesticides on the natural enemy component, as well as the pest species (Metcalf 1980). Recent studies in Virginia orchards indicated that the anthocorid, Orius insidiosus (Say) was a potentially important predator of tetranychid mites and aphids (Parrella et al. 1981a). Because there was little information pertaining to the effects of orchard pesticides on O. insidiosus, it was deemed necessary to establish the relative toxicities of selected orchard chemicals to this predator. Cover spray insecticides and fungicides, miticides, aphicides, and some unregistered compounds were tested. Emphasis was placed on adult tolerance to pesticides, but a limited study of the ovicidal effects of methomyl was also undertaken. Methomyl has shown promise as an ovicide for the eggs of several lepidopterous orchard pests species (Horsburgh et al. 1980; David et al. 1981).

Methods and Materials

Adult Tolerance of Pesticides

Residual toxicity tests were undertaken using a 5 dram glass shell vial, stoppered with cheese cloth as a test

chamber. Prior to introduction of the insects, the vials and cheese cloth were dipped in the appropriate pesticide concentration and air-dried for ca. 3 hours. Adult bugs were obtained immediately before each test from a stand of plumeless thistle (Carduus acanthoides L.) adjacent to a young (7 yr) apple orchard located at the Shenandoah Valley Research Station in Steeles Tavern, Virginia. Large populations of the bugs were associated with the thistle flower heads and this facilitated collecting the number of insects needed for each test. O. insidiosus is a highly mobile insect that moves from plant to plant in search of food and favorable microenvironment; therefore, it was assumed that the population studied was the same as that present in the orchard. The tests were conducted in groups of three to four compounds, each group with its own water control, during July and August, 1979. Two rates of each compound were evaluated. The high rate represented that which was recommended by Horsburgh (1979) for orchards using low volume spraying of every row. The low rate corresponded to that recommended for low volume spraying of alternate middle rows. All experiments were conducted at ambient temperatures (21-32°C) and photoperiod in a ventilated insectary. The bugs were placed individually in test chambers to avoid cannibalism and there were 20 insects per treatment.

Mortality was recorded after 24 h; all data were corrected for control mortality using Abbott's formula.

Ovicidal Effects of Methomyl (Lannate 1.8 L[®])

Orius insidiosus oviposits in the mid-vein of apple leaves with only the operculum exposed. Preliminary studies showed that with excised apple leaves or leaf clusters, high control mortality of eggs occurred due to shrinkage of the leaf mid-vein. To circumvent this, O. insidiosus was allowed to oviposit in green bean pods which did not shrink appreciably during the test period. The pods were then dipped in the methomyl solution and hatch was recorded over a 14-day period. Only one rate of methomyl was evaluated. This rate corresponded to a field rate of 0.95 liters/378.5 liters (32 oz/100 gal). A water control was evaluated at the same time. The eggs were maintained at ambient temperatures (25-32°C) in a ventilated insectary.

Results and Discussion

Adult Tolerance of Pesticides

Of the three common cover spray insecticides evaluated, azinphosmethyl was the most toxic; phosalone and phosmet were slightly to moderately toxic (Table 9). Azinphosmethyl has been previously reported as highly toxic to O.

Table 9. Toxicity of Selected Orchard Pesticides to Adult
O. insidiosus

Treatment	Rate/Hectare ^a	% Mortality ^b
Azinphosmethyl 50W	0.28 kg	100
	0.56 kg	100
Phosmet 50W	0.84 kg	47
	1.68 kg	65
Phosalone 25W	1.40 kg	6
	2.50 kg	24
Methomyl 1.8L	1.17 liter	100
	2.34 liter	100
Penncap-M [®]	0.58 liter	100
	1.16 liter	100
Permethrin 3.2EC	0.22 liter	100
	0.44 liter	100
Propargite 30W	1.12 kg	45
	2.24 kg	75
Cyhexatin 50W	0.15 kg	40
	0.30 kg	60
Phosphamidon 3EC	0.18 liter	30
	0.29 liter	40
Demeton 6EC	0.22 liter	55
	0.44 liter	100
Dikar [®] 80W	2.91 kg	5
	7.28 kg	10
Captan 50W	2.91 kg	5
	7.28 kg	20
Benomyl 50W	0.56 kg	15
	1.12 kg	15
Polyram 80W	2.91 kg	0
	7.28 kg	5

^a/ Based on a dilute rate of 2806 liters/Hectare
(300 gal./A)

^b/ Recorded at 24 h and corrected for control mortality
with Abbott's formula.

insidiosus by Holdsworth (1968) and Meyer (1974). Methomyl, Pennacap-M, [®] and permethrin were very toxic to O. insidiosus. The miticides, cyhexatin and propargite were only moderately toxic. The aphicides, phosphamidon and demeton were moderately to highly toxic. The fungicides Dikar, [®] captan, benomyl, and polyram were only slightly toxic. Meyer (1974) also reported many of the same fungicides as having no effect on O. insidiosus. He also noted that dodine, ferbam, folpet, maneb, and zineb were harmless to O. insidiosus. Insecticides not tested in this study, but reported on by Meyer (1974) include superior oil, carbaryl, and malathion. Superior oil had no effect, while carbaryl and malathion allowed for slow population increases of O. insidiosus in the field.

Ovicidal Effects of Methomyl (Lannate 1.8 L[®])

Twenty eggs were tested in the water control and methomyl treatment; all eggs hatched in each case. Thus, methomyl appeared to be harmless to the eggs of O. insidiosus. However, somewhat different results were obtained by David et al. (1981) in a study carried out in a similar manner, but with more replication and several rates of methomyl. They found that a 0.95 liter/378.5 liter (32 oz/100 gal) rate gave a mean of 58% mortality. Recent studies indicate that coverage is an important factor in the ovicidal

activity of this compound (Horsburgh et al. 1980); therefore, differences in the length of time dipped, how well the material drained off the bean, etc., could have accounted for the differences noted between these two studies. Another factor to consider is that the embryos may be more susceptible to methomyl at one time in their development than another.

The relatively high survival of O. insidiosus eggs observed in both studies is probably related to the fact that only a small portion of the egg is exposed to the insecticide; most of the egg remains protected within the plant tissue.

General Discussion

Orius insidiosus is part of a complex of insect predators inhabiting Virginia orchards (Parrella et al. 1981a). Since the maintenance of the entire predator complex at one time is impossible and perhaps undesirable, it is necessary to determine what complex of natural enemies provides for the most effective management of orchard pests. The differential tolerances of predators to pesticides affords for refined manipulation of predator complexes to occur (Croft and Brown 1975). Hull et al. (1978) illustrated the importance of differential tolerances of pesticides by

two mite predators in Pennsylvania orchards. IPM programs with and without the mite suppressent dinocap were evaluated. Dinocap inhibits population increases of the predaceous mite, Amyseius fallacis (Garman), but has little effect on the coccinellid, Stethorus punctum (LeConte). To utilize A. fallacis, pesticide programs had to be developed in which dinocap was not an important component.

O. insidiosus exhibits tolerance to a number of orchard pesticides and the potential for its manipulation through selective pesticide usage is great. The present knowledge of the selective tolerances of pesticides to O. insidiosus, A. fallacis (Croft and Nelson 1972; Hull et al. 1978), S. punctum (Colburn and Asquith 1970, 1973; Asquith and Hull 1973), and Lepothrips mali (Fitch) (Parrella 1980) provides the foundation for further research on the relative effectiveness of individual and complexes of predators for insect and mite pest management in Virginia.

Finally, studies on the effects of systemic insecticides such as demeton and dimethioate on the eggs of O. insidiosus should be undertaken. These aphicides have been shown to be toxic to the eggs of other anthocorid aphid predators (Elliott and May 1968).

V. POPULATION TRENDS OF ORIU INSIDIOSUS (SAY)
IN VIRGINIA APPLE ORCHARDS

Introduction

This study is part of a larger, more comprehensive evaluation of the population dynamics of phytophagous arthropods and their predators in apple orchards under different pest management programs in Virginia (Parrella 1980, Parrella et al. 1981a). The study was initiated by J. P. McCaffrey in 1977 as part of his M.S. degree research on the spider fauna associated with Virginia orchards (McCaffrey 1978), and was continued in 1978 by M. P. Parrella and J. P. McCaffrey as part of their Ph.D. research programs. As noted by Parrella (1980) and Parrella et al. (1981a), the objective of this study was to determine which predators should be emphasized in pest management programs in Virginia.

The purpose of the following discussion is to provide a more detailed report relating specifically to the activities of one of the more important predators studied, the anthorid, Orius insidiosus (Say).

Methods and Materials

The reader is referred to Parrella (1980) and Parrella et al. (1981a) for a detailed description of the orchard, pesticide programs, sampling methods, and statistical analyses of the data.

Briefly, the study was undertaken in three adjacent, 1.6 ha blocks of apple trees in a commercial orchard in

Nelson Co., Virginia. The blocks, designated blocks A, B, and C respectively were each subjected to a different pest management program. Blocks A and B were under experimental IPM programs utilizing reduced rates of pesticides. Block C was grower maintained, using standard pesticide rates and management procedures. Reduced rates of phosalone and Dikar[®] constituted the major insecticide-fungicide combination applied in block A during 1977 and 1978. Reduced rates of azinphosmethyl and benomyl were used in block B in 1977; phosmet replaced azinphosmethyl in 1978. In 1977, early season frost resulted in substantial fruit loss in block C, therefore, a reduced number of treatments of azinphosmethyl and captan were applied. There was a good crop in 1978 so more applications of those chemicals were used.

Predators were sampled by limb-tapping one-fourth of a tree of each of four trees forming a square (two adjacent trees in two adjacent rows), over a one-meter square muslin covered tray. Ten leaves from each of four trees were sampled for mite pests. Aphids were sampled by visually examining ten leaf clusters per tree on each of four trees. All sampling was conducted at two week intervals from mid-April to early September, 1977 and at about ten-day intervals from June to early September, 1978.

Population trends were plotted on a calendar basis for the comprehensive study (Parrella et al. (1981a). For the

sake of this discussion, population trends will be presented in terms of degree-days (DDs) above a base of 10°C accumulated from January 1. A base temperature of 10°C was established from a laboratory study of O. insidiosus development (Section III). The method of Baskerville and Emin (1969) was used to accumulate DDs.

Results and Discussion

Orius insidiosus overwinters as an adult (Marshall 1930; Barber 1936). Small numbers of overwintering bugs have been collected from orchard litter samples in Virginia (Parrella, unpublished data), but most bugs apparently immigrate into the orchard from surrounding areas. In Missouri, Childers and Enns (1975) collected overwintering adults from orchard litter in March: they noted the first adults in the tree in mid-April. This is essentially what we observed in Virginia. A low number of adult O. insidiosus were found in block A, April 14, 1977 (144 DD) (Fig. 10), feeding on aphids located on water sprouts. In 1977, O. insidiosus populations remained low until early to mid-June (498-684 DD). Populations in all blocks then increased, evidently in response to increasing numbers of the European red mite (ERM), Panonychus ulmi (Koch) and the apple rust mite (ARM), Aculus schelectendali (Nalepa) (Figs. 10, 12, 14). A similar response was noted in 1978, but population increases of O. insidiosus did not occur until late

June to early July (864-1086 DD) (Figs. 11, 13, 15). It appears that the slow but early numerical response of O. insidiosus to aphids may provide populations of this predator which will switch feeding to ERM later in the summer when aphid populations are low and mite populations high (Parrella et al. 1981a).

O. insidiosus was one of six mite predators found associated with populations of ERM and ARM and represented 4.6 to 9.3% of the predator complex in 1977 and 6.3 to 30.7% in 1978 (Table 10). In both years, more O. insidiosus were found in block A than B or C. Also, block B had more than block C. These differences in numbers of O. insidiosus can be related primarily to two factors. First, there were higher mite populations in blocks A and B than in block C which would serve to attract and support higher predator populations. Secondly, O. insidiosus has different tolerances to insecticides used in each block. The insecticides can be rated as follows (least to most toxic to O. insidiosus, based on laboratory data (Section IV)): phosalone (block A, 1977-1978), phosmet (block B, 1978), the low rate of azinphosmethyl (block B, 1977), and the high rate of azinphosmethyl (block C, 1977-1979). The difference in predator numbers among blocks supports the assumption that manipulation of O. insidiosus populations through selective pesticide usage is feasible (see Section IV).

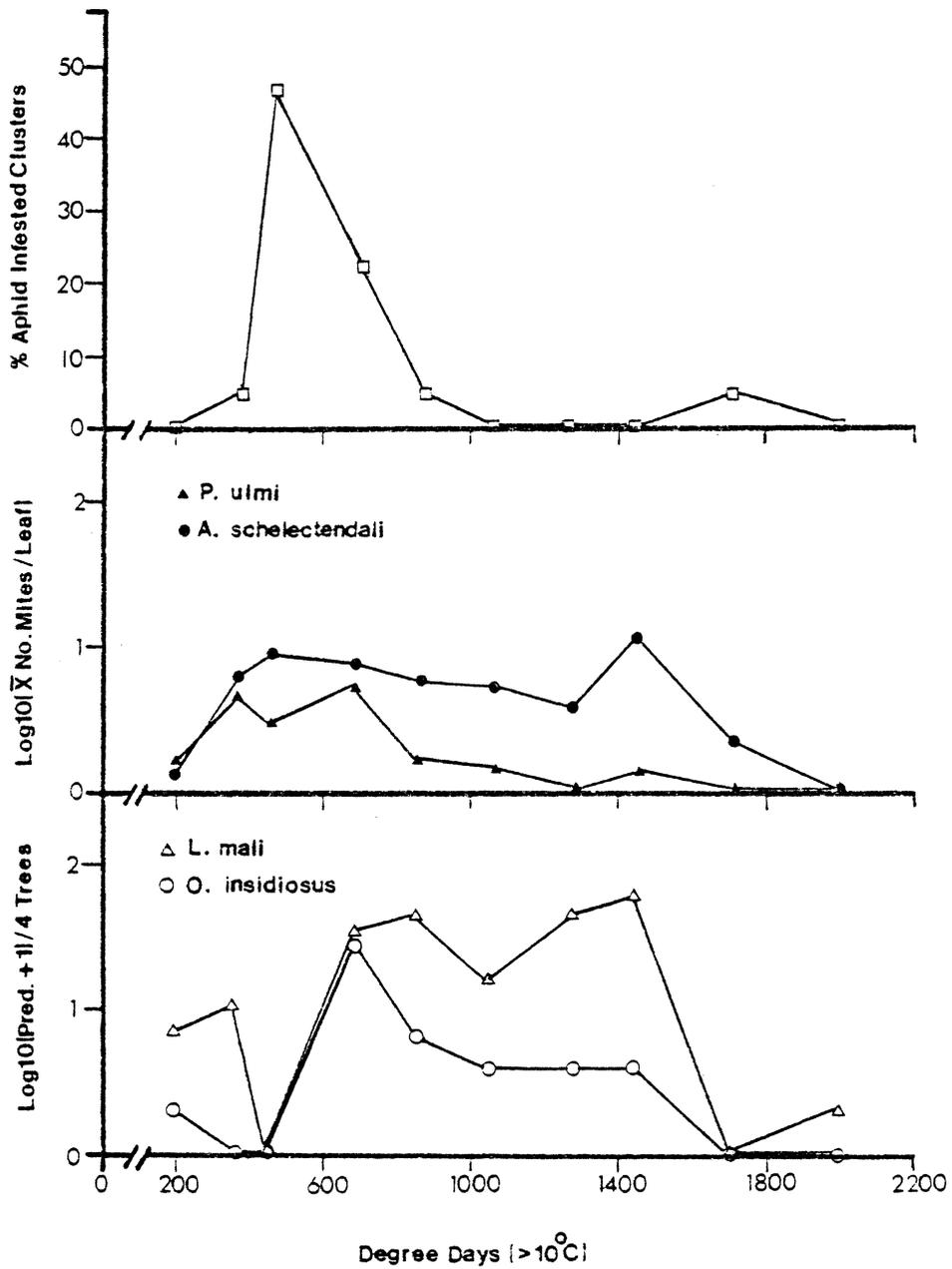


Fig. 10. Population trends of selected pest and beneficial species in Block-A, 1977.

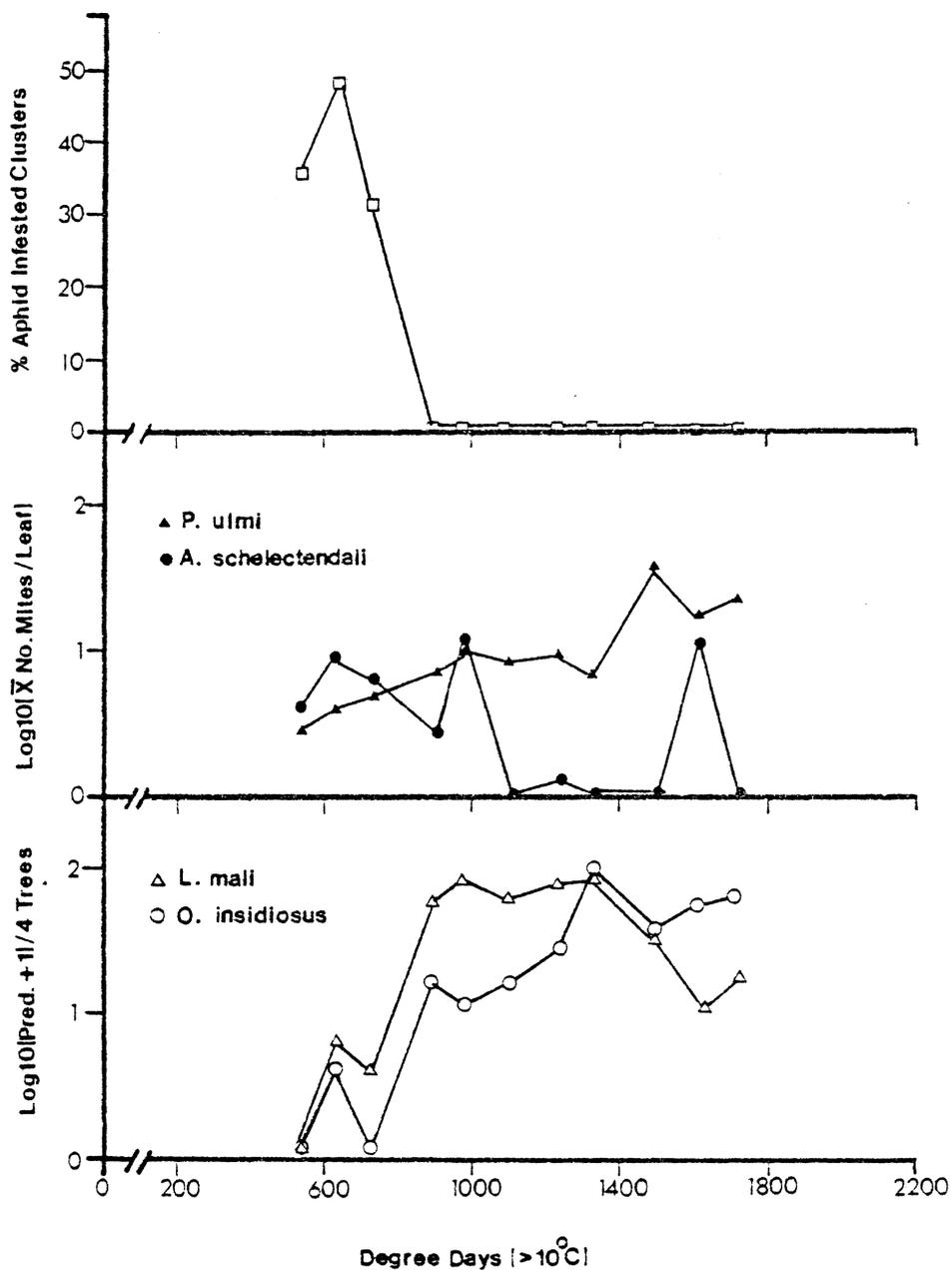


Fig. 11. Population trends of selected pest and beneficial species in Block-A, 1978.

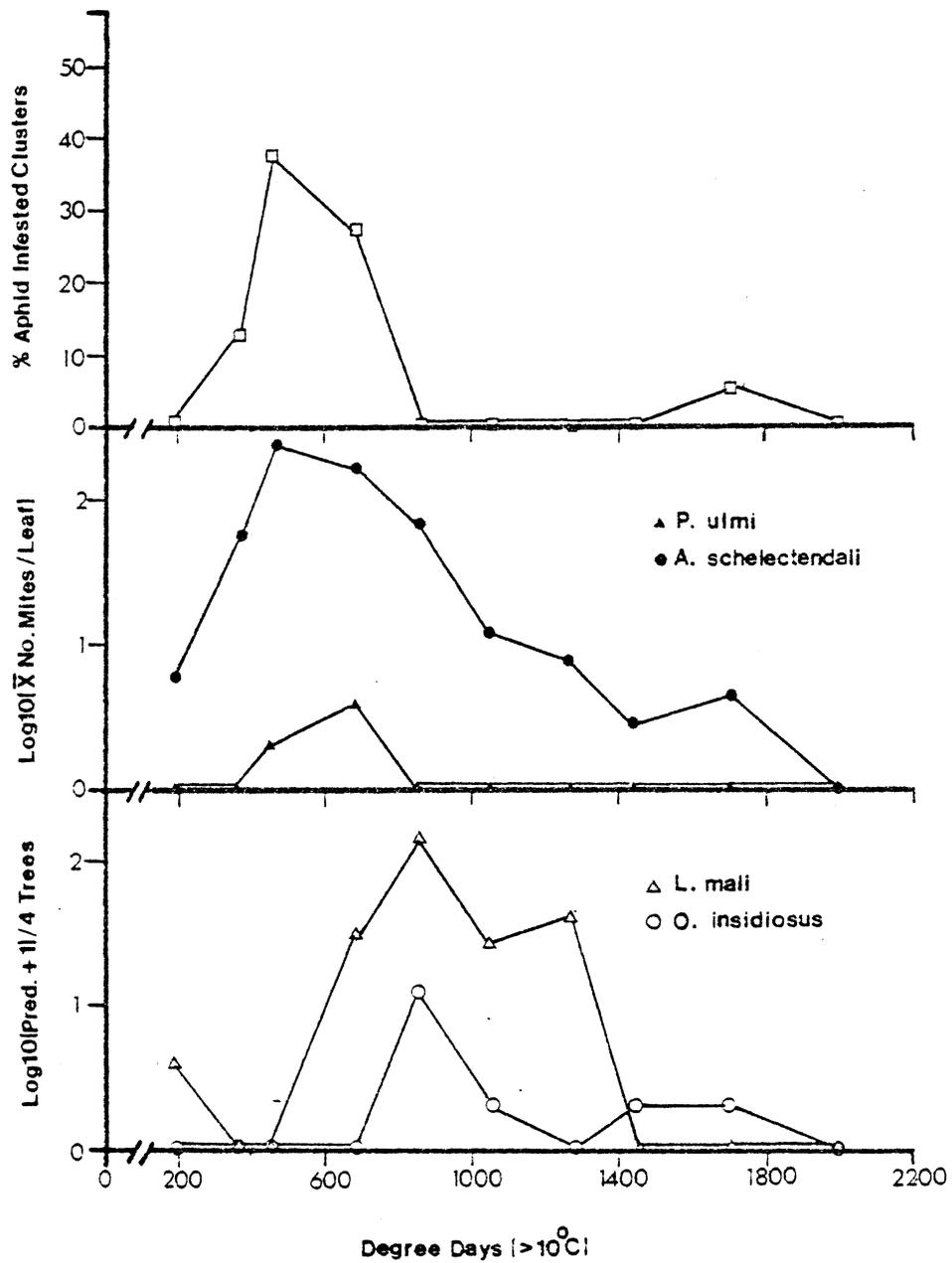


Fig. 12. Population trends of selected pest and beneficial species in Block-B, 1977.

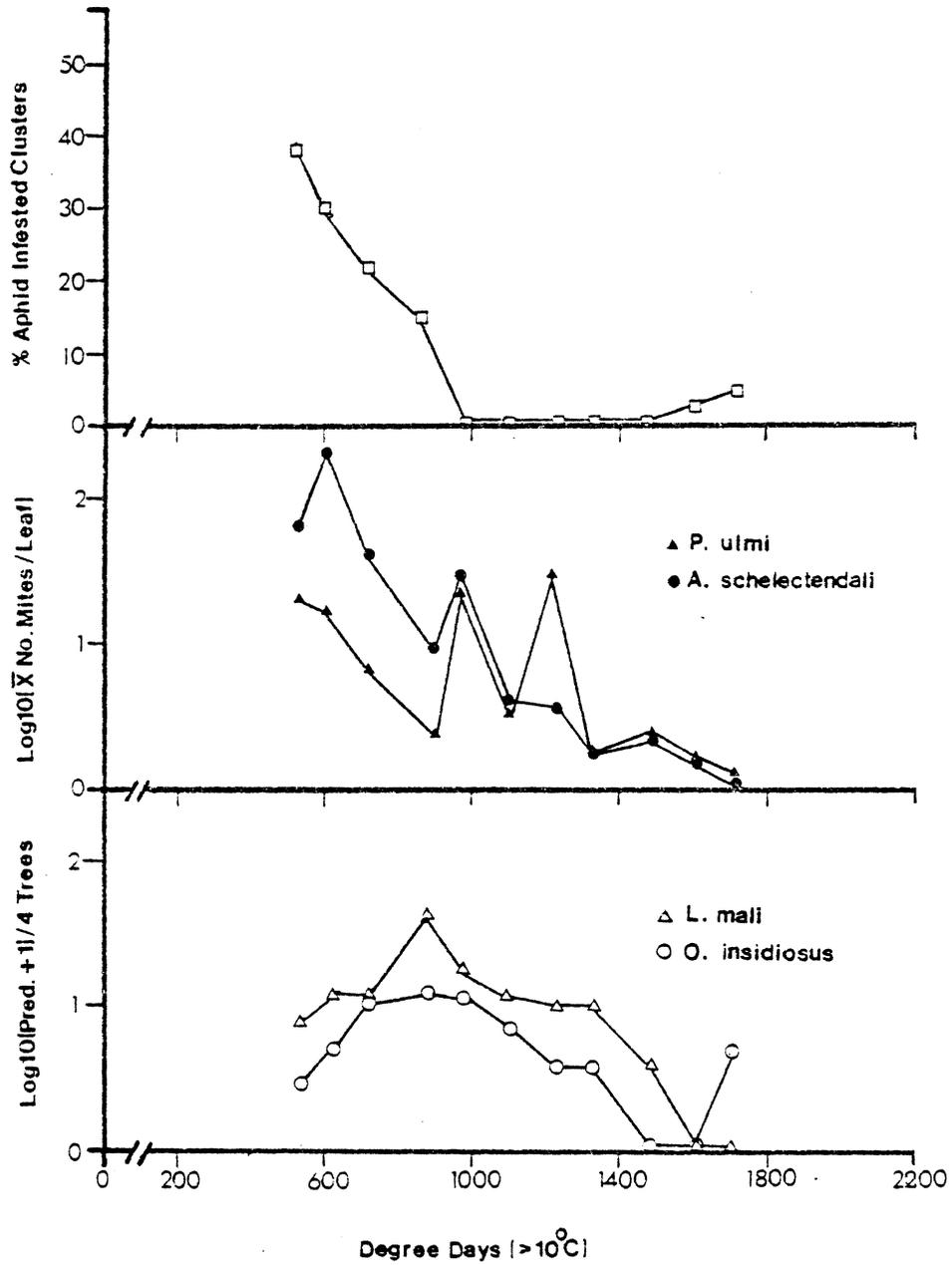


Fig. 13. Population trends of selected pest and beneficial species in Block-B, 1978.

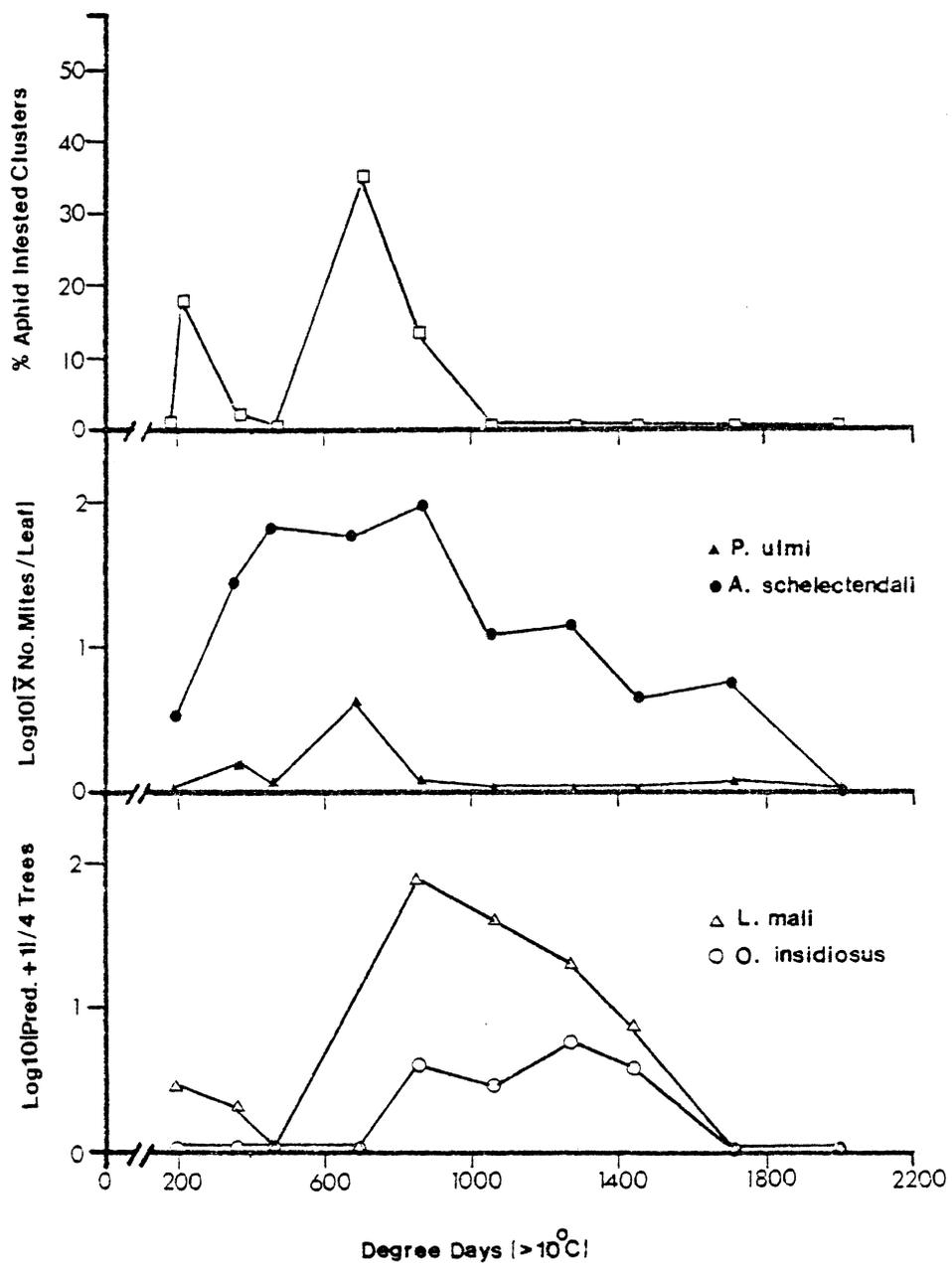


Fig. 14. Population trends of selected pest and beneficial species in Block-C, 1977.

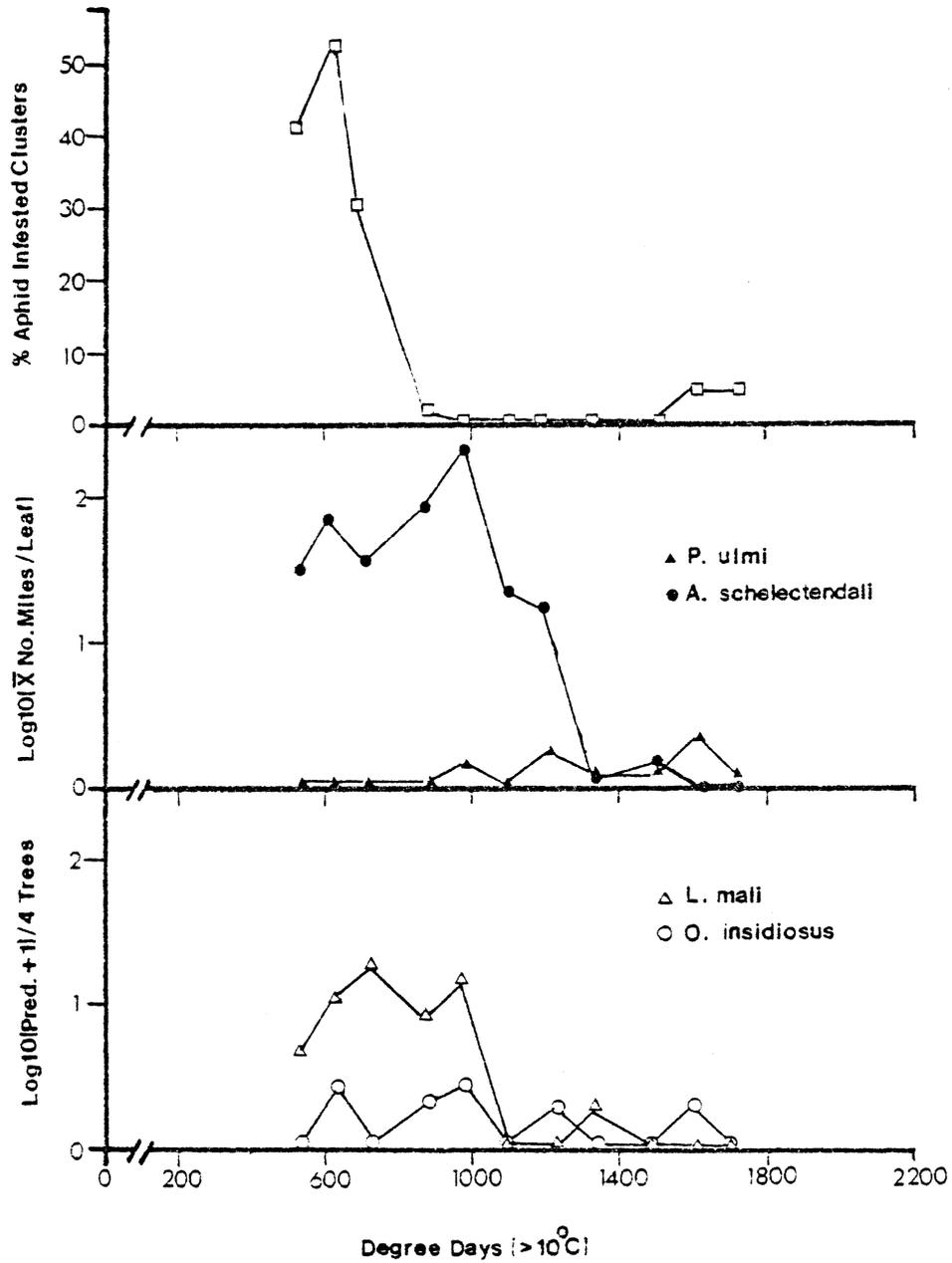


Fig. 15. Population trends of selected pest and beneficial species in Block-C, 1978.

Table 10. Occurrence of Mite Predators in Orchards under Different Pesticide Programs.

Predator	Relative (%) Occurrence of predators in each block					
	Block-A		Block-B		Block-C	
	1977 (452)	1978 (1057) ¹	1977 (302)	1978 (620)	1977 (241)	1978 (111)
<u>Orius insidiosus</u> (Say)	9.3	30.7	4.6	9.0	4.6	6.3
Thrips ²	49.1	43.0	79.5	21.6	65.6	52.3
<u>Stethorus punctum</u> (LeConte)	18.6	14.4	3.3	54.8	19.1	18.0
<u>Chrysopa</u> spp.	9.5	4.5	12.3	7.2	9.5	20.7
<u>Deraeocoris nebulosus</u> (Uhler)	13.5	7.4	0.3	7.4	1.2	2.7

¹/Number in parenthesis is total number of predators on which the percentages are based.

²/Includes two species: Leptothrips mali (Fitch) and Haplothrips subtilissimus (Haliday).

There was some concern, particularly after the first year of study, that O. insidiosus might actually be responding to increasing densities of another mite predator, Leptothrips mali (Fitch). Laboratory studies indicated, however, that the thrips had a defensive behavior which often repelled an attack by O. insidiosus (Parrella et al. 1981b). Later studies indicated that the rate of attack on the thrips was related to the hunger level of the bug (Section V). This indicates that in times when pest-prey such as ERM, ARM, and aphids are increasing in number, attack and capture of L. mali by O. insidiosus is reduced and the numerical and functional response of the bug is towards the pest-prey species. Of course, in times when alternative prey are scarce, successful predation on L. mali will increase, thereby helping to sustain O. insidiosus in the orchard (Parrella et al. 1981a).

Although sampling of predator and pest populations ceased in early September (1916 DD, 1977; 1718 DD, 1978), cursory observations showed that O. insidiosus was active in the study orchard through early October (ca. 2000 DD). Meyer (1974) also observed O. insidiosus feeding on ERM on warm days after frost had occurred. Thus, this predator occurs early in spring and remains a potentially important component of the orchard predator complex throughout the remainder of the season. Considering that O. insidiosus

feeds on a large number of pest-prey species (Section III), maintenance of this predator in Virginia apple orchards would be beneficial.

Finally, it should be noted that other Orius spp. have been recorded as predators in apple orchards in other regions. Collyer (1953) reported O. minutus and O. majusculus (Reuter) as predators of the European red mite in southeastern England. Niemczyk (1978a, b) also reported O. minutus as an important predator of the same mite in Poland. The biologies of these species is very similar to that of O. insidiosus in Virginia. Niemczyk (1978b) indicated that when O. minutus is present in large numbers in apple orchards, it may be able to lower mite populations, but by itself, it probably is incapable of preventing significant leaf damage. He emphasized that in apple orchards, O. minutus always occurs with other predators and thus is an important part of a predator complex which plays a significant role in the reduction of high populations of spider mites.

VI. FUNCTIONAL RESPONSE OF ORIOUS INSIDIOSUS (SAY)
TO THE EUROPEAN RED MITE AT DIFFERENT
CONSTANT TEMPERATURES

Introduction

There has been increasing interest in the integration and utilization of predators for control of the European red mite (ERM), Panonychus ulmi (Koch) in apple orchards. This is exemplified by integrated pest management (IPM) programs for ERM control in Illinois (Meyer 1974), Michigan (Dover et al. 1979), Ohio (Holdsworth 1968), Pennsylvania (Asquith and Colburn 1971; Hull et al. 1979), and Washington (Hoyt and Caltagirone 1971). Recent studies in Virginia indicated that the anthocorid, Orius insidiosus (Say) is a potentially important predator that responds numerically and temporally to ERM populations (Parrella et al. 1981a). This has prompted further evaluation of its predatory potential and importance to our developing IPM programs. Two components that will affect the success of O. insidiosus in controlling its mite prey are its functional and numerical responses (Huffaker et al. 1970; Ever-son 1980). These factors must be considered if the importance of this insect predator is to be evaluated (Murdoch 1972).

The functional and numerical responses were first described by Solomon (1949). The functional response refers to the change in the number of prey consumed per unit time in relation to the change in prey density. The numerical

response refers to the increase in numbers of predators in response to increases in prey density.

Holling (1959, 1966) proposed three types of functional responses. They are the type-1, a linear rise to a plateau; type-2, a curvilinear rise to a plateau; and type-3, a sigmoid curve rising to a plateau. These responses have been extensively reviewed by Royama (1971), Murdoch and Oaten (1975), Hassell et al. (1976), and Hassell (1978).

Many factors influence the functional response of a predator. Of particular importance, especially for predators in temperate regions, is the wide temperature range over which they must find prey (Thompson 1978).

The aim of this study was to evaluate the effects of temperature on the functional response of O. insidiosus to an important orchard pest, P. ulmi.

Methods and Materials

A 9 dram plastic vial cage (see Section III, Fig. 1) was used for all studies. Apple leaves (Red Delicious) cut to 6 x 2 cm (l x w) were infested with field-collected adult female ERM at densities of 5, 10, 20, 40, and 80 mites per leaf. There were 4 replicates for each density. Adult female O. insidiosus were collected from a mite infested

apple orchard in Augusta Co., Virginia and supplied with a surplus of ERM ca. 16 h before each test. The bugs were then introduced singly into cages with one of the five densities of ERM. The experiments commenced at 7:00 am (EDST) and consumed mites were counted and replenished at 3 h intervals until 10:00 pm (EDST) at constant temperatures of 18.3°, 23.9°, 29.4°, and 35.0° \pm 1.0°C. Each temperature was studied on a separate day and the series of experiments were conducted over a two week period in August, 1979.

Models for the type-1 and type-2 responses were taken from Holling (1959). The type-3 model is that presented by Hull et al. (1977). Parameter estimation for the type-1 model was undertaken with least squares, linear regression; type-2 and type-3 parameter estimations were undertaken using a Marquardt nonlinear least squares algorithm (Goodnight, 1979). The criterion for evaluation of models was the R-squared (R^2) value.

Results and Discussion

Mean consumption of ERM by O. insidiosus at each temperature and prey density is presented in Table 11. Note that there was a general increase in mite consumption with increasing temperature. As expected, there was also an increase in mite consumption with a corresponding increase in prey density, indicating that O. insidiosus does

Table 11. Functional Response of O. insidiosus to Densities of P. ulmi of Four Constant Temperatures.

Temp. (°C)	\bar{X} mites consumed/respective density ¹				
	5	10	20	40	80
18.3	0.60 ^a	0.65 ^b	1.30 ^c	2.85 ^c	1.80 ^b
23.9	0.90 ^a	1.55 ^a	2.55 ^c	2.55 ^c	3.25 ^b
29.4	1.50 ^a	2.38 ^a	3.97 ^b	4.95 ^b	9.90 ^a
35.0	1.25 ^a	2.45 ^a	6.35 ^a	8.60 ^a	9.05 ^c

¹/ Means in a column followed by the same letter do not differ significantly ($p > .05$); Duncan's Multiple Range Test.

functionally respond to this prey species. Regression equations representing all three models at each temperature are presented in Table 12. Based on the R^2 criterion, the type-2 ($R^2=0.80-0.96$), and the type-3 ($R^2=0.79-0.98$) models provided the best fit to the data. The type-3 model provided slightly better fit with data from most temperatures, except 29.4°C. In this case, the type-1 ($R^2=0.76$) provided as good a fit as the type-3 ($R^2=0.79$) model; the type-2 ($R^2=0.91$) model provided the best fit.

The type-2 functional response has been characterized as the "invertebrate response" (Holling 1959, 1966) and for the most part, this model has proven acceptable for many single prey, insect predator-prey systems (see Hassell 1978 for review). It was not surprising to find O. insidiosus exhibiting this type of response. It should be noted that there has been some controversy over using the Holling's type-2 disc equation. The major objection is that it does not incorporate changes in prey density due to exploitation (Rogers 1972; Livdahl 1979; Hassell 1978). In the present experiments, however, prey were replenished at 3 h intervals to reduce this problem. Also, the alternative equation proposed by Rogers (1972) is fraught with its own problems (Livdahl 1979).

Table 12. Functional Response of Orius insidiosus to the European Red Mite Panonychus ulmi at Four Constant Temperatures: Comparison of Models.

Model ^{a, c}	Temp. (°C)	Regression Equations	R ²
Type 1		$Y=aN+b$	
	18.3	$Y=0.0189N - 0.8542$	.25
	23.9	$Y=0.0264N - 1.3417$	.34
	29.4	$Y=0.1067N - 1.2307$	.76
	35.0	$Y=0.0987N - 2.4813$	.66
Type 2 ^b		$Y=\frac{aTN}{1+aT_hN}$	
	18.3	$Y=0.1515N/1+0.0530N$	.80
	23.9	$Y=0.2808N/1+0.0755N$	.86
	29.4	$Y=0.2025N/1+0.0087N$	.91
	35.0	$Y=0.4725N/1+0.0355N$	.96
Type 3 ^b		$Y=\frac{A}{1+\text{Exp}(B-CN)}$	
	18.3	$Y=2.32/1+\text{Exp}(2.37-0.16N)$	.83
	23.9	$Y=2.52/1+\text{Exp}(1.66-0.18N)$	.85
	29.4	$Y=5.50/1+\text{Exp}(2.00-0.20N)$	.79
	35.0	$Y=8.87/1+\text{Exp}(2.72-0.18N)$	.98

^{a/} Models 1 and 2, Holling (1959); Model 3, Hull et al. (1977).

^{b/} Parameters estimated using Marquardt least squares algorithm (Goodnight, 1979).

^{c/} Y=No. prey consumed; a=attack rate; N=initial prey population density; b=Y-intercept; T=prey exposure time; T_h=handling time; A,B,C=estimated parameters.

The type-3 functional response was first characterized as a "vertebrate response" (Holling, 1959, 1965), but recent studies indicate it is more widespread. Holling (1965, 1966) first suggested that associative learning was the major component that separated a type-3 from a type-2 response. However, as Akre and Johnson (1979) note, recent studies suggest that sigmoid responses to single prey systems may also be a function of aggregative behavior (Hassell and May 1974), prey refuges in heterogeneous habitats (Crowly 1975; Hildrew and Townsend 1977), or declining search rate at low encounter frequencies (Hassell et al. 1977).

The aggregative response is of special interest considering the searching behavior of Orius spp. and anthocorids in general. The sigmoid curve of the aggregative response can be characterized by three components; an upper plateau where maximum time is spent in a unit area of relatively high prey density; a lower plateau where a constant minimum time is spent in such areas; and lastly, a transition region where there is a marked increase in time spent per unit area as prey density increases (Hassell and May 1974). Therefore, predators hunt more actively as prey densities rise, by spending more time searching for prey. Anthocorids exhibit searching behavior that optimizes for

the above components. For example, Orius tristicolor (White) (Shields and Watson 1980) and Anthocoris confusus (Reuter) (Evans 1976) show increases in the frequency of turning movement following feeding and confine their search in a limited area until a threshold time when, if no further prey were found, they would straighten out their search path. Thus, once a patch or area of high prey density is found, they exploit it.

The importance of distinguishing type-2 from type-3 responses has received considerable attention. As opposed to the type-2 functional response, the sigmoid, type-3 response is density dependent up to some threshold density and may contribute to predator-prey stability (Holling 1959; Murdoch and Oaten 1975; Hassell et al. 1977; Hassell 1978). The type-3 response also has other benefits that have implications to optimum foraging theory. A reduction of searching effort in a low-yield environment reduces costs until conditions improve (Hassell et al. 1977).

The effect of temperature on the functional response of O. insidiosus to ERM can best be evaluated with Holling's type-2 model. Two important parameters, attack rate (a) and handling time (T_h) can be studied. Other studies have found an increase in attack rate and decrease in handling time with increasing temperature (Thompson 1978; Everson

1980). My data generally conform to these observations, but there appears to be an anomaly at 29.4° (Table 13) and I find this difficult to explain. In any case, it is obvious that there are drastic changes in the functional response curves from the lower temperatures (18.3° and 23.9°) to the higher temperatures (29.4° and 35.0°) (Fig. 16). O. insidiosus is apparently not very active at moderately low temperatures.

Temperature has been shown to influence daily feeding rhythms. For example, Stethorus punctum (LeConte) has slightly erratic feeding early in the morning when temperatures are low, but as the day progresses and temperatures rise, feeding by S. punctum increases at all prey densities (Hull et al. 1977). The current study was conducted at constant temperatures, but an Analysis of Variance with temperature, prey density, and time of day as fixed factors indicates that there was a significant ($p < 0.05$) influence of time of day on mite consumption by O. insidiosus (Table 14). This, then, indicates an innate feeding rhythm that is independent of temperature. Separate analyses of mite consumption between individual time intervals showed significant differences ($p < 0.05$) only at the highest prey density at 29.4°. There was significantly ($p < 0.05$) higher mite consumption during the first three feeding intervals. This

Table 13. The Effects of Temperature on the Rate of Successful Search and Handling Time of Orius insidiosus.

Parameter ^a	Temperature (°C)			
	18.3	23.9	29.4	35.0
a	0.0505	0.0936	0.0675	0.1575
T _h	1.0495	0.8063	0.1282	0.2257
R ²	0.80	0.86	0.91	0.96

^a/_a and T_h represent the rate of successful search and handling time respectively in Holling's disk equation (Holling 1959): The R² value is the coefficient of determination for Holling's model fit with the respective parameter estimates.

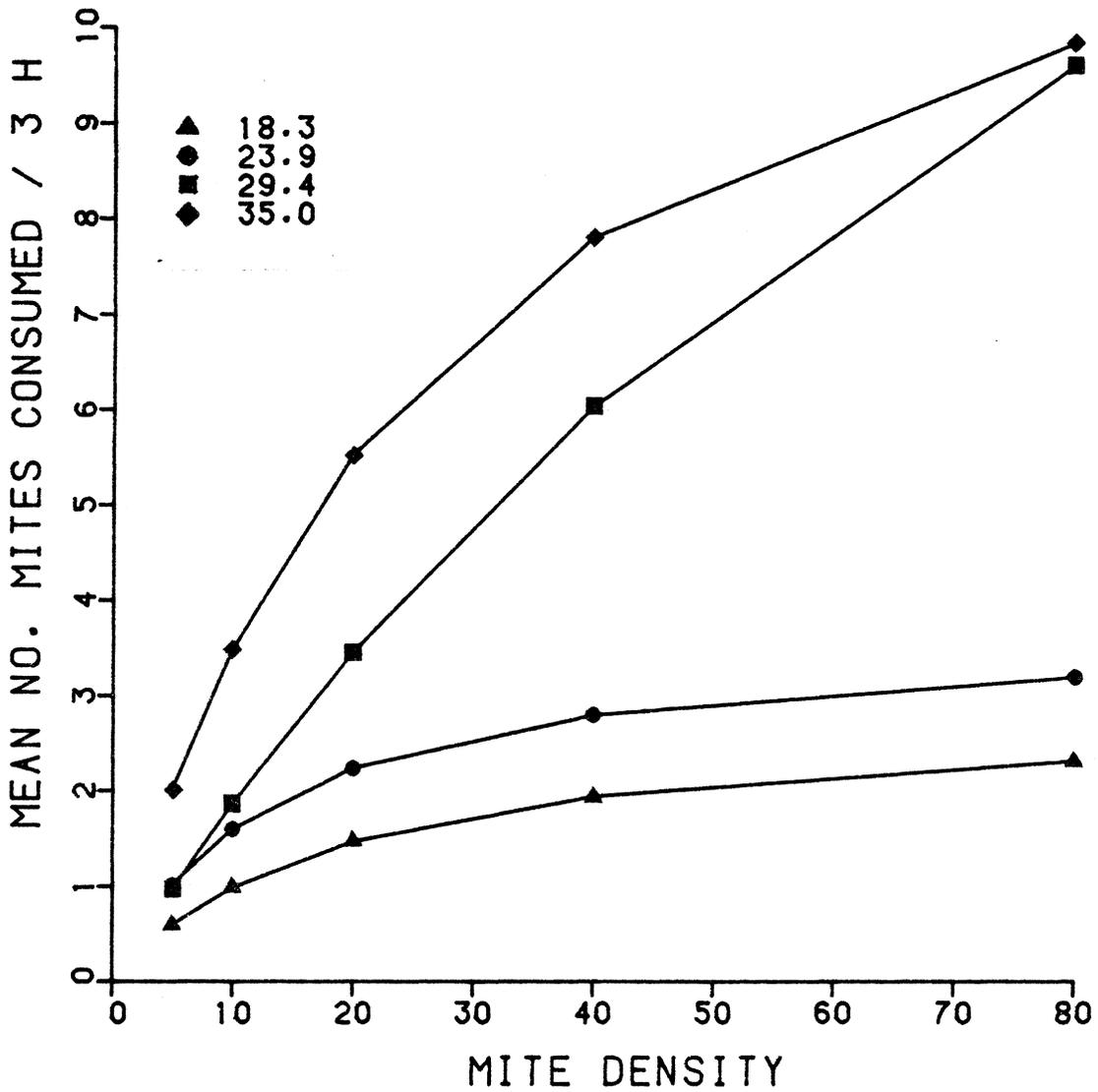


Fig. 16. Functional response (type-2 model) of *O. insidiosus* to *P. ulmi* at four constant temperatures.

Table 14. Three-way ANOVA on Factors Affecting Consumption of P. ulmi by O. insidiosus
(Model 1--fixed factors)

Source	df	MS	F ¹
Temp.	3	374.48	65.73****
Density	4	335.75	58.93****
Time	4	14.36	2.52*
Time * Density	12	55.63	9.76****
Temp. * Time	12	9.08	1.59
Density * Time	16	5.57	0.98
Temp. * Density * Time	48	4.47	0.78
Error	300	5.70	
Corrected Total	399		

¹/₋ *=p<.05; ****=p<.0001.

may indicate that those bugs were at a different initial hunger level or physiological state than the others. This would help explain the anomaly noted for the attack rate at that temperature.

I found in preliminary studies that O. insidiosus would feed at night, but consumption was low and erratic. Considering the normally low nighttime temperatures, such feeding probably is not significant.

In summary, both the type-2 and type-3 functional response models adequately explain the observed consumption response of O. insidiosus to ERM. This observation, plus the numerical response towards ERM noted by Parrella et al. (1981a), suggests this predator is an important component of the mite predator complex in Virginia apple orchards.

VII. INTERSPECIFIC INTERACTIONS BETWEEN ORIOUS INSIDIOSUS
(SAY) AND LEPTOTHIRIPS MALI (FITCH)

Introduction

The anthocorid, Orius insidiosus (Say) and the phlaeothripid, Leptothrips mali (Fitch) are important mite predators in Virginia apple orchards (Parrella et al. 1981a). Studies on the compatibility of these two predators indicated that O. insidiosus would prey upon L. mali, but that not all encounters between the bug and thrips led to a successful attack (Parrella et al. 1981b). It was also noted that the thrips produced a drop of liquid from the anal area which when forced onto O. insidiosus caused the bug to cease its attack and cleanse itself, thereby allowing the thrips to escape.

The following study was undertaken to further investigate the interspecific interactions between these two predators. Emphasis was placed on defining the predatory behavior of O. insidiosus and evaluating factors which affect its successful predation on L. mali.

Methods and Materials

General Procedures

An interaction arena (Fig. 17) consisting of a 2.4 cm diam., white plastic disk that floated on water in a 6 cm diam. x 2 cm deep plastic petri dish was used for all

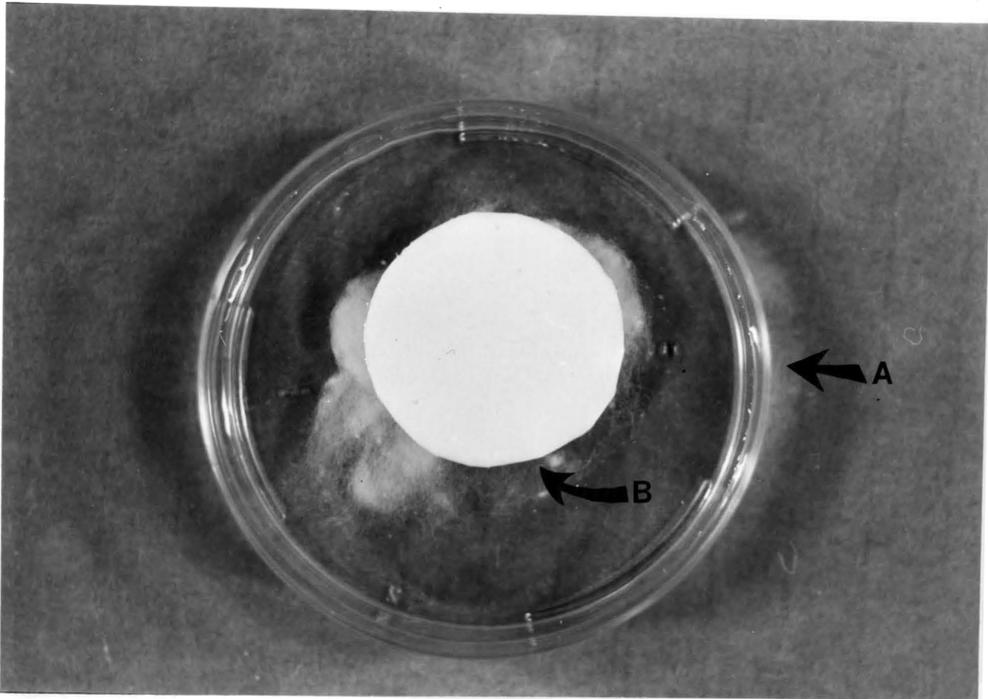


Fig. 17. Interaction arena: A) 6 cm diam. x 2 cm deep petri dish, B) 2.4 cm diam. plastic disk.

behavioral observations. A small piece of cotton placed in the water below the disk kept it stationary.

Second instar thrips were collected from apple trees infested with the European red mite, Panonychus ulmi (Koch), and provided with a surplus of P. ulmi in the laboratory 12-24 h before each test. Fifth instar O. insidiosus were also collected from mite infested apple trees and subjected to one of two treatments: either the bugs were starved for 16 h (N=6) or they were provided with excess P. ulmi (N=23) 12-24 h before a test. Thus, starved and well fed (satiated) bugs were studied.

Preliminary studies were conducted to define the behavioral repertoire of the insects during their interactions. All observations were made with a stereomicroscope at 40 X magnification. The major behavioral elements were listed as column headings on data sheets and the sheets were used to record the frequencies of occurrence for each behavioral element listed. The protocol for each observation period was as follows: the thrips (2nd instar) was placed on the arena and allowed to acclimate for 5 min. A 5th instar O. insidiosus (starved or satiated) was placed on the arena at the furthestmost point away from the thrips. The insects were allowed to interact until 1) one of the insects fell off the arena into the water, 2) O. insidiosus successfully

captured the thrips, or 3) a period of 1 h had lapsed. The 1 h maximum observation period approached the limits of my attention span. All studies were undertaken between 12:00-4:00 pm (EDST), during the period, August 8-28, 1980. A large window 1 m to the right of the arena provided the only light. All studies were conducted at $21.1^{\circ} \pm 2.0^{\circ}\text{C}$.

Description of Major Behavioral Elements

Tactual: Refers to body contact between the thrips and the bug. This could be due to the bug contacting the thrips, the thrips contacting the bug, or mutual contact by both insects.

Visual: Refers to visual and other non-tactual perception of the thrips. It could not be ascertained if vibrations or scents produced by the thrips were cues for O. insidiosus perception, thus the assumption was that all non-tactual perception was visual.

Orient: this was a directed movement of the body of the bug towards the thrips.

RE: This was a complex behavior that included raising of the antennae and extension of the rostrum parallel to the surface of the arena. Usually the two behaviors were linked, but occasionally, only the antennae or the rostrum was raised.

Probe: This was an inspection of the thrips or the area directly proximate to it by the bug with its rostrum.

Attack: An attempt by the bug to capture the thrips.

Successful: Capture and killing of the thrips by the bug.

Unsuccessful: An unsuccessful attempt by the bug to capture the thrips. Either the thrips simply ran away or it used its anal fluid to repel the bug.

Discontinue: The discontinuance of any behavioral event.

Statistical Analysis of Data

The G-test (Sokal and Rohlf 1969) was used when testing for independence. Student's t-test was used for the comparison of two means (Sokal and Rohlf 1969).

Results and Discussion

A total of 327 and 32 encounters were observed for satiated and starved bugs respectively. These encounters are represented in kinematic graphs in Figs. 18-19. Each circle in a graph represents a behavioral element previously described in the methods and materials. The area of the

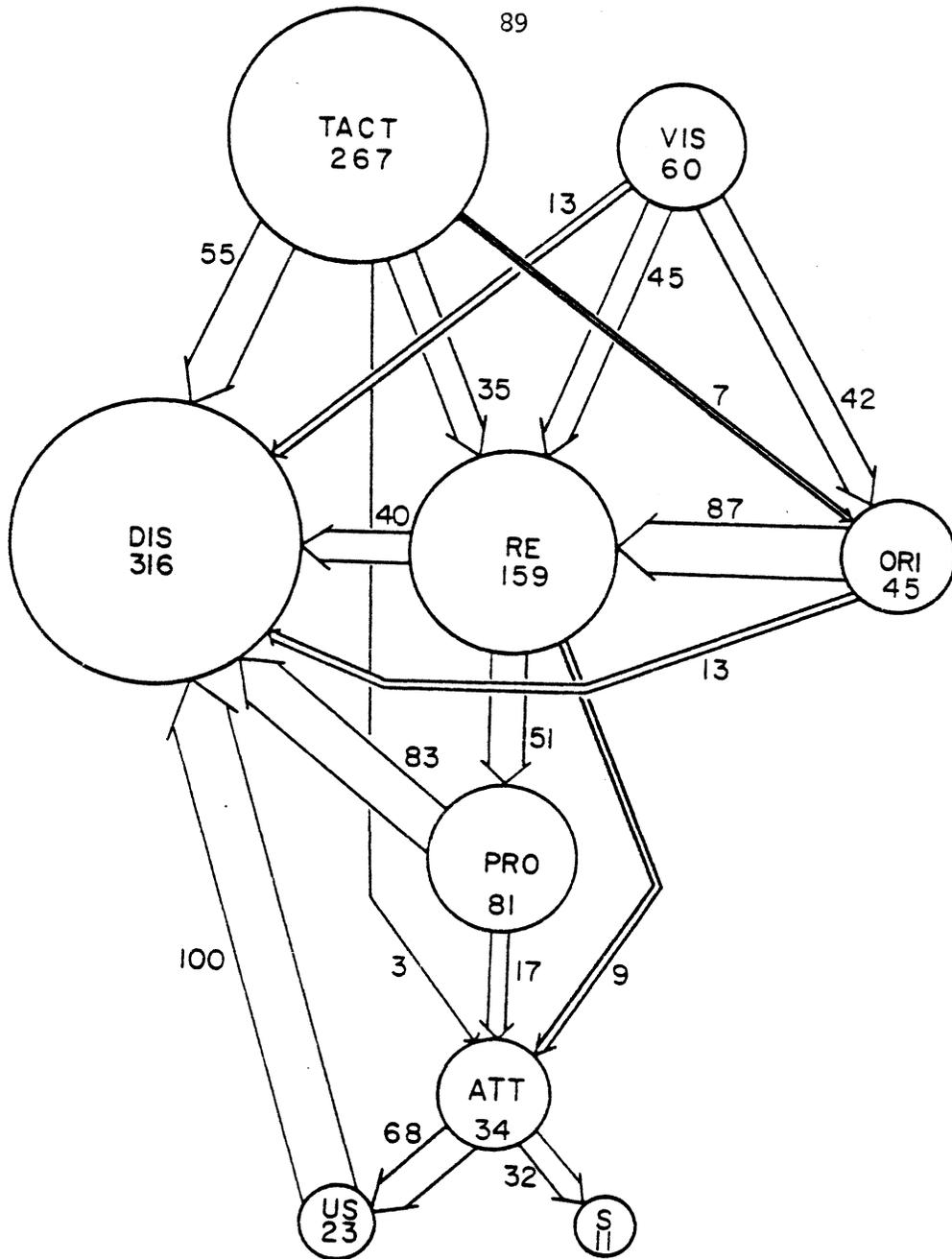


Fig. 18. Kinematic graph of predatory behavior exhibited by satiated *O. insidiosus* towards the thrips, *L. mali*. The circle area represents the relative frequency of occurrence for that behavioral element; TACT=tactual perception, VIS=visual perception, DIS=discontinue, RE=raise antennae-extend rostrum, ORI=orient, PRO=probe, ATT=attack. Width of arrows represents the relative proportion of time transition occurred in that direction.

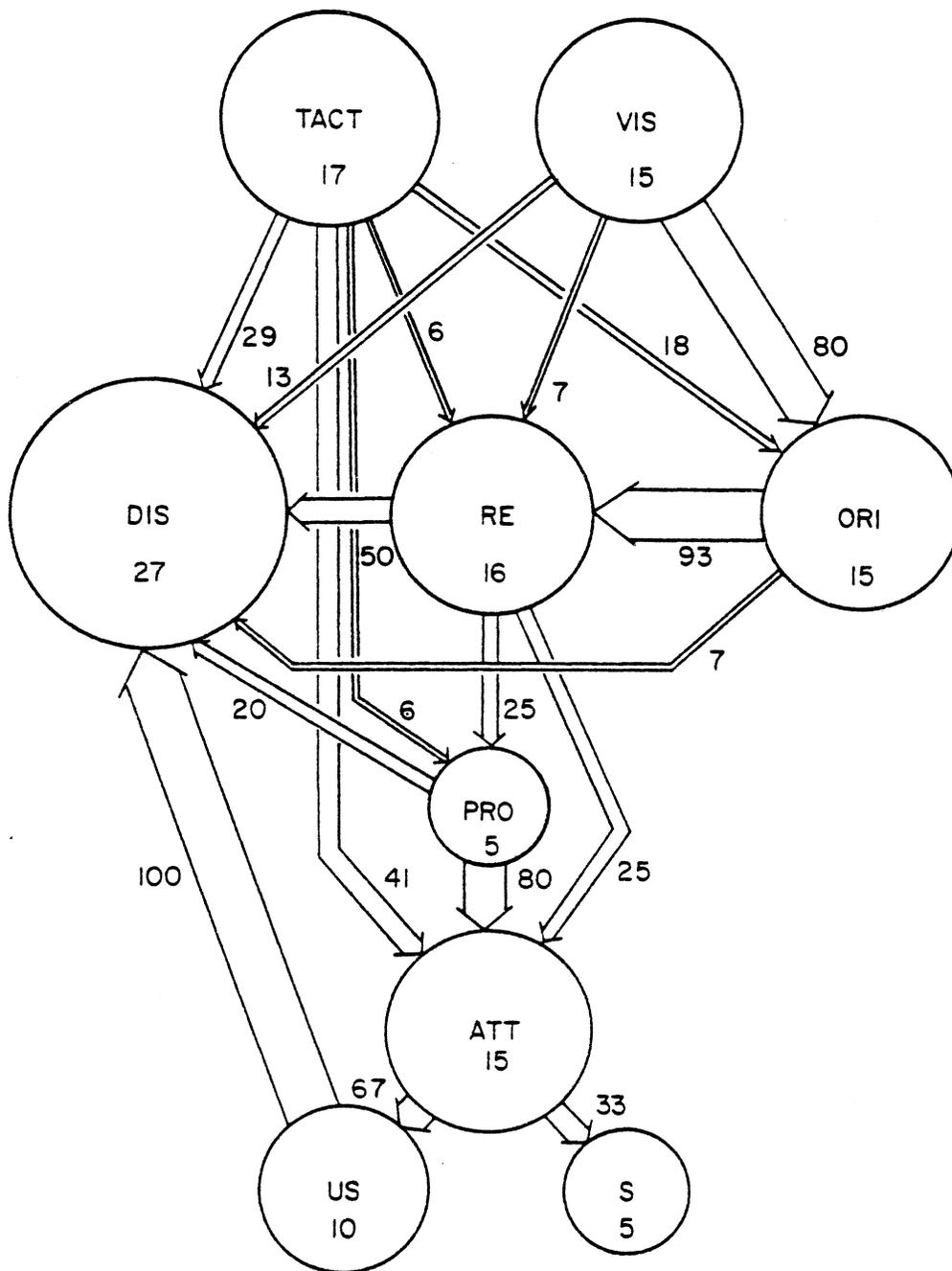


Fig. 19. Kinematic graph of predatory behavior exhibited by starved *O. insidiosus* towards the thrips, *L. mali*. See Fig. 18 for legend.

circle represents the relative frequency of occurrence for that element. All behavioral sequences begin at perception (visual or tactual) and proceed down. The arrows represent the sequence of transitions from one behavioral element to another. The width of the arrow relates to the relative proportion of the time that the transition occurred in that direction (Sustare 1978).

The behavior of O. insidiosus on the arena was similar to that reported for O. tristicolor (White) on cotton leaves (Shields and Watson 1980). Satiated bugs moved rapidly around the edge of the arena with their rostrums tucked beneath their heads. Starved bugs moved somewhat less rapidly along the arena edge, often with their rostrums tapping the substrate in front of them.

As already noted, perception of L. mali occurred visually or tactually. Visual perception occurred significantly ($p < .005$; G-test, $df=1$) more often with starved (53.1%) than satiated (18.3%) bugs (Figs. 18-19). Thus, hunger resulted in increased attentiveness and response by bugs to movement of objects in close proximity. Hunger levels may affect the distance at which O. insidiosus reacts to its prey (Holling 1966; Stubbs 1980), but my observations indicate that visual perception does not extend beyond a distance approximate to the length of the bug's antenna.

As indicated by Figs. 18-19 most tactual encounters by satiated bugs were discontinued. This represents bump and run interactions, usually by both insects, resulting in mutual avoidance. Rarely did satiated bugs immediately attack L. mali after contact. Starved bugs were more likely to attack the thrips when contact first occurred (Fig. 19).

Visual perception by satiated and starved bugs usually led to orient or re (extend proboscis, raise antennae) Figs. 18-19). From this point, probe (inspection), attack, or discontinue occurred. At no time was O. insidiosus observed to attack L. mali immediately after visual perception. While it was apparent that vision played an important role in prey perception in this study, it has not been considered in studies of the searching behavior of other anthocorids. Dixon and Russell (1972), Evans (1976b), Brunner and Burts (1975), and Shields and Watson (1980) only noted tactual perception of prey by the bugs they studied.

Probing of the thrips by satiated bugs usually led to discontinue (82.7%), but sometimes to attack (17.3%). This is in contrast to starved bugs where attack occurred 80.0% of the time and discontinue only 20.0% (Figs. 18-19).

The percent of all encounters that led to an attack (the attack rate) differed significantly ($p < .005$; G-test,

df=1) between satiated and starved bugs; the attack rates were 10.4% and 46.9% respectively. This indicates that the rate of attack was directly related to hunger.

The rate of successful attack (successful attacks/total no. of attacks) did not differ significantly ($p > .05$; G-test, df=1) between starved (33.3%) and satiated (32.3%) bugs, indicating that the efficiency of capture of the thrips by O. insidiosus was not influenced by hunger. However, since there was a higher attack rate associated with starved bugs, a higher incidence of successful attacks was noted. The rate of successful attacks per total number of encounters was 3.4% for satiated bugs and 15.6% for starved bugs; these values differ significantly ($p < .01$; G-test, df=1).

Of all unsuccessful attacks by satiated bugs, 73.9% were due to the thrips simply running away; 26.1% were due to repulsion of the bugs by the thrips' anal fluid. This was about the same for starved bugs (70.0% and 30.0%, respectively).

The mean cleaning time for satiated bugs repelled by the thrips' anal fluid was 1.7 min. This was not significantly different ($p > .05$; Student's t-test, df=6) from the mean cleaning time of starved bugs, which was 1.1 min. The

range in cleaning time was 0.5-3.0 min for satiated bugs (N=5) and 0.3-1.8 min for starved bugs (N=3). It should be noted that some bugs, especially those that were starved, would successfully capture L. mali even after contacting its anal fluid. The bugs would usually kill the thrips, then groom themselves for 1-3 min before feeding.

The direction of attack by O. insidiosus significantly ($p < .05$); G-test, $df=2$) influenced capture. The rate of successful attack was 33.3%, 20.8%, and 71.4% for head (N=18), rear (N=24), and side (N=7), respectively. Head and rear attack were most common because of the similar behaviors of the thrips and the bug on the arena. Both moved along the periphery of the arena during the study; therefore, the chance to meet head-on or from the rear was greater than from the side. Considering that these two predators may also search similar areas of the apple leaf, such as the mid-vein, most encounters would also be head-on or from the rear. So, while side attacks are more successful, such attacks probably occur less frequently.

Parrella et al. (1981b) indicated that L. mali and O. insidiosus might not be compatible because of predation by the bug on the thrips. However, they noted that in the closed system of the interaction arena, repeated confrontations occurred and thus it did not necessarily reflect a

field situation where predator-predator contact might stimulate movement of predators to other leaves. This would reduce thrips mortality and possibly promote more efficient control of pest-prey at low prey densities (McMurtry et al. 1970). The present study indicates that most encounters, particularly by well-fed bugs led to mutual avoidance, or at most, a relatively low rate of successful attack. Since hunger affected the rate of attack by O. insidiosus on the thrips, it might be expected that when mite or other pest-prey densities are high, predation on the thrips would be low. Of course, as densities of the pest-prey are reduced, predation on the thrips would increase. In the study of Parrella et al. (1981b), prey were not replenished, therefore, the predators decreased the food supply. This might have accounted for the high rate of predation on the thrips during the 24 h course of those studies.

In summary, O. insidiosus and L. mali do appear to be compatible, at least during periods when moderate to high densities of pest-prey are available. However, further research on the consequences of interference between O. insidiosus and L. mali are needed. Mutual interference may occur between these predators even if contact does not result in successful attack. Such interference may result in reduced fecundity, increased dispersal, and perhaps reduced feeding by one or both species (Hassell 1971; Hassell and

Southwood 1978; Evans 1976b). Also other predator species interact with O. insidiosus and L. mali in Virginia apple orchards. They too need to be considered in the context of mutual interference.

VIII. LITERATURE CITED

LITERATURE CITED

- Akre, B. G., and D. M. Johnson. 1979. Switching and sigmoid functional response curves by damselfly naiads with alternative prey available. *J. Anim. Ecol.* 48: 703-720.
- Altieri, M. A., and W. H. Whitcomb. 1979. Manipulation of insect populations throughout seasonal disturbance of weed communities. *Prot. Ecol.* 1: 185-202.
- Arbogast, R. T. 1976. Suppression of Oryzaephilus surinamensis (L.) (Coleoptera, Cucujidae) on shelled corn by the predator Xylocoris flavipes (Reuter) (Hemiptera, Anthrocoridae), a predator of stored product insects. *Ann. Entomol. Soc. Amer.* 64: 1131-1134.
- Arnold, C. Y. 1959. The determination and significance of the base temperature in a linear heat unit system. *J. Amer. Soc. Hort. Sci.* 74: 430-445.
- Asquith, D., and R. Colburn. 1971. Integrated pest management in Pennsylvania apple orchards. *Bull. Entomol. Soc. Amer.* 17: 89-91.
- Asquith, D., and L. A. Hull. 1973. Stethorus punctum and pest-population responses to pesticide treatments on apple trees. *J. Econ. Entomol.* 66: 1197-1203.
- Barber, G. W. 1936. Orius insidiosus (Say), an important natural enemy of the corn ear worm. *USDA Tech. Bull.* No. 504. 24 pp.
- Baskerville, G. L., and P. Emin. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. *Ecology* 50: 514-517.
- Brunner, J. F., and E. C. Burts. 1975. Searching behavior and growth rates of Anthocoris nemoralis (Hemiptera: Anthocoridae), a predator of the pear psylla, Psylla pyricola. *Ann. Entomol. Soc. Amer.* 68: 311-315.

- Carayon, J. 1961. Quelques remarques sur les Hemipteres-Heteropteres: leur importance comme insectes auxiliaires et les possibilites de leur utilisation dans la lutte biologique. *Entomophaga* 6: 133-141.
- Carayon, J., and J. R. Steffan. 1959. Observations sur le regime alimentaire des Orius et particulierement d' Orius pallidicornis (Reuter) (Heteroptera:Anthocoridae). *Cahiers. Nat.Bull. N.P., n.s.* 15: 53-63.
- Casagrande, R. A. 1971. An approach to alfalfa weevil management in Michigan. M.S. Thesis, Michigan State University, East Lansing, MI. 60 pp.
- Childers, C. C., and W. R. Enns. 1975. Predaceous arthropods associated with spider mites in Missouri apple orchards. *J. Kans. Entomol. Soc.* 48: 453-471.
- Clancy, D. W., and H. N. Pollard. 1952. The effect of DDT on mite and predator populations in apple orchards. *J. Econ. Entomol.* 45: 108-114.
- Colburn, R., and D. Asquith. 1971. Tolerance of the stages of Stethorus punctum to selected insecticides and miticides. *Ibid.* 64: 1072-1074.
- Colburn, R., and D. Asquith. 1973. Tolerance of Stethorus punctum adults and larvae to various pesticides. *Ibid.* 66: 961-962.
- Collyer, E. 1953. Biology of some predatory insects and mites associated with the fruit tree spider mite (Metatetranychus ulmi Koch) in south-eastern England. II. Some important predators of mites. *J. Hort. Sci.* 28: 85-97.
- Conway, G. R. 1976. Man versus pests. In *Theoretical Ecology*. R. M. May, ed. W. B. Saunders, Philadelphia, 317 pp.
- Croft, B. A. 1975. Tree fruit pest management. Pages 471-507 in R. L. Metcalf and W. Luckman, eds. *Introduction to insect pest management*. John Wiley & Sons, N.Y.
- Croft, B. A., and E. E. Nelson. 1972. Toxicity of apple orchard pesticides to Michigan populations of Amblyseius fallacis. *Environ. Entomol.* 1: 576-579.

- Croft, B. A., and A. W. A. Brown. 1975. Responses of arthropod natural enemies to insecticides. *Ann. Rev. Entomol.* 20: 285-335.
- Crowley, P. H. 1975. Spatial heterogeneity and the stability of a predator-prey link. Ph.D. dissertation, Michigan State University, East Lansing, MI.
- David, P. J., R. L. Horsburgh, J. P. McCaffrey, and L. F. Ponton. 1981. Apple: The ovicidal effects of methomyl (Lannate-L) on beneficial insects 1980. *Insect. Acar. Tests* (in press).
- Dixon, A. F. G., and R. J. Russel. 1972. The effectiveness of Anthocoris nemorum and A. confusus (Hemiptera: Anthocoridae) as predators of the sycamore aphid, Drepanosiphum platanoides. II. Searching behavior and the incidence of predation in the field. *Entomol. Exp. Appl.* 15: 35-50.
- Dover, M. J., B. A. Croft, S. M. Welch, and R. L. Tummala. 1979. Biological control of Panonychus ulmi (Acarina: Tetranychidae) by Amblyseius fallacis (Acarina: Phytoseiidae) on apple: a predator-prey model. *Environ. Entomol.* 8: 282-292.
- Ehler, L. E. 1977. Natural enemies of cabbage looper on cotton in the San Joaquin Valley. *Hilgardia* 45: 73-106.
- Ehler, L. E., and J. C. Miller. 1978. Biological control in temporary agroecosystems. *Entomophaga* 23: 207-212.
- Ehler, L. E., and R. van den Bosch. 1974. An analysis of the natural biological control of Trichoplusia ni (Lepidoptera: Noctuidae) on cotton in California. *Can. Entomol.* 106: 1067-1073.
- Elliott, W. M., and Way, M. J. 1968. The action of some systemic aphicides on the eggs of Anthocoris nemorum and A. confusum. *Ann. Appl. Biol.* 62: 215-226.
- Evans, H. F. 1976a. The population dynamics of Anthocoris confusus in a laboratory cage ecosystem. *J. Anim. Ecol.* 45: 773-789.
- Evans, H. F. 1976b. The searching behavior of Anthocoris confusus (Reuter) in relation to prey density and plant surface topography. *Ecol. Entomol.* 1: 163-169.

- Everson, P. 1980. The relative activity and functional response of Phytoseiulus persimilis (Acarina: Phytoseiidae) and Tetranychus urticae (Acarina: Tetranychidae): the effect of temperature. *Can. Entomol.* 112: 17-24.
- Force, D. C. 1972. r- and K-strategists in endemic host-parasitoid communities. *Bull. Entomol. Soc. Amer.* 18: 135-137.
- Force, D. C. 1974. Ecology of insect host-parasitoid communities. *Science*, 184: 624-632.
- Fye, R. E. 1980. Weed sources of lygus bugs in the Yakima Valley and Columbia Basin in Washington. *J. Econ. Entomol.* 73: 469-473.
- Garman, H., and H. H. Jewett. 1914. The life history and habits of the corn ear worm. *Ky. Agric. Exp. Stn. Bull.* 187: 511-519.
- Garman, P., and J. F. Townsend. 1939. The European red mite and its control. *Bull. Conn. Agric. Exp. Stn.* No. 418, 34 pp.
- Hassell, M. P. 1971. Mutual interference between searching insect parasites. *J. Anim. Ecol.* 40: 473-486.
- Hassell, M. P. 1978. The dynamics of arthropod predator-prey systems. *Monographs in Population Biology* 13. Princeton Univ., Princeton, NJ. 237 pp.
- Hassell, M. P., and D. J. Rogers. 1972. Insect parasite responses in the development of population models. *J. Anim. Ecol.* 42: 661-676.
- Hassell, M. P., and R. M. May. 1974. Aggregation of predators and insect parasites and its effect on stability. *J. Anim. Ecol.* 45: 135-164.
- Hassell, M. P., J. H. Lawton, and J. R. Beddington. 1976. The components of arthropod predation. I. The prey death rate. *J. Anim. Ecol.* 45: 135-164.
- Hassell, M. P., J. H. Lawton, and J. R. Beddington. 1977. Sigmoid functional responses in invertebrate predators and parasitoids. *Ibid.* 46: 249-262.
- Hassell, M. P., and T. R. E. Southwood. 1978. Foraging strategies of insects. *Ann. Rev. Ecol. Syst.* 9: 75-98.

- Herring, J. L. 1966. The genus Orius of the Western Hemisphere (Hemiptera:Anthocoridae). Ann. Entomol. Soc. Amer. 59: 1093-1109.
- Hildrew, C. W., and C. R. Townsend. 1977. The influence of substrate on the functional response of Plectrocnemia conspersa (Curtis) larvae (Trichoptera:Polycentropodidae). Oecologia (Berl.) 31: 21-26.
- Holdsworth, R. P., Jr. 1968. Integrated control: effect on European red mite and its more important predators. J. Econ. Entomol. 61: 1602-1607.
- Holdsworth, R. P., Jr. 1970. Aphids and aphid enemies: Effect of integrated control in an Ohio apple orchard. J. Econ. Entomol. 63: 530-535.
- Holling, C. S. 1959. Some characteristics of simple types of predation and parasitism. Can. Entomol. 91: 385-398.
- Holling, C. S. 1965. The functional response of predators to prey density and its role in mimicry and population regulation. Mem. Entomol. Soc. Can. 45: 3-60.
- Holling, C. S. 1966. The functional response of invertebrate predators to prey density. Mem. Entomol. Soc. Can. 48: 1-86.
- Horsburgh, R. L. 1979. Reduced pesticide and integrated pest management program for apples. Publ. 830, Ext. Div. VPI & SU, Blacksburg, VA. 15 pp.
- Horsburgh, R. L., and D. Asquith. 1968. Initial survey of arthropod predators of the European red mite in south-central Pennsylvania. J. Econ. Entomol. 61: 1752-1754.
- Horsburgh, R. L., J. P. McCaffrey, M. P. Parrella, and L. F. Ponton. 1980. Apple: Ovicidal effects of Lannate-L, 1979. Insect. Acar. Tests. 5: 17.
- Hoyt, S. C., and L. E. Caltagirone. 1971. The developing programs of integrated control of apples in Washington and peaches in California. p. 421. In Biological Control, C. B. Huffaker, ed. Plenum Press, NY. 511 pp.
- Huffaker, C. B., M. van de Vrie, and J. A. McMurtry. 1970. Ecology of tetranychid mites and their natural enemies: A review. II. Tetranychid populations and their possible control by predators: An evaluation. Hilgardia 40: 391-458.

- Hull, L. A., D. Asquith, and P. D. Mowery. 1977. The functional response of Stethorus punctum to densities of the European red mite. *Environ. Entomol.* 6: 85-90.
- Iglinsky, W., and C. F. Rainwater. 1950. Observations and life history notes on Orius insidiosus (Say), an important natural enemy of the red spider mite, Spoganychus spp., on cotton in Texas. *J. Econ. Entomol.* 43: 567-568.
- Isenhour, D. J. 1977. Seasonal fluctuations of Orius insidiosus (Say) and Thysanoptera in adjacent soybeans and corn in Missouri. M.S. Thesis, University of Missouri, Columbia, MO. 83 pp.
- Isenhour, D. J., and K. W. Yeargan. 1981. Effect of temperature on the development of Orius insidiosus, with notes on laboratory rearing. *Ann. Entomol. Soc. Amer.* (in press).
- Isenhour, D. J., and N. L. Marston. 1981. Seasonal cycles of Orius insidiosus in Missouri soybeans and corn. *J. Kans. Entomol. Soc.* 54: 129-142.
- Jubb, G. L., Jr., E. C. Masteller, and A. G. Wheeler, Jr. 1979. Survey of arthropods in vineyards of Erie County, Pennsylvania: Hemiptera-Heteroptera. *Environ. Entomol.* 8: 982-986.
- Kelton, L. A. 1963. Synopsis of the genus Orius Wolff in America north of Mexico (Heteroptera:Anthocoridae). *Can. Entomol.* 95: 631-636.
- Kelton, L. A. 1978. The insects and arachnids of Canada, Part 4: The Anthocoridae of Canada and Alaska. Biosystematics Research Institute, Ottawa, 101 pp.
- Kramer, P. 1961. Untersuchungen uber den Einfluss einiger Arthropoden auf Raubmilben (Acari). *Z. angew. Zool.* 48: 257-311.
- LeCato, G. L., J. M. Collins, and R. T. Arbogast. 1976. Reduction of residual populations of stored-product insects in a warehouse by Xylocoris flavipes. *J. Kans. Entomol. Soc.* 50: 84-88.
- Lewis, T. 1973. Thrips. Their biology, ecology, and economic importance. Academic Press, London and NY. 349 pp.

- Livdahl, T. P. 1979. Evolution of handling time: the functional response of a predator to the density of sympatric and allopatric strains of a prey. *Evolution* 33: 765-768.
- Lord, F. T. 1949. The influence of spray programs on the fauna of apple orchards in Nova Scotia. III. Mites and their predators. *Can. Entomol.* 81: 217-230.
- MacArthur, R. H., and E. O. Wilson. 1967. The theory of island biogeography. Monographs in Pop. Biol., Princeton Univ. Press, Princeton, NJ.
- MacLellan, C. R. 1963. Predator populations and predation on the codling moth in integrated control orchard--1961. *Mem. Entomol. Soc. Can.* 32: 41-54.
- Madsen, H. F. 1961. Notes on Anthocoris melanocerus Reuter (Hemiptera:Anthocoridae) as a predator of the pear psylla in British Columbia. *Can. Entomol.* 93: 660-662.
- Marshall, G. E. 1930. Some observations on Orius (Triphleps) insidiosus (Say). *J. Kans. Entomol. Soc.* 3: 29-30.
- McCaffrey, J. P. 1978. Spiders associated with apple trees in Virginia with notes on their importance in controlling orchard insect pests. M.S. Thesis. Virginia Polytechnic Institute and State University. 108 pp.
- McCaffrey, J. P., and R. L. Horsburgh. 1980. The spider fauna of apple trees in central Virginia. *Environ. Entomol.* 9: 247-252.
- McMullen, R. D. 1971. Psylla pyricola Foerster, pest psylla (Hemiptera: Psyllidae). Pages 33-38 in Biological control programs against insects and weeds in Canada. Tech. Commun. Commonw. Inst. Biol. Control. Vol. 4.
- McMurtry, J. A., C. B. Huffaker, and M. van de Vrie. 1970. Ecology of tetranychid mites and their natural enemies: a review. I. Tetranychid enemies: their biological characters and the impact of spray practices. *Hilgardia*. 40: 331-390.
- Metcalfe, R. L. 1980. Changing role of insecticides in crop protection. *Ann. Rev. Entomol.* 25: 219-256.

- Meyer, R. H. 1974. Management of phytophagous and predatory mites in Illinois. *Environ. Entomol.* 3: 333-340.
- Murdoch, W. W. 1972. The functional response of predators. Quantitative evaluation of natural enemy effectiveness. 14th Intern. Congr. Entomol. 335-341.
- Murdoch, W. W., and A. Oaten. 1975. Predation and population stability. *Adv. Ecol. Res.* 9:1-131.
- Niemczyk, E. 1978a. Orius minutus (L) (Heteroptera, Anthocoridae): the occurrence in apple orchards, biology, and effect on different food on the development. *Pol. Pismo Entomol.* 48: 203-209.
- Niemczyk, E. 1978b. The role of Orius minutus (L) in controlling the European red mite Panonychus ulmi (Koch) on young apple trees. *Pol. Pismo Entomol.* 48: 211-229.
- Oatman, E. R., E. F. Legner, and R. F. Brooks. 1964. An ecological study of arthropod populations on apple in northeastern Wisconsin: insect species present. *J. Econ. Entomol.* 57: 978-83.
- Office of Technology Assessment. 1979. Pest management strategies. Vol. II--Working papers: Northern deciduous tree-fruits, B. A. Croft, Chairman. 52 pp.
- Parrella, M. P. 1980. Leptothrips mali (Fitch): a potentially important predator in Virginia apple orchards. Ph.D. Dissertation, VPI & SU, Blacksburg, VA. 125 pp.
- Parrella, M. P., J. P. McCaffrey, and R. L. Horsburgh. 1981a. Population trends of selected phytophagous arthropods and predators under different pesticide programs in Virginia apple orchards. *J. Econ. Entomol.* (in press)
- Parrella, M. P., J. P. McCaffrey, and R. L. Horsburgh. 1981b. Compatibility of Leptothrips mali with Stethorus punctum and Orius insidiosus: predators of Panonychus ulmi. *Environ. Entomol.* 9: 696-696.
- Pianka, E. R. 1970. On r- and K-selection. *Amer. Natur.* 104: 592-597.
- Pickett, A. D., N. A. Patterson, H. T. Stultz, and F. T. Lord. 1946. The influence of spray programs on the fauna of apple orchards in Nova Scotia. I. An appraisal of the problem and a method of approach. *Sci. Agr.* 26: 590-600.

- Press, J. W., B. R. Flaherty, and R. T. Arbogast. 1975. Control of the red flour beetle, Tribolium castaneum, in a warehouse by a predaceous bug, Xylocoris flavipes. J. Ga. Entomol. Soc. 10: 76-78.
- Putman, W. L., and D. H. C. Herne. 1966. The role of predators and other biotic agents in regulating the population density of phytophagous mites in Ontario peach orchards. Can. Entomol. 98: 808-820.
- Ravlin, F. W. 1980. Development of management concepts in parasite systems. Ph.D. Dissertation, Michigan State University, East Lansing, MI. 186 pp.
- Rogers, D. J. 1972. Random search and insect population models. J. Anim. Ecol. 41: 369-383.
- Royama, T. 1971. A comparative study of models for predation and parasitism. Res. Pop. Ecol. Suppl. 1: 1-91.
- Ryerson, S. A., and J. D. Stone. 1979. A selected bibliography of two species of Orius: the minute pirate bug, Orius tristicolor, and Orius insidiosus (Heteroptera: Anthocoridae). Bull. Entomol. Soc. Amer. 25: 131-135.
- Salas-Aguilar, J., and L. E. Ehler. 1977. Feeding habits of Orius tristicolor. Ann. Entomol. Soc. Amer. 70: 60-62.
- Shields, E. J., and T. F. Watson. 1980. Searching behavior of female Orius tristicolor. Ann. Entomol. Soc. Amer. 73: 533-535.
- Simpson, H. G., and C. C. Burkhardt. 1960. Biology and evaluation of certain predators of Therioaphis maculate (Buckton). J. Econ. Entomol. 53: 89-94.
- Sokal, R. R., and F. J. Rohlf. 1969. Biometry. The principles and practice of statistics in biological research. W. H. Freeman and Co., San Francisco. 776 pp.
- Solomon, M. E. 1949. The natural control of animal populations. J. Anim. Ecol. 18: 1-35.
- Stubbs, M. 1980. Another look at prey detection by coccinellids. Ecol. Entomol. 5: 179-182.

- Sustare, B. D. 1978. Systems Diagrams. Pages 274-311 in P. W. Colgan, eds. Quantitative Ethology. John Wiley & Sons, NY.
- Thomas, H. A., H. B. Specht, and B. F. Driggers. 1959. Arthropod fauna found during the first season trial of a selective spray schedule in a New Jersey apple orchard. J. Econ. Entomol. 52: 819-821.
- Thompson, D. J. 1978. Towards a realistic predator-prey model: The effect of temperature on the functional response and life history of larvae of the damselfly, Ischnura elegans. J. Anim. Ecol. 47: 757-767.
- van den Bosch, R., and K. S. Hagen. 1966. Predaceous and parasitic arthropods in California cotton fields. Calif. Agric. Exp. Stn. Bull. 820. 32 pp.
- Wheeler, A. G., Jr. 1977. Studies on the arthropod fauna of alfalfa. VII. Predaceous insects. Can. Entomol. 109: 423-427.
- Whitcomb, W. H., and K. Bell. 1964. Predaceous insects, spiders, and mites of Arkansas cotton fields. Ark. Agric. Exp. Stn. Bull. 690. 83 pp.
- Zandstra, B. H., and P. S. Motooka. 1978. Beneficial effects of weeds in pest management--A review. Pans. 24: 333-338.

**The vita has been removed from
the scanned document**

BIONOMICS OF THE ANTHOCORID, ORIU INSIDIOSUS

(SAY) IN VIRGINIA APPLE ORCHARDS

by

Joseph Peter McCaffrey

(ABSTRACT)

The anthocorid, Orius insidiosus (Say) is a common polyphagous predator in Virginia apple orchards, particularly in orchards under reduced pesticide programs. The purpose of this research was to contribute to the basic knowledge of the biology and ecology of O. insidiosus in Virginia orchards and to evaluate the potential for its incorporation into IPM programs currently being developed.

Egg and nymphal development of O. insidiosus was studied at 17°, 23°, 29°, and 35°C. Nymphs were supplied with an excess of the European red mite, Panonychus ulmi (Koch). There was a linear relationship between development rate (1/Days) of O. insidiosus and temperature. Developmental threshold temperatures were calculated as 10.2°C for the eggs; 8.9°, 7.5°, 10.7°, 12.5°, and 9.9°C for nymphal instars 1-5 respectively; and 10.0°C for total nymphal development. Mean degree-days (DD) requirements were 75.8 for eggs; 45.0, 38.0, 27.8, 28.8, and 64.9 for instars 1-5 respectively; 201.7 DD were required for total nymphal development.

Nymphal development was also studied using aphids and pollen as food sources. Mean time (days \pm S.E.) for total nymphal development at 23°C was 19.0 \pm 0.0 with aphids and 20.0 \pm 0.5 with pollen.

As already mentioned, O. insidiosus is a polyphagous predator. Extensive laboratory and field observations established a number of small, soft-bodied insects and mites as well as the eggs of several lepidoptera are acceptable as prey. O. insidiosus also feeds on other beneficial species including predaceous thrips and mites.

O. insidiosus falls prey to a number of other general orchard predators, particularly spiders, chrysopids, and other predaceous Heteroptera.

During 1977-1978, the population dynamics of O. insidiosus along with a complex of predators and pests in orchards under three different pesticide programs was studied. O. insidiosus underwent 2-3 generations per year in Virginia orchards, depending on the availability of prey. Adults overwintered in the orchard, but most migrated into the orchard during May-early June from other areas. O. insidiosus first responded to aphid populations, but as this prey became scarce in late June, O. insidiosus fed on the European red mite whose populations were usually building up at that time. This study indicated that O. insidiosus

responded numerically to increasing mite densities.

Numerous weeds and crops serve as alternate sites for O. insidiosus populations. Corn and alfalfa are often adjacent to orchards in Virginia and apparently serve as a reservoir for O. insidiosus throughout the season. Thistle (Carduus spp.) harbors large numbers of O. insidiosus which prey on thrips. These natural and cultivated alternate sites may be important to the management of O. insidiosus populations.

Since pesticides are an important component of an IPM program for apples, the relative toxicity of 14 compounds (2 rates of each) to adult O. insidiosus was evaluated. Common cover-spray materials, aphicides, miticides, new materials such as synthetic pyrethroids, and fungicides were tested. Generally, O. insidiosus tolerated many of the compounds being considered for use in our developing IPM programs--especially at the lower rates.

The functional response of O. insidiosus to densities of the European red mite was studied at 18.3°, 23.9°, 29.4°, and 35.0°C. Prey densities ranged from 5-80 mites/cage. Mite consumption was recorded during five, three-hour intervals during the day. O. insidiosus did exhibit a functional response and increasing temperatures resulted in

increased feeding at most prey densities. The data provided a good fit to both the type-2 and type-3 functional response models.

The interspecific interactions of 5th instar O. insidiosus and 2nd instar larvae of another mite predator, Leptothrips mali (Fitch) was studied in the laboratory. L. mali is a potential prey for O. insidiosus, but has a defensive anal secretion which repels predator attacks. Most contacts between well fed O. insidiosus and L. mali resulted in mutual avoidance. Most attacks by O. insidiosus were unsuccessful, especially if the approach was from the rear. Contact with the thrips' anal secretion resulted in immediate repelling of O. insidiosus with subsequent cleaning activity lasting 1-3 minutes. This study supports earlier work that indicated these two predators were compatible, especially in the presence of another food source such as the European red mite.