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BIOLOGICAL STUDIES OF TETRANYCHUS CINNABARINUS AND
TYPHLODROMUS OCCIDENTALIS (ACARINA: PHYTOSEIIDAE) AT THREE
DIFFERENT TEMPERATURE REGIMES

The University of Arizona

PH.D. 1984

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BIOLOGICAL STUDIES OF TETRANYCHUS CINNABARINUS AND
TYPHLODROMUS OCCIDENTALIS (ACARINA: PHYTOSEIIDAE)
AT THREE DIFFERENT TEMPERATURE REGIMES

by

Philip Doddridge Northcraft

A Dissertation Submitted to the Faculty of the
DEPARTMENT OF ENTOMOLOGY
In Partial Fulfillment of the Requirements
For the Degree of
DOCTOR OF PHILOSOPHY
In the Graduate College
THE UNIVERSITY OF ARIZONA

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THE UNIVERSITY OF ARIZONA
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As members of the Final Examination Committee, we certify that we have read
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entitled Biological Studies of *Tetranychus cinnabarinus* and
Typhlodromus occidentalis (Acarina: Phytoseiidae) at
Three Different Temperature Regimes

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for the Degree of Ph.D.

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BIOGRAPHICAL SKETCH

Philip Doddridge Northcraft was born in Northampton, Massachusetts, on August 1, 1948, near his home town of Amherst, Massachusetts. He was graduated from Point Loma High School in San Diego, California in 1967.

He attended California Polytechnic State University in San Luis Obispo, California. He received a Bachelor of Science degree in Pomology in 1975, and a Master of Science degree in Agricultural Science, with an interest area in Plant Science in 1977.

In July 1979, he accepted an appointment of Graduate Assistant in Research with the Department of Entomology, The University of Arizona, in Tucson, Arizona. He received a Doctor of Philosophy degree in Entomology in 1984.

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ABSTRACT

Temperature effects on the biology of Tetranychus cinnabarinus (Boisduval) and Typhlodromus occidentalis (Nesbitt) (Acarina: Phytoseiidae) were studied in the laboratory. Temperature had a definite effect on the developmental time, longevity and survival of adult females, and duration and rate of oviposition in both T. occidentalis and T. cinnabarinus. Increases in temperature significantly decrease developmental time, pre-oviposition periods, oviposition duration and rate, and the longevity and survival rates of both adult females. However, the daily consumption rate of T. occidentalis protonymph, deutonymph and adult gravid female increased significantly with an increase in temperature. Mean generation times decreased for both mites with an increase in temperature. The intrinsic rate of natural increase rose with each temperature increase. However, the r_m of T. occidentalis was less than that for T. cinnabarinus at all temperature regimes, and it decreased from the 26.6° C regime to the 30.5° C regime. Of the three temperatures studied, 22.7°, 26.6°, and 30.5° C, 22.7° C proved to be the optimum for the predator to maintain control over the prey.

INTRODUCTION

Conditions which permit economic pests to increase to destructive numbers are of particular interest to agricultural entomologists. Numerous environmental factors interact to cause fluctuations of insect populations in nature. Furthermore, the inherent capacity of a species to increase in number conversely interacts with the numerous environmental factors surrounding it.

"The power to increase in favorable conditions, inherent in all living things, is the mainspring of population dynamics" (Solomon 1957). The carmine spider mite, Tetranychus cinnabarinus (Boisduval), is widely distributed throughout the warmer regions of the world. It is the number one mite pest on cotton in Arizona, and may often appear during the early part of the growing season in southern Arizona (Werner, et al. 1979). However, improper choice of insecticides for other insect problems may induce spider mite population outbreaks which increase to destructive levels within a short period of time. Pesticides used to control insect pests in Arizona, such as carbaryl (Sevin®) and pyrethroids, permethrin (Ambush® or Pounce®) or fenvalerate (Pydrin®), can cause serious spider mite outbreaks by killing predators, by stimulating spider mite reproduction, or by causing dispersal of spider mites which

also may enhance their reproduction. Determining the reproductive and developmental capability of T. cinnabarinus under southern Arizona's desert conditions is needed to evaluate the importance of its destructive potential.

Typhlodromus occidentalis (Nesbitt) is an important natural enemy of several species in the tetranychid family. Recently, it has proven effective in orchards and vineyards of central California against the Pacific and two-spotted spider mites, Tetranychus pacificus (McGregor) and Tetranychus urticae (Koch), respectively (Hoy, et al. 1982). With the emergence of its importance as a natural enemy, T. occidentalis has been investigated for possible resistance to agricultural chemicals (Roush and Plapp 1982). Hoy, et al. (1982) recently selected T. occidentalis as part of a genetic improvement project as a pesticide resistant spider mite predator. T. occidentalis has been found to be resistant to organophosphorus insecticides.

The genus, Galendromus (=Typhlodromus), is by far the most abundant phytoseiid on plants in Arizona (Tuttle and Muma 1973). It is found statewide, at all elevations and during all seasons. Since the genus is so abundant on both agricultural and non-agricultural plants in Arizona, it must be considered as a potentially effective biological control agent. Also, with the continued reliance on insecticides in Arizona and the recent work being done on

the genetic improvement of T. occidentalis for pesticide-resistant strains, there seems to be a future in the role of T. occidentalis as a biological control agent in southern Arizona. However, the biology of T. occidentalis and its potential as a predator of T. cinnabarinus has not been investigated under southern Arizona's unique desert climatic conditions.

This study was concerned with the comparative developmental biologies of T. cinnabarinus and T. occidentalis. The study was also concerned with the elucidation of relevant biological information of each specie in the predator/prey relationship.

Primary objectives included: determining the biology of T. cinnabarinus and its predator, T. occidentalis; elucidating the searching capacity and consumptive rate of T. occidentalis.

LITERATURE REVIEW

Description

Tetranychus cinnabarinus has a confused taxonomic history (Boudreaux and Dosse 1963). It belongs to the Tetranychus telarius complex. T. telarius is the previously used name for T. cinnabarinus. T. telarius was sometimes used for a green form. It is now known as Tetranychus urticae (Koch). T. telarius was also sometimes used for a red form, which is now known as T. cinnabarinus.

The carmine spider mite, T. cinnabarinus (Boisduval), has been designated a separate specie from the two-spotted spider mite, T. urticae (Koch), because of differences in morphology, habits, host preferences, geographic distribution, and crossbreeding results (Smith and Baker 1968). Boudreaux and Dosse (1963) observed that the variations in cuticular lobes of the females could be used in separating species. Kono and Papp (1977) noted that this discovery showed that T. cinnabarinus, which had been placed in synonymy with the two-spotted mite, was, in fact, a valid specie.

The carmine mite belongs to the family Tetranychidae which has undergone considerable change. The group was given the suprageneric name, Tetranychides, by Donnadieu and raised

to family status by Murray in 1877 (Jeppson, et al. 1975). Tuttle and Baker (1968) reviewed the family extensively.

The body of the female T. cinnabarinus contains dark lateral internal markings and is carmine in color. The red phase is the prevalent form for overwintering females in Arizona (Werner, et al. 1979). Migrating forms during the summer months are also red. The female is oval and about 510 microns in length. The male is slender, diamond shaped, and about 370 microns long. The aedeagus has an extremely small and nearly evenly shaped distal knob; some variation in the shape of the anterior angle of the knob may occur.

Biology of Tetranychus cinnabarinus

Life History

T. cinnabarinus is mainly a pest of low-growing plants in semitropical areas of the world. It is a major pest of cotton and is the number one mite pest on cotton in Arizona (Werner, et al 1979). The carmine mite appears to thrive in areas where climatic conditions are most suitable for the production of cotton. The mite remains on its host plant and does not enter into diapause during the winter. Warm weather during the winter months may stimulate activity, feeding, and egg production.

Eggs. The eggs of the carmine spider mite are deposited singly and usually on the undersurfaces of the

leaves or they may be attached to the fibrils of the webbing. Newly oviposited eggs are spherical, colorless, and clear. However, they become opaque as they develop. Hazan, et al. (1974) reported that at 30° C the eggs of T. cinna-
barinus hatched after 5.2 days at 100% RH and, after 3.0 days, at 63% RH. No hatching occurred at 24° C and 100% RH. Harrison and Smith (1961) discovered that the egg incubation period of T. urticae at 25° C was affected by relative humidity; at 90% it was 4.2 days and at 98%, 7.0 days with no eggs hatching at 100% RH. Shih, et al. (1975) reported that the minimum incubation time was four days for the two-spotted mite, T. urticae, held at 22.8° C.

Larva. The larval stage of the carmine mite is very inactive. Consequently, this is a critical stage in the life cycle of this mite. Larvae emerging from eggs deposited on webbing may be unable to reach a suitable food supply. Hazan, et al. (1974) reported that larval developmental rates were affected very little by the relative humidities at any given temperature, except for prolonged periods at very high humidities. However, the survival of the larvae was greatly affected by the prevalent relative humidity. Laing (1969a) found that the larval stage of T. urticae averaged 3.7 days of 20.3° C.

Protonymph. The protonymph is more active than the larva. The duration of this stage is generally shorter than

that of the other active stages. Hazan, et al (1974) reported that the protonymph usually suffers less mortality than the other stages. Laing (1969a) observed that the average duration of the protonymphal stage of T. urticae for 22 males was 2.7 days and for 26 females was 3.0 days. Hazan, et al. (1974) noted that the average duration of the protonymphal stage of T. cinnabarinus at 30° C was 5.1 days at 63% RH.

Deutonymph. The deutonymphal stage is the longest period among the developmental stages of the mite. Hazan, et al. (1974) reported that this stage was the most sensitive one to 30° C and 100% RH. The deutonymphal stage of T. cinnabarinus at 63% RH and 30° C had a duration of 1.2 days. Laing (1969a) observed that the deutonymphal stage of T. urticae females was 3.5 days at 20° C. The deutonymphs also spent nearly one-half of their time in a quiescent state prior to molting to the adult stage.

Adult. Laing (1969a) reported that the preovipositional period of T. urticae averaged 2.1 days at 20° C with a range of 1.0 to 5.2 days. Iglinsky and Rainwater (1954) observed that Tetranychus bimaculatus developed from hatching of the egg to adult in 6.6 days at 31.1° C. Hazan, et al. (1974) concluded that the developmental duration from egg to adult was affected mainly by temperature, with relative humidity playing a minor part.

Davis (1961) stated that 32° C and low humidities were optimal for the development of Tetranychus multisetis. The fastest development occurred at 35° C and under dry conditions. Hazan, et al. (1974) found the optimal conditions for T. cinnabarinus that produced the highest R_0 were at 24° C and 38% RH. Jeppson, et al. (1975) reported that the optimum temperature for development of T. cinnabarinus is about 32° C. However, the carmine spider mite is able to reproduce at temperatures well above 35° C, if exposed for limited periods of time.

Importance of Typhlodromus occidentalis as a Predator

Spider mites are quickly becoming a worldwide problem. Many factors interact to affect the abundance of tetranychid mites: (1) features of the life cycle; (2) meteorological conditions; (3) the nutrition afforded by the host plant; (4) action of enemies, particularly predators; and, (5) the horticultural programs, including use of chemicals and resistance to them (Huffaker, et al. 1969). Gunther and Jeppson (1960) stated that the extensive use of organic pesticides could be attributed to the worldwide increase in tetranychids.

Huffaker and Flaherty (1966) reported their conclusions as to why the post-World War II tetranychid outbreaks occurred. These are:

1) Plant-feeding mites in natural areas untreated with chemicals or uninfluenced by man, dust, etc., seldom extensively damage their hosts. 2) These mites, though injurious at times, before the introduction of DDT and other synthetic materials, were not as perennially severe as they became after extensive use of these materials.

Mites of the family Phytoseiidae have been reported to occur throughout the world. The first-published notes concerning the possible value of phytoseiids in the control of phytophagous mites were by Parrot, Hodleiss and Schoene (McMurtry, et al. 1970). Recently T. occidentalis has been investigated for its effectiveness as a predator of tetranychid spider mites (Huffaker, et al. 1969, Laing 1969b, Flaherty and Huffaker 1970, McMurtry, et al. 1970, Laing and Osborne 1974, and Hoy, et al. 1982). The use of dimethoate, methomyl, carbaryl and other chemicals induced spider mite outbreaks in apples, almonds, and grapes in the San Joaquin Valley, California, and in the state of Washington (Hoyt, 1969, Hoy, et al. 1979a, Hoy, et al. 1979b, Roush and Plapp 1982). Consequently, research is being conducted into the genetics of resistance to insecticides in T. occidentalis (Hoy, et al. 1979a, Roush and Plapp 1982).

Predatory mites of the Phytoseiid family occur on a wide variety of plants in Arizona. Phytoseiids are also known to be associated with and feed upon injurious plant-feeding mites in Arizona. However, Typhlodromus occidentalis

(Nesbitt) has not been identified in Arizona (Tuttle and Muma 1973). It is the Phytoseiid most commonly associated with spider mites in apple orchards of northern Utah (Lee and Davis 1968) and Hoyt and Caltagirone (1970) have reported it as an integral part of the pest management programs in orchards in the state of Washington. Hoy, et al. (1982) worked with T. occidentalis most recently in large scale releases of pesticide-resistant mites in almond orchards in the San Joaquin Valley, California. T. occidentalis is an important natural enemy of T. urticae in strawberry fields in southern California (Oatman, et al. 1977) and in apple orchards in southern Africa (Pringle 1975).

Biology of *Typhlodromus occidentalis*

No studies on the biology of Phytoseiids under southern Arizona climatic conditions have been reported in the literature and few studies have been reported at all. Chant (1959) observed the bionomics of seven species in southeastern England. He used systemic dyes to determine that *Typhlodromus pyri* (Scheuten) and *Typhlodromus findlandicus* (Oudemans) fed on leaves of apple, blackberry and black currant, and that *T. pyri* completed its life cycle on apple powdery mildew, *Podosphaera leucotricha* (Solms). Chant (1959) concluded that pollen may be used as a food source in the early season and enable females to lay eggs before other

types of food are available. Laing (1969b) placed various stages of T. occidentalis in isolated cells with only strawberry pollen as a source of nourishment. He reported that the individuals were never observed to feed on the pollen. Huffaker and Kennett (1953) reported that Typhlodromus reticulatus (Oudms) and T. occidentalis (Nesbitt) were observed to feed on honeydew, sugar solution, and egg yolk. However, they could not rear them in the absence of tarsonemid prey. Klostermeyer (1959) reported that Typhlodromus cucumeris could be reared almost totally without the two-spotted spider mite, indicating that T. cucumeris is a general predator and not dependent on the two-spotted spider mite for food.

Herbert (1956) reported that Typhlodromus tiliae (Oudms) female adults consumed 40 T. bimaculatus eggs per day. Ballard (1953) observed deutonymphs, protonymphs, and larvae of Typhlodromus fallacis consume 3.9, 6.6, and 4.8 T. bimaculatus males per day, respectively. He reported that mated female T. fallacis consumed 8 T. bimaculatus males per day.

Putnam (1962) studied the life history of Typhlodromus caudiglans at constant temperatures of 76.7° and 58.6° F. Herbert (1956) conducted similar studies of T. tiliae at 50°, 60° and 70° F, and reported that incubation time differed from 21.6 days at 50° to 4.8 days at 70° F. Ballard (1953) conducted studies of Typhlodromus fallacis at

78° F, and reported that T. fallacis laid 2.2 eggs per day.

Waters (1955) reported that T. occidentalis took 4.8 days to develop from egg to adult at 28° C. Immature individuals during this time consumed an average of 16.1 eggs of the six-spotted mite, Eotetranychus sexmaculatus (Riley). Lee and Davis (1968) concluded that the immature stage of T. occidentalis required 6.3 days at 23.9° C. Sharma (1966) reported that the immature stages of T. occidentalis at 25.6° C consumed 24 T. urticae eggs and took 13 days to develop.

Laing (1969b) reported T. occidentalis had a preovipositional period of 3.2 days. Lee and Davis (1968) observed a preovipositional period of 1.3 days for T. occidentalis. Waters (1955) found that mated females lived an average of 31 days and consumed 6.1 eggs of E. sexmaculatus per day and laid 2.1 eggs per day for 13.5 days. Laing (1969b) observed that T. occidentalis females lived for 20.2 days, ate an average of 8.5 prey eggs per day, and oviposited 2.2 eggs per day for 15.9 days. Lee and Davis (1968) reported that adult females lived an average of 38.7 days and laid 1.1 eggs per day for 30.6 days at 23.9° C.

The mean generation time (T) reported by Laing (1969b) for T. occidentalis was 17.43 days at 20.3° C. A population increase of 24.3 times ($R_0 = 24.3$) would occur during the mean generation time. The intrinsic rate of increase (r_m) for T. occidentalis at 20.3° C was 0.183.

METHODS AND MATERIALS

This study was conducted at the University of Arizona, Campus Agricultural Center, Department of Entomology Research Laboratory. Research was begun in the fall of 1980 and completed in the spring of 1983.

Four colonies of Tetranychus cinnabarinus were obtained from various greenhouses and fields surrounding the laboratory. Specimens were identified by Dr. D. M. Tuttle, Department of Entomology, University of Arizona, Yuma Valley Agricultural Center, Yuma, Arizona. A colony of Typhlodromus occidentalis was obtained from Mr. Walter White at the University of California, Riverside.

Rearing Host Plants

One lot of baby lima bean, Phaseolus vulgaris, seeds was obtained from the University of California at Davis. It was in sufficient quantity to ensure uniformity in all test plants throughout the course of these studies. A modified procedure was adapted from Tahori and Raccah (1970) for rearing host plants. Host plants were grown in pest-free greenhouses.

Soil was screened through quarter-inch mesh screen and sterilized. It was then mixed with 1/3 peat and 1/3

vermiculite. The 45.70 cm X 91.40 cm flats were planted with four rows of 15 seeds each and watered. A 16-8-8 fertilizer was mixed into the soil after four to six weeks. Three flats of beans were planted at 10 to 14 day intervals. This helped to provide a constant supply of leaves of the desired size and age for use in petri-dish cultures for the study.

Primary leaves were frequently used for the mite colonies in petri-dish cultures. Usually the terminal bud was excised to limit plant growth to primary leaves which lasted up to 10 days in petri-dish culture.

Rearing of *Tetranychus cinnabarinus*
and *Typhlodromus occidentalis*

Two procedures of maintaining mite populations were used in this research. A distinction is made between the two to aid in the discussion of the methods used in the research. Culture represents individuals or small groups which were obtained from colonies and maintained under an experimental condition. The term colony is used to denote mites originating from a common or singular source. These populations were maintained at fluctuating levels throughout the investigations. These mites served as the stock or source material.

T. cinnabarinus was reared in a greenhouse to serve as prey for T. occidentalis. At seven to 10 day intervals new colonies of the host mite were started in the laboratory

from the greenhouse source in order to provide prey in all stages of development. The basic rearing procedures were adapted from Chant (1961). These colonies were prepared by floating a trimmed bean leaf on water in a petri-dish. New colonies were also started by placing bean leaves on sterile cotton that was saturated with tap water in a petri-dish. Gravid female spider mites were placed on the leaf with a No. 00 camel's hair brush. These methods for rearing host mites proved successful. Bean leaves lasted up to two weeks with watering as necessary. The water and saturated cotton was also very effective in keeping tests and cultures uncontaminated.

Colonies of T. occidentalis were also established by using the petri-dish bean leaf method. Twenty-five to 50 gravid tetranychid females were placed on a bean leaf with five to 10 gravid typhlodromid females. A second method consisted of placing 20 to 25 gravid tetranychid females on a bean leaf and allowing them to oviposit for 48 to 72 hours before introducing five gravid typhlodromid females. Stock colonies of the predator were started at about seven-day intervals.

Stock colonies of both the phytophagous and predaceous mites were reared in environators in the laboratory. The environators were programmed for fluctuating cycles with average temperatures of 22.7° and 26.6° C. The

colonies were placed beneath 20-watt daylight General Electric fluorescent lamps for a 12-hour light period, followed by 12 hours of darkness.

The predaceous stock colonies lasted 10 to 14 days. Periodic culling, adding, and subtracting both mite species were done to ensure the desired number of predaceous and host mites in all stages for future tests. In about eight to 10 days at 26.6° C maximum production of progeny was reached. If the leaf's food value was exhausted and its general condition was deteriorating, the predaceous mites that were needed at the time were removed from the leaf. The leaf, plus the remaining typhlodromid mites, were recycled in the greenhouse, where it was placed on a bean plant with a heavy population of host mites. Three greenhouses were used to rear pest-free plants, bean plants with prey and plants with both predator and prey, respectively.

Tetranychus cinnabarinus Biology

Life cycle investigations were conducted in the laboratory on T. cinnabarinus. Fluctuating cyclic temperatures used in the studies were selected to correspond with the average temperatures occurring in the Yuma, Arizona area during April, May and June. The temperature cabinets were modified refrigerators with a Partlow single-switch, cam programmed recording temperature controller. General

Electric daylight 20-watt F20+12D fluorescent tubes were used in the refrigerator. Light regimes were 12 hours daylight and 12 hours night.

The temperatures that corresponded to these three months were recorded at the University of Arizona, Yuma Valley Agricultural Center, Yuma, Arizona. The fluctuating temperatures corresponding to the low, medium and high temperature periods averaged 22.7°, 26.6°, and 30.5° C, and fluctuated from 15.0-30.0°, 19.4-33.6°, and 23.1-38.6° C, respectively. The relative humidity ranged from 50 to 95%. All studies conducted on the biology to T. cinnabarinus and T. occidentalis unless otherwise stated were conducted at these temperatures (Table 1).

Petri-dishes were prepared and bean leaves of proper size and age were collected from the greenhouse, placed in a petri-dish and infested with 25 gravid spider mites. Mites were allowed to oviposit for eight to 12 hours. Observations were made every 24 hours until the eggs hatched. Daily observations were continued to determine the duration of all immature stages. When female mites reached maturity, two males per female were placed on the leaf.

The effect of temperature on adult female longevity was studied under conditions and in a manner similar to the life cycle studies. Petri-dishes and leaves were prepared. Newly-emerged females were provided with two adult males

Table 1. Summary of Environmental Conditions for Experimental Temperature Regimes.

| Mean Tempera- ture °C | Temperature Range °C | Temperature Readings | | | | Relative Humidity (%) |
|--------------------------------|-------------------------|-------------------------|------|----|------|-----------------------------|
| | | PM | | AM | | |
| 22.7 | 15.0-30.0 | 12 | 27.7 | 12 | 18.6 | 60-95 |
| | | 3 | 30.0 | 3 | 16.6 | |
| | | 6 | 17.7 | 6 | 15.0 | |
| | | 9 | 22.7 | 9 | 22.2 | |
| 26.6 | 19.4-33.6 | 12 | 31.4 | 12 | 22.2 | 55-95 |
| | | 3 | 33.6 | 3 | 20.0 | |
| | | 6 | 31.9 | 6 | 19.4 | |
| | | 9 | 25.8 | 9 | 26.6 | |
| 30.5 | 23.1-38.6 | 12 | 35.3 | 12 | 25.5 | 50-90 |
| | | 3 | 38.6 | 3 | 24.2 | |
| | | 6 | 36.1 | 6 | 23.1 | |
| | | 9 | 29.7 | 9 | 24.2 | |

which were selected from stock colonies and placed on each leaf. When females began ovipositing, males were removed. Progeny were removed daily and observations continued until the death of the females occurred.

The effect of temperature on rate and duration of oviposition was studied. Cultures prepared for studying the effect of temperature on the longevity of the adult female also provided data. In addition, more individuals were used to obtain data on the rate of oviposition. The number of eggs that T. cinnabarinus produced was observed and recorded daily.

Typhlodromus occidentalis Biology

Life-cycle and all other investigations were made under the same conditions and in similar fashion as with T. cinnabarinus. Mite cultures of single adult females on 5.1 cm² leaf discs were established. The females were fed only T. cinnabarinus eggs to determine the consumptive capacity of individual female mites. Egg consumption was determined by counting the number of eggs remaining after a 24-hour period. Twenty host eggs were placed on the leaf discs at all three temperature regimes. Typhlodromid eggs were removed daily.

Starvation data were obtained by placing and observing gravid female predaceous mites. The only food source was the bean leaf. Observations were made daily to

determine the time required for starvation to occur.

Daily consumption of host eggs by T. occidentalis deutonymphs was studied by placing 15 eggs on a 5.1 cm² bean leaf disc. Counts were made 24 hours later. The number consumed was calculated from the number that was left uneaten. The unconsumed eggs were removed and replaced daily with fresh eggs.

Egg consumption by protonymphs of T. occidentalis was studied in the same manner as mentioned above for deutonymphs. Fifteen fresh host eggs were offered daily from the stock colonies.

Temperature Effect on Predation of Typhlodromus occidentalis

The effect of temperature on predation of T. cinnabarinus eggs by all stages of T. occidentalis was studied at 22.7°, 26.6°, and 30.5° C. The predatory stages were selected from the stock colonies daily.

Temperatures were maintained by the Partlow temperature controller in the environators previously described. The study was conducted in a day-night regime of 12:12. Individuals were observed at 24-hour intervals. The performance of each predatory stage was observed at the temperatures mentioned above.

Cultures were started to investigate predator/prey ratios by placing one T. cinnabarinus gravid female mite on

bean leaves in petri-dishes. They were allowed to oviposit for 24 hours. Then one, two, four, or 10 T. occidentalis gravid female mites were introduced into each culture. These cultures were observed daily until all T. cinnabarinus were destroyed.

Cultures were then started on whole bean plants. T. cinnabarinus gravid females were allowed to establish themselves for 24 hours on the plant before T. occidentalis was introduced. Only the 1:10 ratio was used. Total counts were made at the end of seven, 14, 21, and 28 days with the aid of a binocular microscope.

Consumption and Searching

Once the proper size leaf had been grown, a 5.1 cm² leaf-disc punch was used to cut leaf discs. The discs were then placed on water in petri-dishes. Host eggs were placed on the leaf discs to determine consumptive rates of each stage of the predator.

Upon determining the average consumptive rate of the predator at the three different temperature regimes, one egg was subtracted from the mean. Eggs were placed in the center of a 5.1 cm² leaf disc in order to help determine the searching capacity. In order to increase the complexity of the search, eggs were moved away from one another toward the edge of the disc. The final test was the placement of the

eggs at the edge of the disc.

Trifoliate leaves were used to further increase the complexity of the search. Eggs were placed on the three leaflets and the female predator was placed on the stem. The stem was cut so that it rose 2.54 cm above the water in a petri-dish. The trifoliates were floated face down. All tests were conducted at the three temperature regimes.

A study to determine a predator/prey ratio which would not annihilate either population was initiated in January, 1983. Two hundred and fifty lima bean plants were grown in 15.00 cm pots. The plants were grown to the three trifoliate stage. Gravid female T. cinnabarinus mites were placed on each host plant with a No. 00 camel's hair brush. The host mite was allowed to establish itself for 24 hours before the predatory mite was introduced. Ratios of 0:10, 1:5, 1:10, and 1:20 were chosen.

The infested plants were placed in a greenhouse which had been lightly white-washed; one-half of the plants were placed on the west side and the other half was placed on the east side. A hygrothermograph was also placed in the greenhouse to record temperature and humidity. Each infested plant was surrounded with four pest-free plants at the same stage of growth. Each plant was placed to allow the free movement of both predator and prey among the five plants. Each treatment (ratio) was replicated four times. Around

each treatment (five plants) additional buffer plants were placed to slow any movement of mites from treatment to treatment. Treatments were placed in a randomized block design.

One trifoliolate per plant per week was taken randomly from each five plants per treatment. Counts of all stages of predator and prey were made with the aid of a binocular microscope. After the counts were made, the trifoliolate was placed back on the plant as close as possible to the original area from which it was removed.

Calculations

The mean and standard deviation were calculated for consumption, fecundity and longevity for each temperature regime for both T. occidentalis and T. cinnabarinus. Analysis of variance was also performed on these data after they were grouped within each category. Data that were determined to be significant were further analyzed by the Least Significant Difference (LSD) technique. All analyses were performed at the 95% level of confidence. Procedures were followed according to Little and Hills (1978).

Life Table Calculations

Life tables have been used extensively in the field of life insurance to ascertain the probability of death (Harcourt, 1969). The rate at which insect populations will increase is one of the ultimate objectives in studying the

biology of insect pests (Howe 1953).

The accepted basic ecological parameter for this is the intrinsic rate of increase (r_m). Andrewartha and Birch (1954) described r_m as the actual rate of increase of a population under specified constant environmental conditions, in which space and food supply are unlimited and other animals of different species are being excluded. Under defined environmental conditions, this rate may be calculated from the age-specific fecundity and survival rates. The statistic r_m is calculated by the equation:

$$\sum e^{-r_m x} l_x m_x = 1$$

in which x equals the pivotal age group, l_x equals the probability of survival to age x , and m_x equals the number of female offspring produced at age x (Appendices A-F).

The mean generation time (T) is the time it takes for a generation to occur under specified conditions. T is calculated by the equation:

$$T = \frac{\log_e R_0}{r_m}$$

The net reproductive rate (R_0) is the factor by which a population will multiply per generation. R_0 is calculated

by the equation:

$$R_0 = \sum l_x m_x$$

Birch (1948) discusses a method for calculating the intrinsic rate of increase. Andrewartha and Birch (1954) discuss the use of life tables. Watson (1964) and Southwood (1966) also describe the construction of life tables and calculations of intrinsic rate of natural increase.

RESULTS AND DISCUSSION

Biology Studies

Temperature Effect on the Life Cycle

Increases in temperature had a direct influence on the length of the life cycles of Typhlodromus occidentalis and Tetranychus cinnabarinus. Table 3 summarizes the average length of time for each immature stage of T. occidentalis. The duration of each immature stage was shortened as the temperature was increased.

These data agree with those of Smith (1965), who reared Typhlodromus fallacis. He reported the T. fallacis had a developmental period of 7.3 days at 21.1° C. Lee and Davis (1968) observed that, at 23.8° C, T. occidentalis developed from egg to adult in 6.3 days. Laing (1969b) reported that T. occidentalis' developmental period lasted 8.7 days at 20.3° C. Putnam (1962) reported that Typhlodromus caudiglans had developmental periods of 33.4 and 6.7 days at 14.7° and 24.8° C, respectively. Waters (1955) found that developmental time, from egg to adult, for T. occidentalis, averaged 4.8 days at 28° C. Sharma (1966) observed that it took about 13 days for the immature stage of T. occidentalis to develop at 25.6° C.

Table 2. Temperature Effects on the Life Cycle of T. cinnabarinus.

| Temperature °C Range | X | Number Observed | Average Number of Days Each Stage | | | | Total |
|-------------------------|------|--------------------|-----------------------------------|------------|------------|------------|-------|
| | | | Egg | Larva | Protonymph | Deutonymph | |
| 15.0-30.0 | 22.7 | 38 | 6.95 ± .81 | 1.16 ± .56 | 1.22 ± .25 | 2.7 ± .34 | 12.07 |
| 19.4-33.6 | 26.6 | 38 | 3.6 ± .69 | .87 ± .49 | .95 ± .28 | 2.13 ± .30 | 7.55 |
| 23.1-38.6 | 30.5 | 38 | 2.51 ± .67 | .70 ± .25 | .69 ± .27 | 1.38 ± .37 | 5.28 |

Table 3. Temperature Effects on the Life Cycle of T. occidentalis.

| Temperature °C Range | X | Number Observed | Average Number of Days Each Stage | | | | Total |
|-------------------------|------|--------------------|-----------------------------------|------------|------------|------------|-------|
| | | | Egg | Larva | Protonymph | Deutonymph | |
| 15.0-30.0 | 22.7 | 38 | 4.21 ± .38 | 1.13 ± .33 | 1.26 ± .25 | 1.3 ± .36 | 7.9 |
| 19.4-33.6 | 26.6 | 38 | 2.22 ± .38 | .74 ± .25 | .97 ± .54 | .99 ± .27 | 4.92 |
| 23.1-38.6 | 30.5 | 38 | 1.7 ± .52 | .62 ± .22 | .77 ± .50 | .77 ± .24 | 3.92 |

The largest difference in the completion of immature stages at different temperature regimes was observed between the 22.7° and the 26.6° C regimes. At the 22.7° C temperature, 7.9 days were required to complete the immature stages, while at 26.6° C, only 4.9 days were required. However, at 30.5° C, the time required to complete the immature stages was decreased by only one day to 3.92 days. This indicates that a threshold temperature may have been reached, possibly affecting some component of its metabolic rate.

Increases in temperature also had a direct influence on the duration of the life cycle of T. cinnabarinus. Again, as the temperature increased, the duration of each immature stage was shortened. Table 2 summarizes the average length of time for each immature stage of T. cinnabarinus.

These data tend to agree with those of Carey and Bradley (1982), who reared Tetranychus urticae, Tetranychus turkestanii, and Tetranychus pacificus on cotton plants. They observed a definite trend in which an increase in temperature caused a decrease in the duration of the immature stage. Laing (1969a) reported that, at 20.3° C, developmental time for the immature stages of T. urticae was 6.7 days. Hazan, et al. (1974) observed that T. cinnabarinus at 30° C, took 7.7 days and at 24° C, took 11.5 days to complete the life cycle.

The total days required to complete the immature stages again was reduced by the largest number of days between 22.7° and 26.6° C. T. cinnabarinus completed its immature stages in 12.07 days at 22.7° C and 7.55 days at 26.6° C.

Temperature Effect on Adult Female Longevity

Table 4 summarizes the data showing the effect of temperature on adult female longevity of T. cinnabarinus. Mean longevity ranged from 25.8 ± 6.75 days at the 22.7° C regime to 15.89 ± 3.76 days at the 30.5° regime. Reduction in longevity was highly significant between these temperature regimes. The results showed a definite trend for a decrease in longevity of the adult female with each increase in temperature.

These data agree with those of Hazan, et al. (1974). They showed that T. cinnabarinus adult female longevity tended to decrease with an increase in temperature. Carey and Bradley (1982) reported that T. urticae adult females' longevity was 14.71 days at 23.86° C and 9.71 days at 29.4° C.

Table 5 summarizes the effect of temperature on mean longevity of adult female T. occidentalis. Mean longevity ranged from 30.8 days at 22.7° C to 19.5 days at the 30.5° C regime. Reduction in longevity was highly significant only

Table 4. Temperature Effects on Adult Female Longevity of T. cinnabarinus.

| Temperature °C | | Number Observed | Longevity in Days | | LSD ($\alpha=0.01$) |
|----------------|-----------|-----------------|-------------------|---------|-----------------------|
| Range | \bar{X} | | Average | Range | |
| 15.0-30.0 | 22.7 | 81 | 25.8 ± 6.75 | 13 - 45 | A |
| 19.4-33.6 | 26.6 | 105 | 18.87 ± 4.24 | 11 - 29 | B |
| 23.1-38.6 | 30.5 | 94 | 15.84 ± 3.76 | 10 - 27 | C |

Table 5. Temperature Effects on Adult Female Longevity of T. occidentalis.

| Temperature °C | | Number Observed | Longevity in Days | | LSD ($\alpha=0.01$) |
|----------------|-----------|-----------------|-------------------|---------|-----------------------|
| Range | \bar{X} | | Average | Range | |
| 15.0-30.0 | 22.7 | 42 | 30.8 ± 19.66 | 14 - 52 | A |
| 19.4-33.6 | 26.6 | 47 | 23.0 ± 14.55 | 10 - 46 | B |
| 23.1-38.6 | 30.5 | 37 | 19.5 ± 7.5 | 9 - 40 | B |

at the 22.7° C temperature regime. The results indicated, however, a definite trend of decreased longevity of adult female T. occidentalis with each increase in temperature.

These data agree with Smith (1965), who worked with T. fallacis. He also reported that an increase in temperature had a highly significant effect on the longevity of adult female mites held at three different temperatures. Laing (1969b) reported that the average longevity of an adult female T. occidentalis was 20 days at 20.3° C and Sharma (1966) observed that T. occidentalis females lived an average of 17.7 days at 25.6° C. These data tend to support the findings of this study.

Survival curves for female adults at the three temperature regimes are shown in Figures 1 through 8. The 30.5° C temperature regime caused 50% mortality by the 17th day in the T. occidentalis population. The 50% mortality level was reached only two days earlier in the T. cinnabarinus population at 30.5° C. At 26.6° and 22.7° C, 50% of the T. cinnabarinus population survived for 18 and 25 days, respectively. However, 50% of the predatory mites survived until the 22nd day at 26.6° and to the 32nd day at 22.7° C. These results are similar to those of Hazan, et al. (1974).

These data suggest that, as the temperature increased, the difference between the mites' survivorship rates was neutralized. It is important to note, therefore,

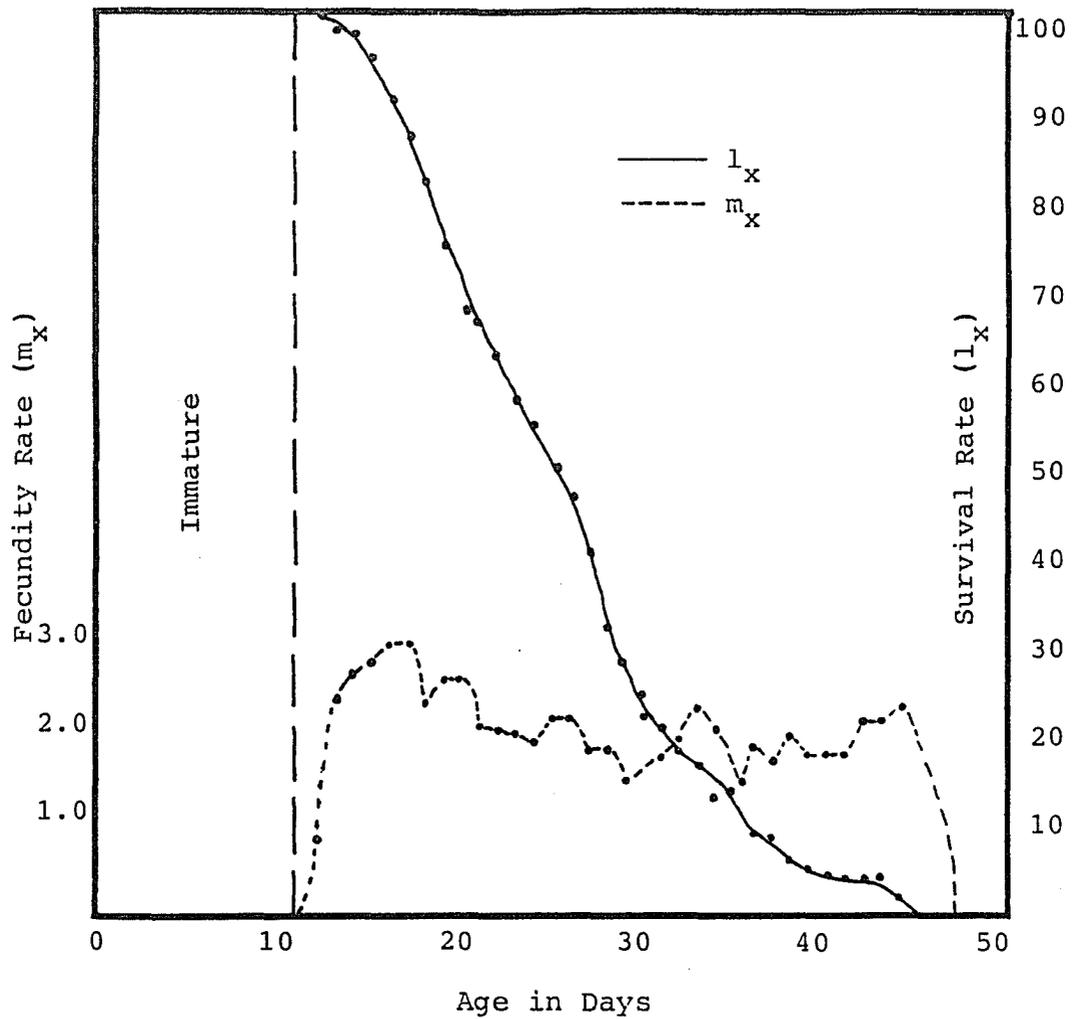


Figure 1. Survival and Age-specific Fecundity Curves for *T. cinnabarinus* Female Adults at 22.7° C.

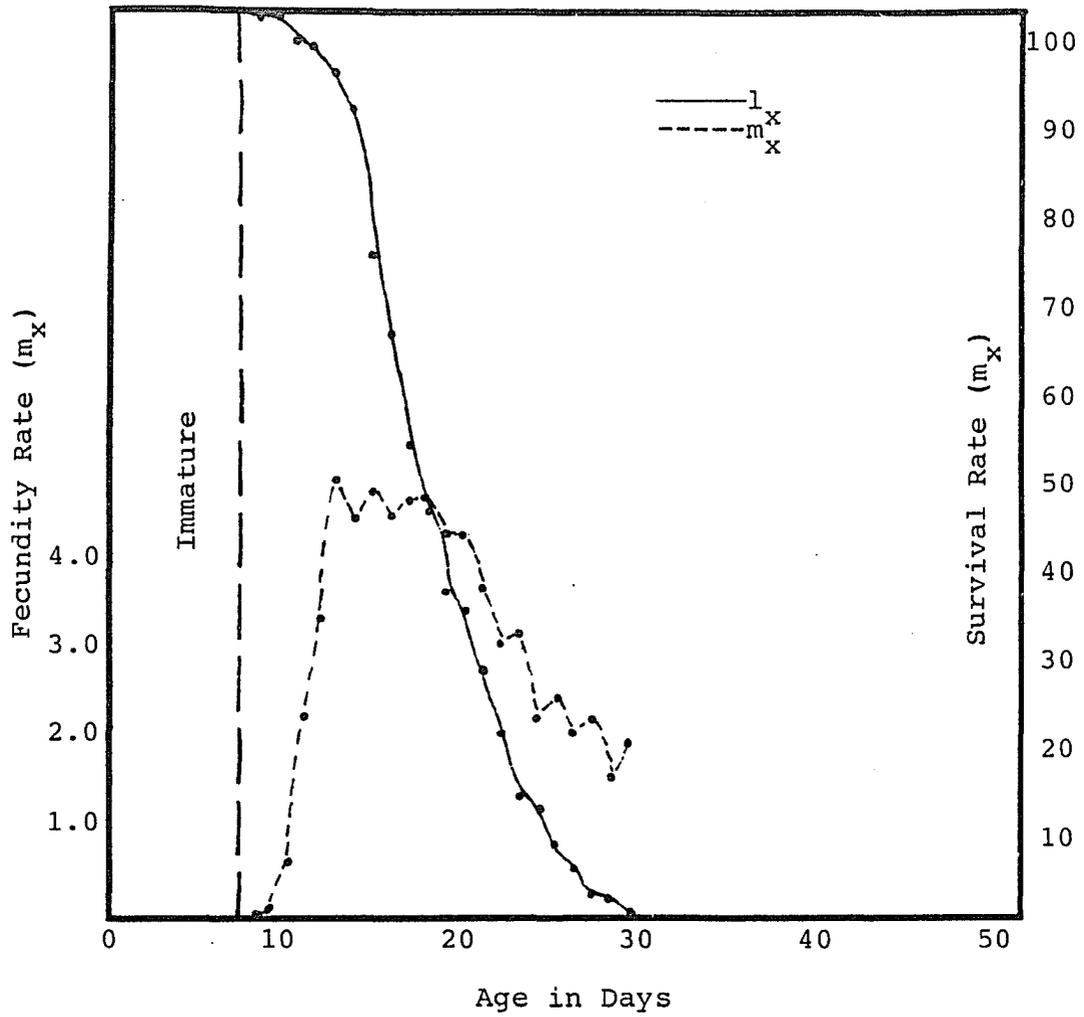


Figure 2. Survival and Age-specific Fecundity Curves for *T. cinnabarinus* Female Adults at 26.6° C.

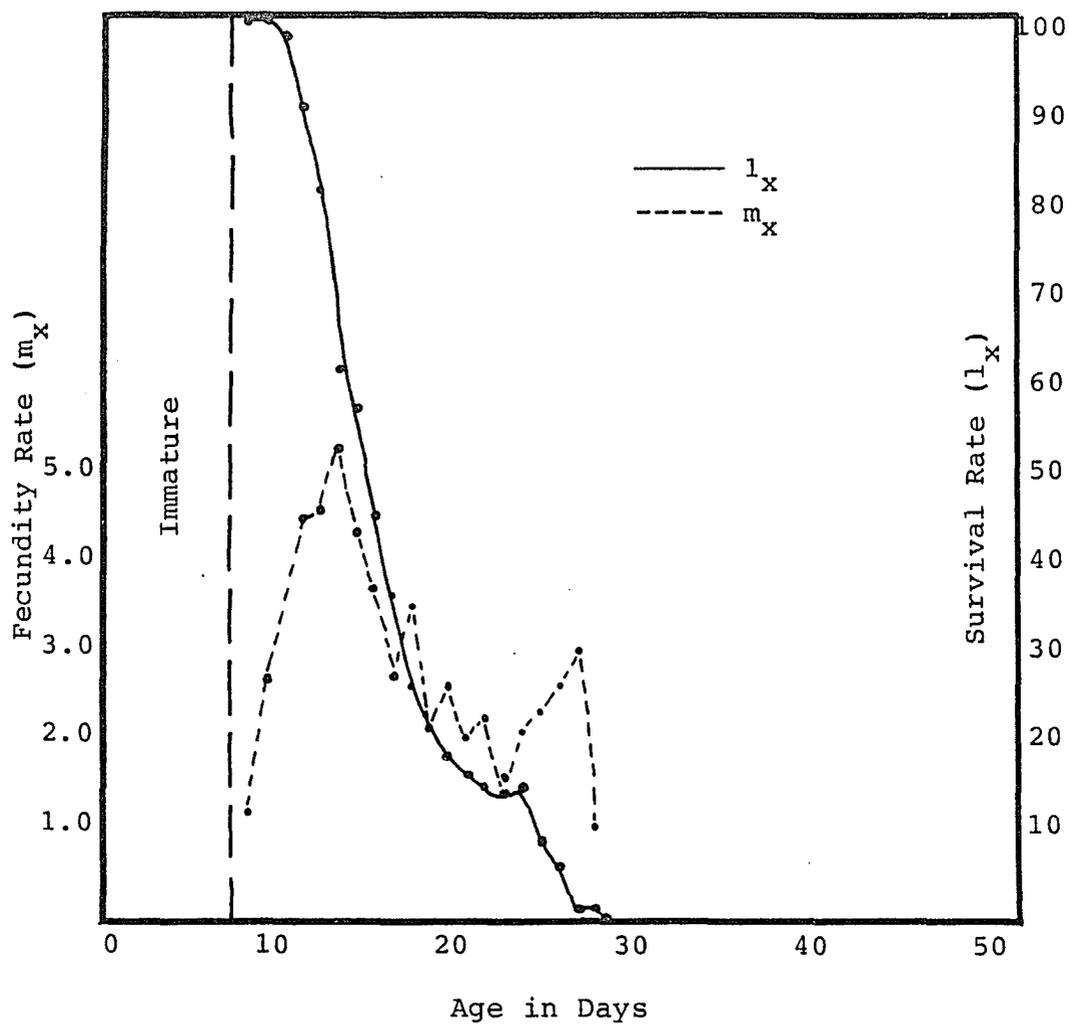


Figure 3. Survival and Age Specific Fecundity Curves for *T. cinnabarinus* Female Adults at 30.5° C.

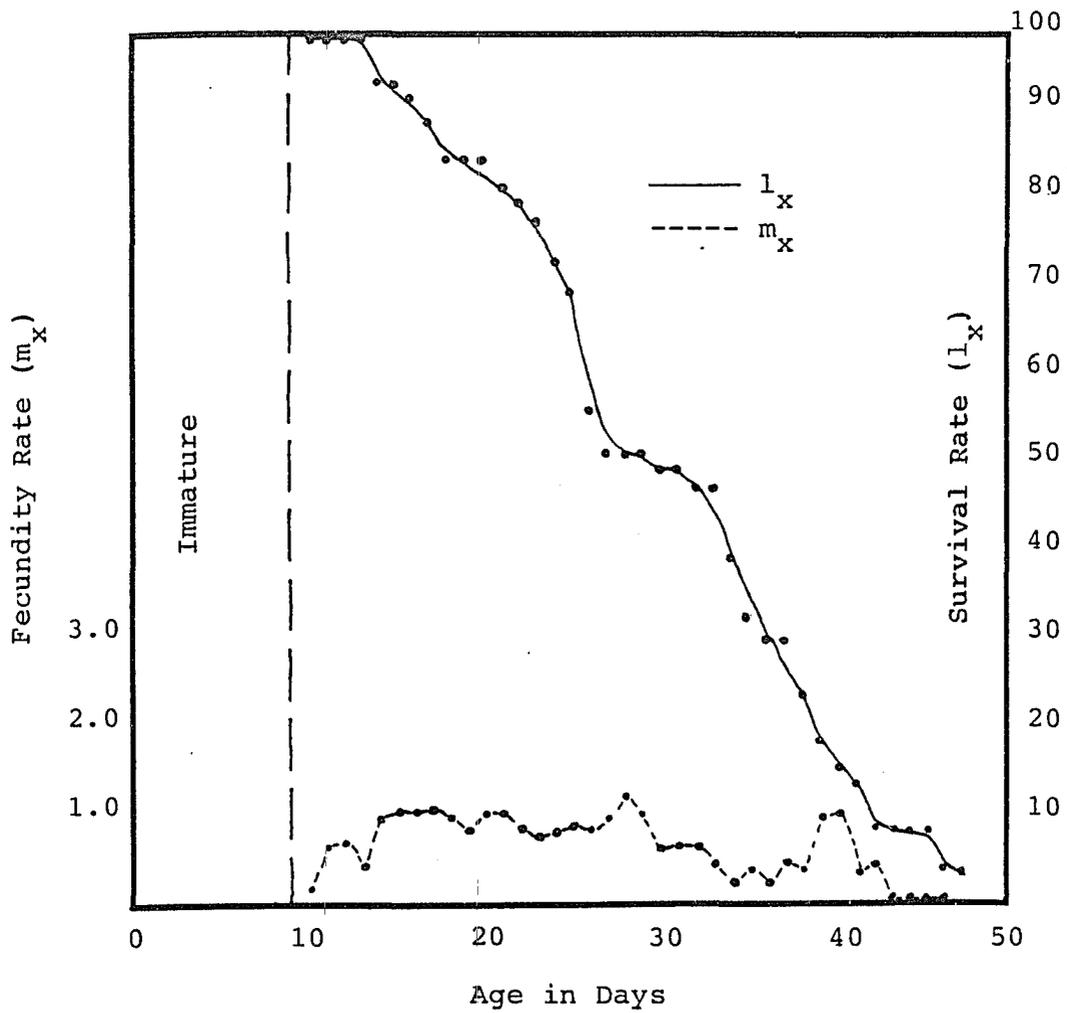


Figure 4. Survival and Age-specific Fecundity Curves for *T. occidentalis* Female Adults at 22.7° C.

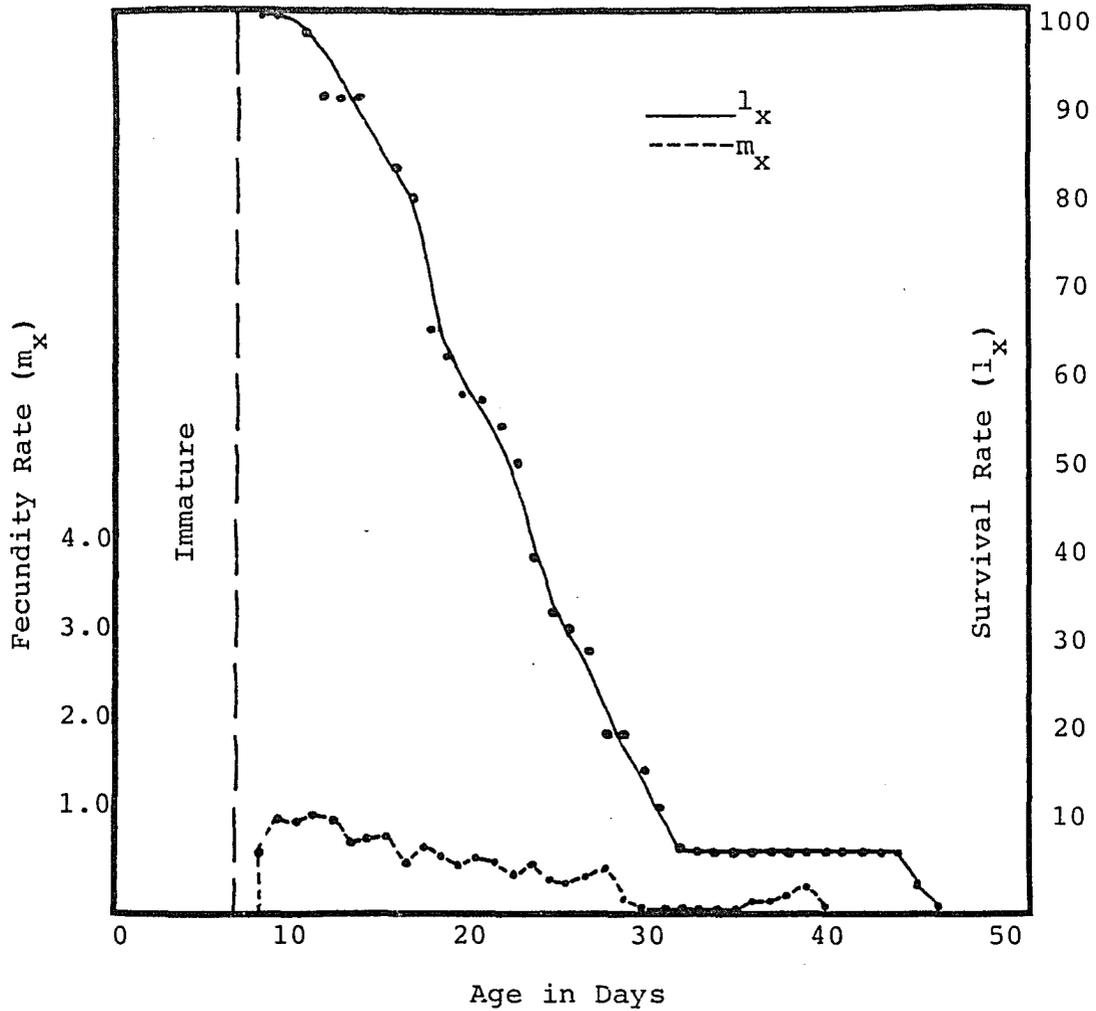


Figure 5. Survival and Age-Specific Fecundity Curves for *T. occidentalis* Female Adults at 26.6° C.

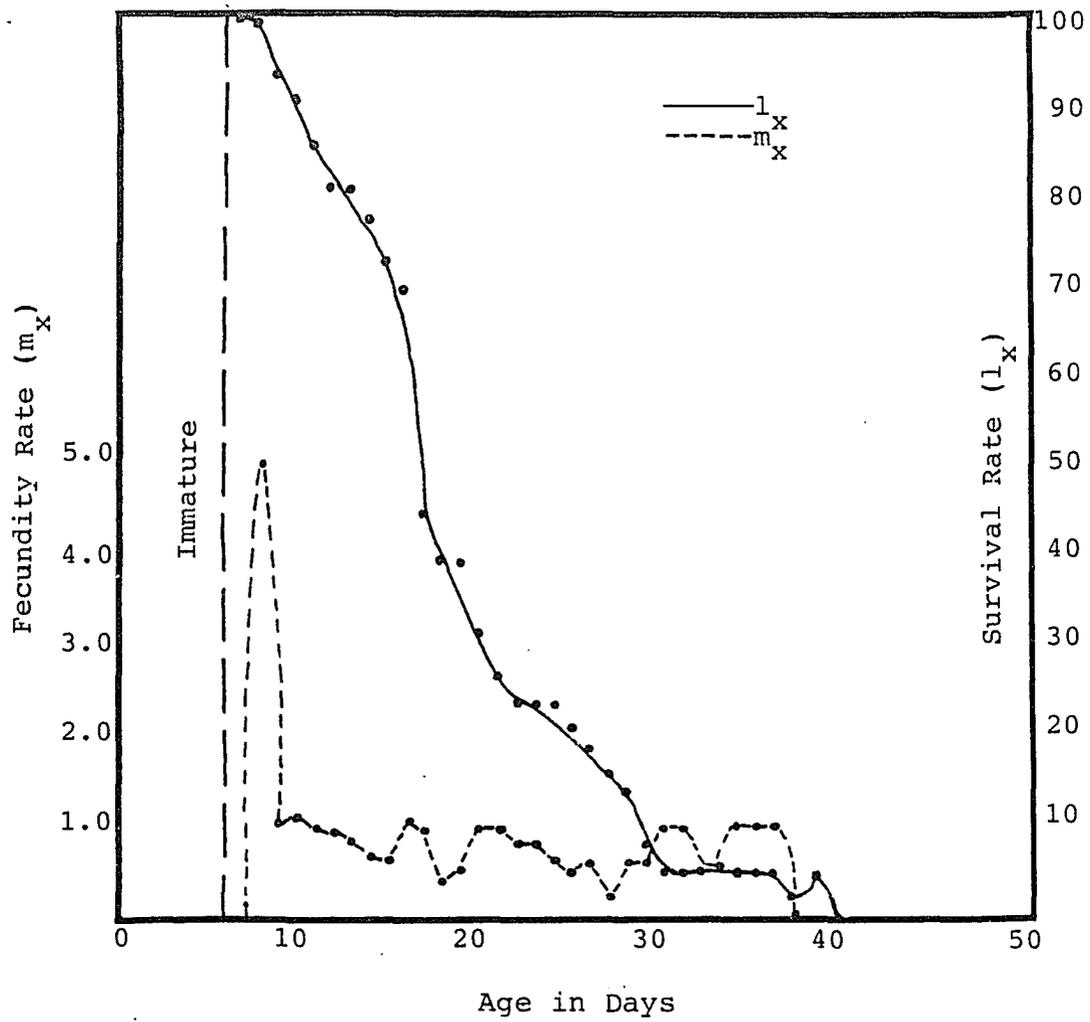


Figure 6. Survival and Age-specific Fecundity Curves for *T. occidentalis* Female Adults at 30.5° C.

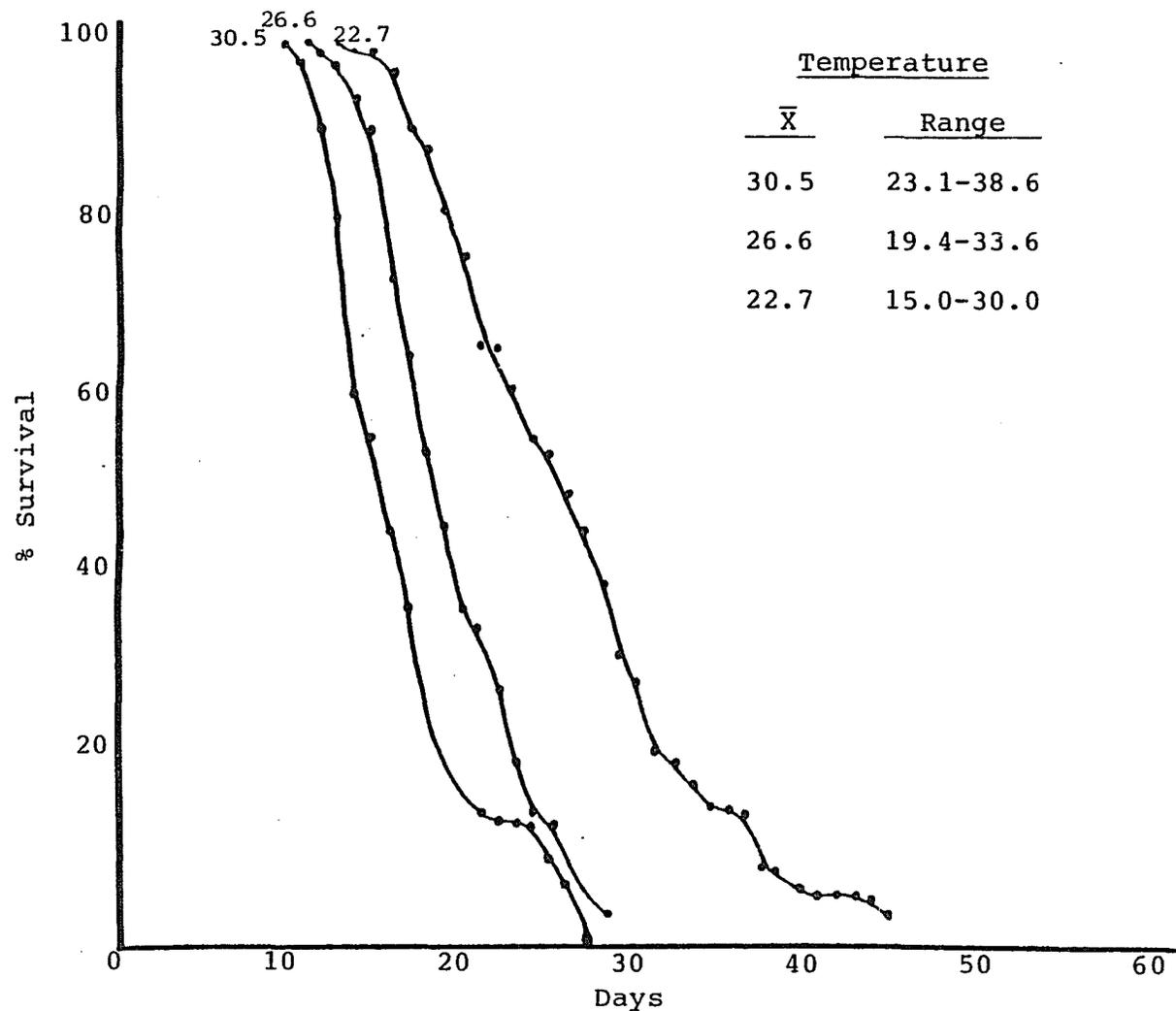


Figure 7. Survival of Adult Female T. cinnabarinus at Three Temperature Regimes.

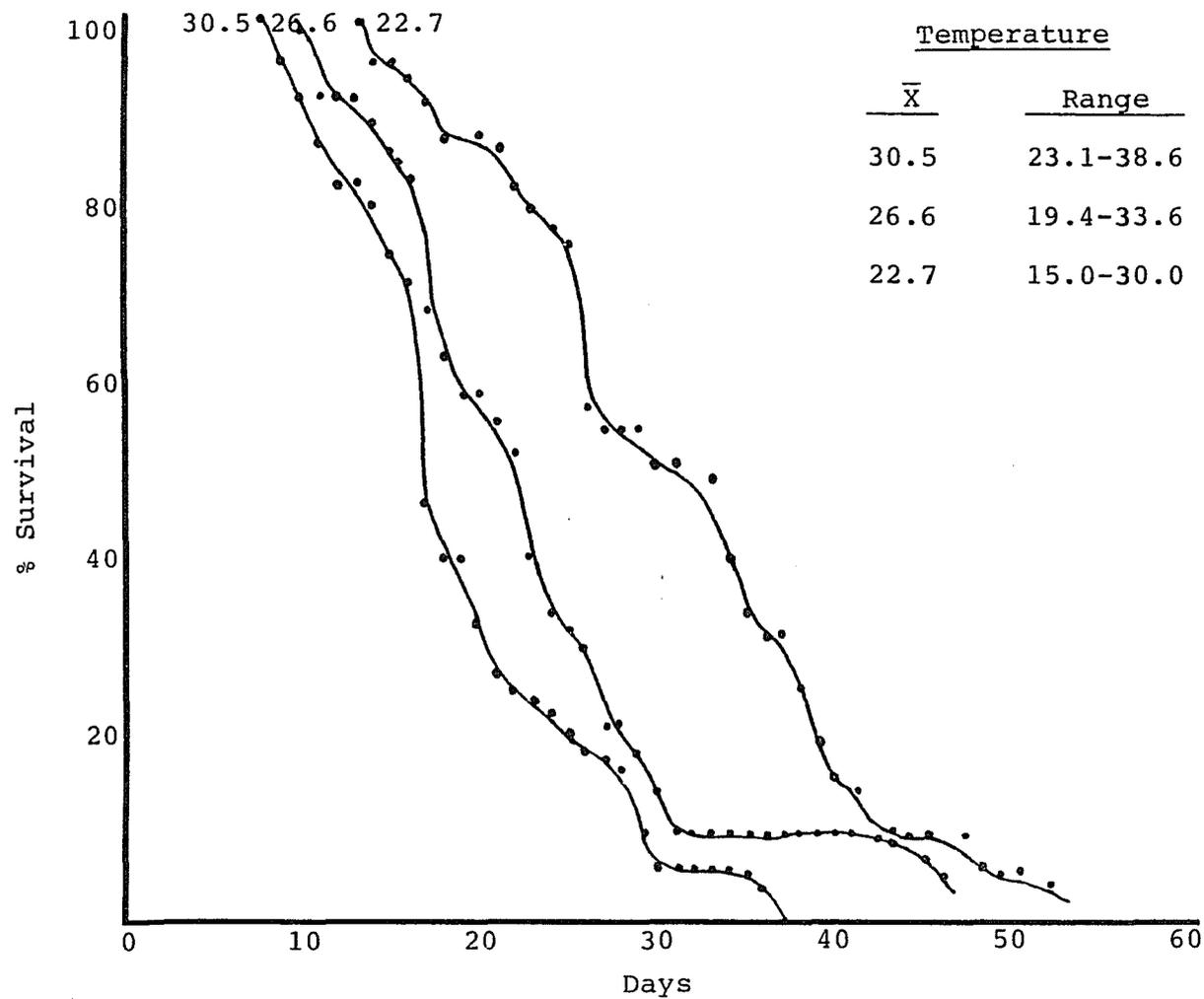


Figure 8. Survival of Adult Female T. occidentalis at Three Temperature Regimes.

that summer temperatures in southern Arizona tend to average above 26.6° C for almost three months. Consequently, differences in survivorship of T. cinnabarinus and T. occidentalis adult females in the predator/prey interaction in the field may be minimal.

Temperature Effect on Preoviposition

Preoviposition periods of T. occidentalis and T. cinnabarinus are shown in Tables 6 and 7. Hazan, et al. (1974) reported that T. cinnabarinus had a preoviposition period of less than one day at 30° and one day at 24° C. Laing (1969a) observed that T. urticae had a preovipositional period of 2.1 days at 20.3° C. These data tend to agree with those in the current study, where preoviposition periods were 1.27, 1.08, and 0.86 days, respectively for the temperature regimes of 22.7°, 26.6°, and 30.5° C. This showed clearly that, as temperatures were increased, preovipositional periods were reduced. There was also a highly significant difference between preoviposition periods at the different temperature regimes.

Preovipositional periods for T. occidentalis were considerably longer than those for T. cinnabarinus. Preovipositional period at 22.7° C was 2.43 days. However, the periods declined to 1.91 days at 26.6° and to 1.11 days at 30.5° C; there was a highly significant difference at each

Table 6. Mean Pre-oviposition Periods of T. cinnabarinus at Three Temperature Regimes.

| Temperature °C | | Number Observed | Number Days | | LSD ($\alpha=0.01$) |
|----------------|-----------|-----------------|-------------|-----------|-----------------------|
| Range | \bar{X} | | Average | Range | |
| 15.0-30.0 | 22.7 | 38 | 1.37 ± .43 | 1.0 - 1.0 | A |
| 19.4-33.6 | 26.6 | 38 | 1.08 ± .18 | 1.0 - 1.5 | B |
| 23.1-38.6 | 30.5 | 38 | .86 ± .23 | .5 - 1.0 | C |

Table 7. Mean Pre-oviposition Periods of T. occidentalis at Three Temperature Regimes.

| Temperature °C | | Number Observed | Number Days | | LSD ($\alpha=0.01$) |
|----------------|-----------|-----------------|-------------|-----------|-----------------------|
| Range | \bar{X} | | Average | Range | |
| 15.0-30.0 | 22.7 | 38 | 2.43 ± .48 | 1.5 - 3.0 | A |
| 19.4-33.6 | 26.6 | 38 | 1.91 ± .42 | 1.0 - 2.5 | B |
| 23.1-38.6 | 30.5 | 38 | 1.11 ± .21 | 1.0 - 1.5 | C |

temperature regime. Laing (1969b) reported a preoviposition period of 3.2 days at 20.3° C, and Lee and David (1968) observed it to be 1.3 days at 23.8° C. Preoviposition period was reduced more than 50% when the temperature was increased from 22.7° to 30.5° C. This would bring the preovipositional periods of T. cinnabarinus and T. occidentalis more closely in synchrony with one another. However, at the lowest temperature, 22.7° C, T. occidentalis required an additional day for preoviposition.

Temperature Effect on Oviposition Rate and Duration

From data obtained in the investigation of the effect of temperature on adult female longevity, it was hypothesized that temperature also had a direct effect on rate and duration of oviposition. Data showing the effect of temperature on rate and duration of oviposition are summarized in Tables 8 and 9, respectively, for T. occidentalis and T. cinnabarinus.

Oviposition duration of T. cinnabarinus was highly significant only between 22.7° and 30.5° C. The duration of oviposition was decreased by 40% with the 7.8° C increase in temperature. This trend also was observed by Hazan, et al. (1974). While working with T. cinnabarinus, they reported a 50% decrease in duration of oviposition with a 6° rise in temperature from 24° C to 30° C.

Table 8. Temperature Effects on Oviposition Duration and Rate of T. cinnabarinus.

| Temperature °C | | Number Observed | Number Days | | LSD ($\alpha=0.05$) | Daily Rate | | Number Progeny Average |
|----------------|-----------|-----------------|---------------|-------|-----------------------|-------------|-----------|------------------------|
| Range | \bar{X} | | Average | Range | | Average | Range | |
| 15.0-30.0 | 22.7 | 81 | 14.18 ± 10.76 | 2-32 | A | 3.97 ± .88 | 2.73-5.92 | 61.7 ± 10.32 |
| 19.4-33.6 | 26.6 | 105 | 11.88 ± 4.21 | 3-22 | B | 6.04 ± 3.11 | 1.37-9.81 | 65.8 ± 13.6 |
| 23.1-38.6 | 30.5 | 94 | 8.85 ± 3.96 | 2-19 | C | 5.96 ± 2.38 | 2.8-10.55 | 52.9 ± 10.78 |

Table 9. Temperature Effects on Oviposition Duration and Rate of T. occidentalis

| Temperature °C | | Number Observed | Number Days | | LSD ($\alpha=0.01$) | Daily Rate | | Number Progeny Average |
|----------------|-----------|-----------------|--------------|-------|-----------------------|------------|----------|------------------------|
| Range | \bar{X} | | Average | Range | | Average | Range | |
| 15.0-30.0 | 22.7 | 41 | 22.24 ± 9.02 | 4-38 | A | 2.41 ± 1.0 | .57-4.19 | 53.5 ± 10.2 |
| 19.4-33.6 | 26.6 | 47 | 14.7 ± 6.28 | 2-22 | B | 2.29 ± .93 | .93-3.53 | 33.6 ± 7.9 |
| 23.1-38.6 | 30.5 | 37 | 13.02 ± 6.44 | 2-25 | B | 2.27 ± .81 | .80-3.66 | 29.6 ± 8.1 |

Average daily rate of oviposition at 22.7° was 52% less than at 26.6° C. Average daily oviposition rate decreased 5% with an increase in temperature to 26.6° C. Thus, it appears that T. cinnabarinus may reach its maximum daily rate of oviposition at 26.6° C. Further rise in temperature may tend to lead to decreased longevity and a shortened oviposition period.

Duration of oviposition of T. occidentalis was decreased by 34% when mean temperature was increased from 22.7° and 26.6° C; it was also decreased by 42% between 22.7° and 30.5° C. Smith (1965) reported that the duration of oviposition of T. fallacis was decreased by 50% with each temperature rise of 10 degrees. Sharma (1966) found that T. occidentalis oviposited an average of 13.6 days at 25.6° C, while Laing (1969b) observed that T. occidentalis oviposited an average of 15.9 days at 20.3° C. The present study corroborates the findings of these workers that the duration of oviposition tends to decline with a rise in the temperature, once the optimum temperature for duration has been reached.

Oviposition rates were only decreased by 5% and 6%, respectively, with a 3.9° and 7.8° C rise in temperature in the present study. Sharma (1966) reported that T. occidentalis deposited 1.3 eggs/day at 25.6° C, while Lee and Davis (1968) determined that T. occidentalis oviposited

1.1 eggs/day at 23.9° C. However, Laing (1969b) reported that T. occidentalis oviposited an average of 2.2 eggs/day at 20.3° C. This rate tends to be closer to the rates observed in the present study.

It appears that the duration of oviposition by T. occidentalis is more sensitive to an increase in temperature than is that of T. cinnabarinus. However, T. occidentalis has the potential to oviposit for up to eight days longer than does T. cinnabarinus at 22.7° C.

Age-specific fecundity curves at the three different temperatures are shown in Figures 1 through 6. The sex ratio was considered as unity for the purpose of this study. Only female eggs are shown in the fecundity rate (m_x). Inspection of the age-specific fecundity data at 30.5° C indicates a very high initial fecundity period for both T. cinnabarinus and T. occidentalis, followed by a sharp decline. However, at 22.7° C, they both had a more gradual increase and decline in fecundity. This shortening of the initial high fecundity period at the high temperatures may indicate a type of senescent effect attributed to the high rate of metabolism associated with high temperatures (Bursell, 1970).

The maximum average number of eggs laid per female by T. cinnabarinus was obtained at 26.6° C (Table 8), and the minimum number occurred at 30.5° C, the highest temperature regime. However, the predator also showed the lowest number

of eggs laid per female at 30.5° C, but the highest average of 53.5 eggs per female occurred at 22.7° C, the lowest temperature regime. The temperature at which the largest disparity occurred was 26.6° C; where the averages laid per female were 65.8 and 33.6 for T. cinnabarinus and T. occidentalis, respectively.

Therefore, based strictly on average number of eggs laid per female, there appears to be a stronger possibility for control or suppression at the lower (22.7°) springtime temperatures. Furthermore, the chances for a mite outbreak seem to be more likely at the higher or summer temperatures (26.6° and 30.5° C). However, there are many other interacting factors that contribute to the outbreak of a pest population. The inherent capacity of a female mite to reproduce is just one.

Temperature Effect on the Consumptive Capacity of Typhlodromus occidentalis

Adult Female vs. Eggs. T. occidentalis adult females of generally the same age were selected at random from stock cultures and offered T. cinnabarinus eggs. The predatory female demonstrated a highly significant difference in predatory potentials when held under different temperature regimes. These data are presented in Table 10.

In general, the predatory capacity of the predaceous mites was increased as the temperature increased.

Table 10. Daily Consumption of the Egg Stage of T. cinnabarinus by Adult Females of T. occidentalis at Three Temperature Regimes

| <u>Temperature °C</u> | | Number Observed | \bar{X} Number Prey Offered Daily | <u>Daily Consumption</u> | | LSD ($\alpha=0.01$) |
|-----------------------|-----------|-----------------|-------------------------------------|--------------------------|-------|-----------------------|
| Range | \bar{X} | | | Average | Range | |
| 15.0-30.0 | 22.7 | 110 | 25 | 3.55 ± 1.31 | 1-8 | A |
| 19.4-33.6 | 26.6 | 60 | 25 | 9.51 ± 2.88 | 2-16 | B |
| 23.1-38.6 | 30.5 | 62 | 25 | 13.65 ± 3.71 | 5-19 | C |

Statistically there was a highly significant difference in daily consumption of eggs between adult female predators at each temperature regime.

Laing (1969b) reported that T. occidentalis consumed an average of 8.5 eggs/day at 20.3° C. Smith (1965) observed that T. fallicis consumed 10.6 eggs/day at 26.6° C. Results in the present study indicate a great difference between the 3.55 eggs consumed per day of 22.7° and the 13.65 eggs/day consumed at 30.5° C. This would seem to be in agreement with the general rule that, as temperature increases, the metabolic rate increases and, therefore, more eggs are consumed.

Protonymph vs. Eggs. Protonymphs consumed more T. cinnabarinus eggs at 30.5° C than when held at either 26.6° or 22.7° C (Table 11). However, only at the temperature of 22.7° C was consumption significantly less. Laing (1969b) reported that T. occidentalis protonymphs consumed an average of 3.5 eggs/day at 20.3° C and Lee and David (1968) observed that T. occidentalis consumed an average of 2.2 eggs/day at 23.8° C.

Deutonymphs vs. Eggs. Data on consumption of Tetranychid eggs by deutonymphs at temperatures of 22.7°, 26.6°, and 30.5° C are presented in Table 12. Deutonymphs of T. occidentalis held at 30.5° C were more effective as predators than those held at 22.7° or 22.6° C. However, there was no significant difference in consumption among any of the temperature regimes.

Table 11. Daily Consumption of the Egg Stage of T. cinnabarinus by Protonymphs of T. occidentalis at Three Temperature Regimes.

| Temperature °C | | Number Observed | \bar{X} Number Prey Offered Daily | Daily Consumption | | LSD ($\alpha=0.01$) |
|----------------|-----------|-----------------|-------------------------------------|-------------------|-------|-----------------------|
| Range | \bar{X} | | | Average | Range | |
| 15.0-30.0 | 22.7 | 36 | 5 | 1.77 ± .51 | 1-3 | A |
| 19.4-33.5 | 26.6 | 38 | 10 | 3.21 ± 1.16 | 1-7 | B |
| 12.1-37.6 | 30.5 | 36 | 10 | 4.14 ± 1.67 | 1-8 | B |

Table 12. Daily Consumption of the Egg Stage of T. cinnabarinus by Deutonymphs of T. occidentalis at Three Temperature Regimes.

| <u>Temperature °C</u> | | Number Observed | \bar{X} Number Prey Offered Daily | <u>Daily Consumption</u> | |
|-----------------------|-----------|-----------------|-------------------------------------|--------------------------|-------|
| Range | \bar{X} | | | Average | Range |
| 15.0-30.0 | 22.7 | 43 | 10 | 2.56 ± 1.05 | 1-5 |
| 19.4-33.6 | 26.6 | 42 | 10 | 3.31 ± 1.35 | 1-7 |
| 32.1-38.6 | 30.5 | 42 | 10 | 3.64 ± 1.65 | 2-8 |

Temperature Effect on Total Egg Consumption
by All Stages of Typhlodromus occidentalis

Data presented in Table 13 show that highly significant differences occurred among total consumptive rates of T. occidentalis at three different temperature regimes. Average increase in consumption from 22.7° to 26.6° C was more than doubled and from 22.7° to 30.5° C it was almost tripled.

It may appear that T. occidentalis, based on its consumptive capacity, would have a great advantage in controlling T. cinnabarinus. However, there are other aspects of the predator/prey interaction that need to be considered. Some behavioral change, for example, of one or both of the species, in response to changes in the environment, may produce a new balance of reproductive potentials between the two. The new reproductive potentials may, in turn, have a moderating effect on the high consumptive rate of the predator, at higher temperature levels.

Furthermore, if the prey is completely exterminated, the predator may, theoretically, die out from lack of food and would, therefore, be unable to control a newly introduced pest population. For effective control, the prey should not be exterminated. The predator would not die out from lack of food; thus, a reserve supply of predators would always exist

Table 13. Mean and Total Egg Consumption by T. occidentalis at Three Temperature Regimes.

| Temperature °C | Protonymph | Deutonymph | Adult | Total |
|-------------------------------|------------|------------|-------|-------|
| 15.0-30.0 $\bar{X} = 22.7$ | 1.77 | 2.56 | 3.55 | 7.88 |
| 19.4-33.6 $\bar{X} = 26.6$ | 3.21 | 3.31 | 9.51 | 16.03 |
| 23.1-38.6 $\bar{X} = 30.5$ | 4.14 | 3.64 | 13.65 | 21.43 |

to control the remaining or newly-introduced pest population.

Temperature Effect on Population Increase

Population increase is dependent upon more than total offspring produced (Watson (1964)). Age-specific fecundity schedules, average number of progeny per female, developmental times and immature mortality are among interacting factors that may be considered.

Life-fecundity tables were used in the present study to calculate r_m , R_o , and T. The net reproduction rate (R_o) is an estimate of the number of times a single female will reproduce itself during one generation under conditions of unlimited food supply and protection from natural enemies, at any particular combination of physical conditions (Nickel 1960). The mean time it takes for a generation to occur under specified conditions is "T," or the mean generation length. Of the population statistics presented in this study, the intrinsic rate of natural increase (r_m) may give the most complete and accurate description of an insect's population increase. This statistic may account for nearly all of an organism's life cycle. This is also a system for weighting these data according to age, which enhances this population statistic.

Tables 14 and 15 present a comparison of the mean generation time (T), net reproduction rates (R_o) and the

Table 14. Comparative Population Statistics of T. cinnabarinus at Three Temperature Regimes.

| Temperature °C | | r_m | R_o | T |
|----------------|-----------|-------|-------|-------|
| Range | \bar{X} | | | |
| 15.0-30.0 | 22.7 | .196 | 31.2 | 17.65 |
| 19.4-33.6 | 26.6 | .244 | 33.0 | 14.34 |
| 23.1-38.6 | 30.5 | .286 | 27.3 | 11.57 |

Table 15. Comparative Population Statistics of T. occidentalis at Three Temperature Regimes.

| Temperature °C | | r_m | R_o | T |
|----------------|-----------|-------|-------|-------|
| Range | \bar{X} | | | |
| 15.0-30.0 | 22.7 | .158 | 17.31 | 18.03 |
| 19.4-33.6 | 26.6 | .192 | 12.30 | 13.07 |
| 23.1-38.6 | 30.5 | .182 | 9.97 | 12.64 |

intrinsic rates of increase (r_m), when no immature mortality was considered.

From the life table studies, mean generation times of T. occidentalis and T. cinnabarinus were remarkably close at the three temperature regimes. T. cinnabarinus at 26.6° C took 1.27 days longer to complete a generation than did T. occidentalis. The longest generation time was observed at 22.7° C in which T. occidentalis took 18.03 days to complete. Shortest was T. cinnabarinus which took 11.57 days at 30.5° C. Mean generation time for T. cinnabarinus in the present study tends to agree with Hazan, et al. (1974); they reported that the mean generation time for T. cinnabarinus at 24° C was 17.34 days at 38% RH and 16.95 at 80% RH. The mean generation time in the present study was 14.34 at 26.6° C. Further, Hazan, et al. (1974) observed a mean generation time of 11.04 days at 30.0° C, compared to 11.57 days at 30.5° C, in the present study.

Net reproduction rate greatly favored T. cinnabarinus over T. occidentalis at all three temperatures. Largest differences between the two were recorded at 30.5° C. The T. cinnabarinus population almost tripled that of T. occidentalis. The smallest difference between the predator and prey was at 22.6° C. T. occidentalis showed a definite trend towards a lower rate of population increase

with an increase in temperature. However, T. cinnabarinus showed that a temperature threshold for maximal R_0 (33.0) may have been reached at 26.6° C; R_0 was reduced to 27.3 at 30.5° C. Hazan, et al. (1974) obtained similar results, finding the highest net reproduction rate for T. cinnabarinus at 24° C and a reduced R_0 at 30° C.

The intrinsic rate of increase (r_m) is a synthesis of the biological data available from this study for T. occidentalis and T. cinnabarinus. Therefore, this statistic may be expected to reflect the phenomenon which has been previously described with an increase in temperature. Effect of minimum threshold temperature seems to have been reflected at the lower temperature. This may help explain the greatest increases in r_m occurring between 22.7° and 26.6° C for both T. cinnabarinus and T. occidentalis. Hazan, et al. (1974) corroborate the results of the present study with their observations that T. cinnabarinus generally had the greatest increase in r_m between 19° and 24° C.

It was observed in the present study that the average number of days of oviposition was decreased at higher temperatures for both T. cinnabarinus and T. occidentalis. Total number of progeny was generally reduced. However, the values for r_m generally rose and did not reflect the decreasing trends in the length of oviposition period and number of total progeny. This may be explained partly

because of the preferential weighting that is placed on the shortened time of development at higher temperatures. Also, heavy initial fecundity, which was observed at 30.5° C for both mites was also weighted and, therefore, more important in calculating the values for r_m . However, r_m did decrease by 0.1 at 30.5° C for T. occidentalis. This may be explained by the mean generation time only being decreased by .43 days from 26.6° to 30.5° C.

In comparing both r_m values, T. occidentalis lagged behind T. cinnabarinus with its r_m values at each temperature. It was .104 below the r_m value for T. cinnabarinus at 30.5° C. More importantly, the r_m value for T. occidentalis was decreasing as the r_m value for T. cinnabarinus was increasing at 30.5° C (Figures 9-15).

Ability of a predator to persist and increase in abundance in niches where its host exists is extremely important. Some of the most important criteria that can be presumed are the predator's temperature tolerance limits and rapidity with which it can develop within these limits (Force and Messenger 1964), the wider the predator's geographic range can become; all other factors being equal, the more rapidly it can complete its life cycle, the more rapidly it can be expected to increase in numbers in relation to its prey.

The most favorable temperature for T. occidentalis growth potential and, therefore, possible control of

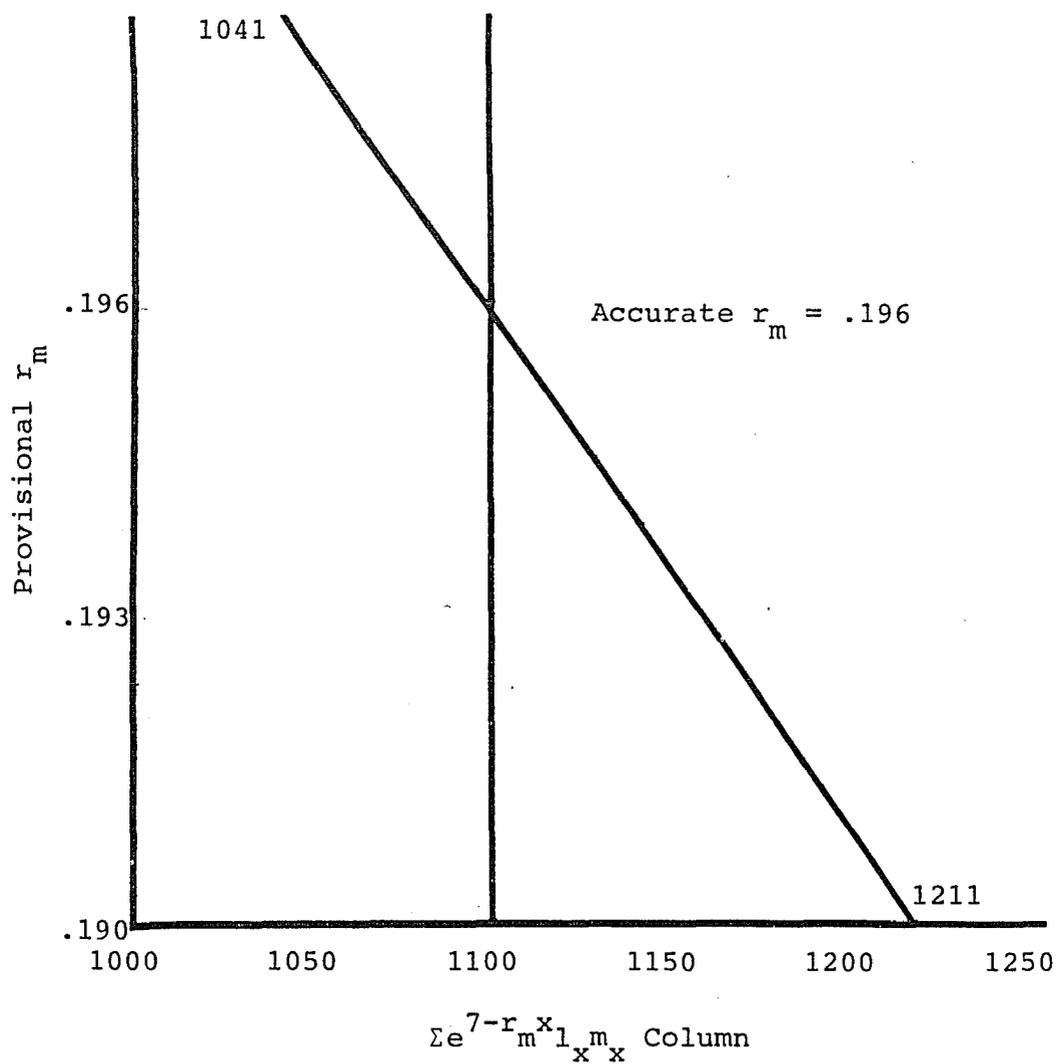


Figure 9. Determination of the Intrinsic Rate of Increase (r_m) for T. cinnabarinus at 22.7° C.

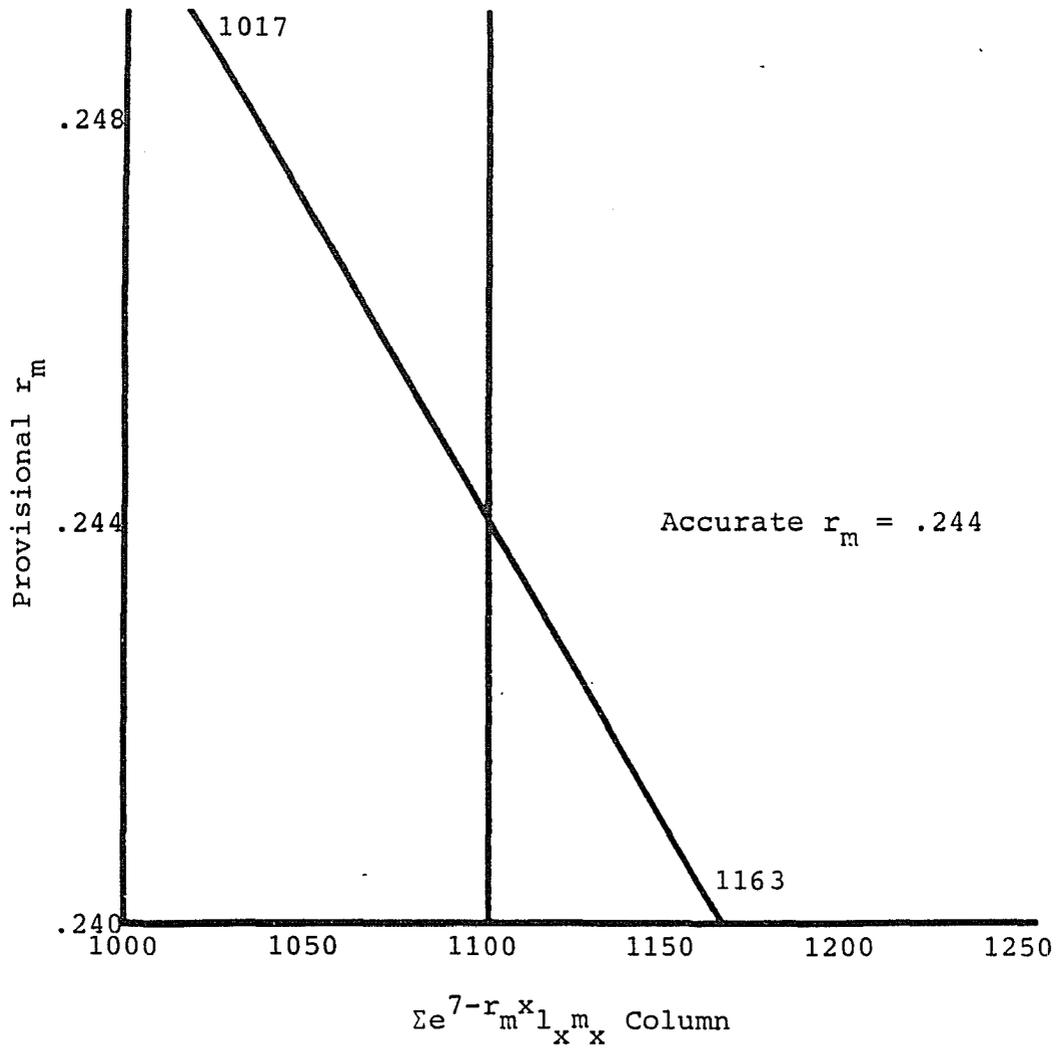


Figure 10. Determination of the Intrinsic Rate of Increase (r_m) for T. cinnabarinus at 26.6° C.

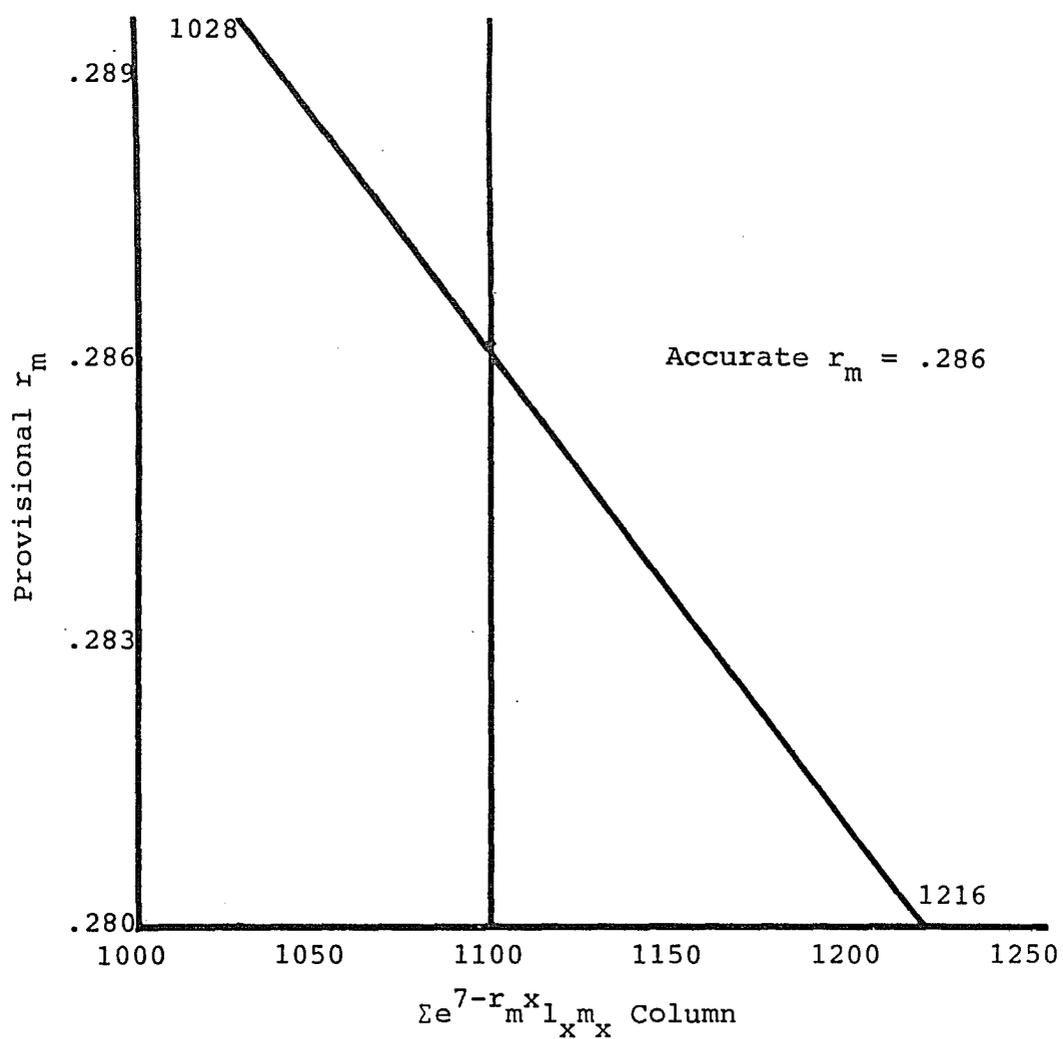


Figure 11. Determination of the Intrinsic Rate of Increase (r_m) for T. cinnabarinus at 30.5° C.

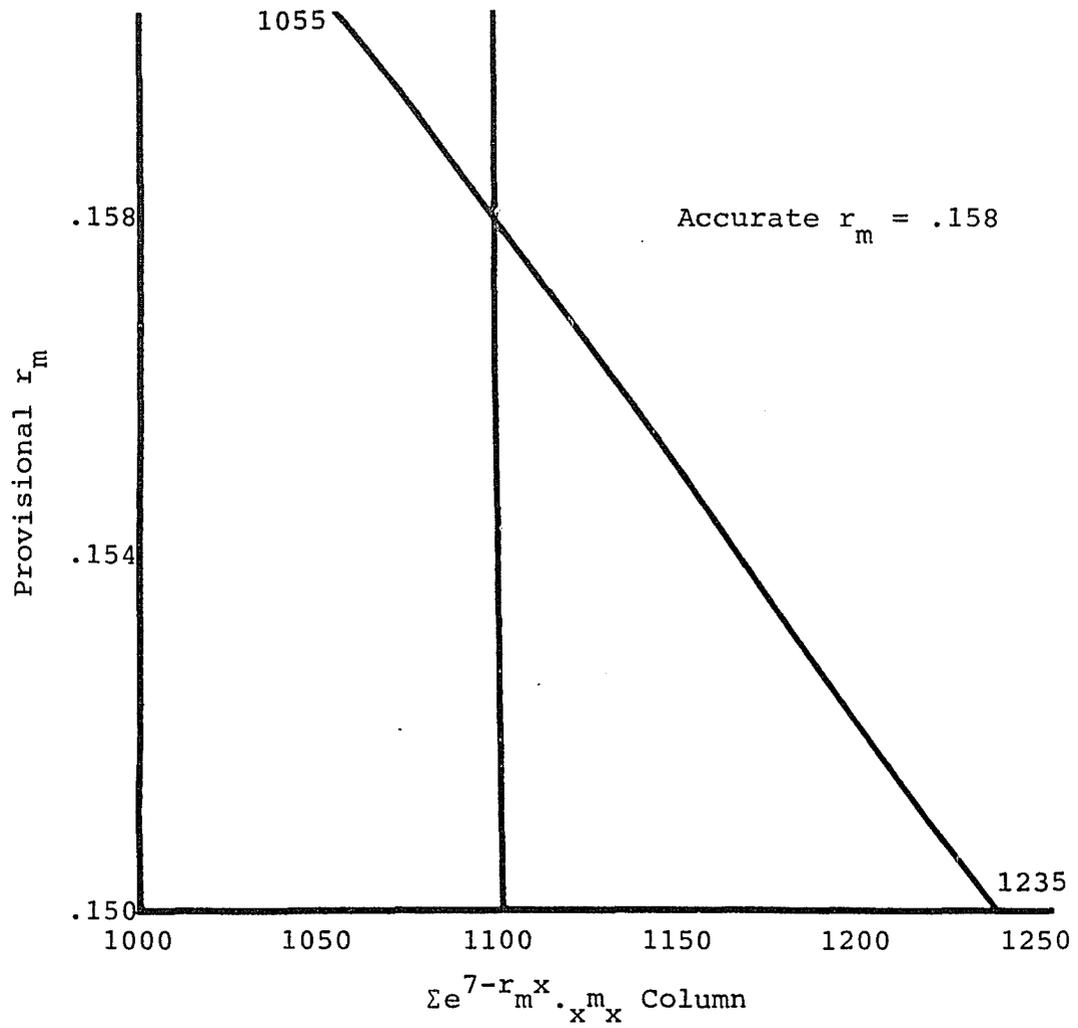


Figure 12. Determination of the Intrinsic Rate of Increase (r_m) for T. occidentalis at 22.7° C.

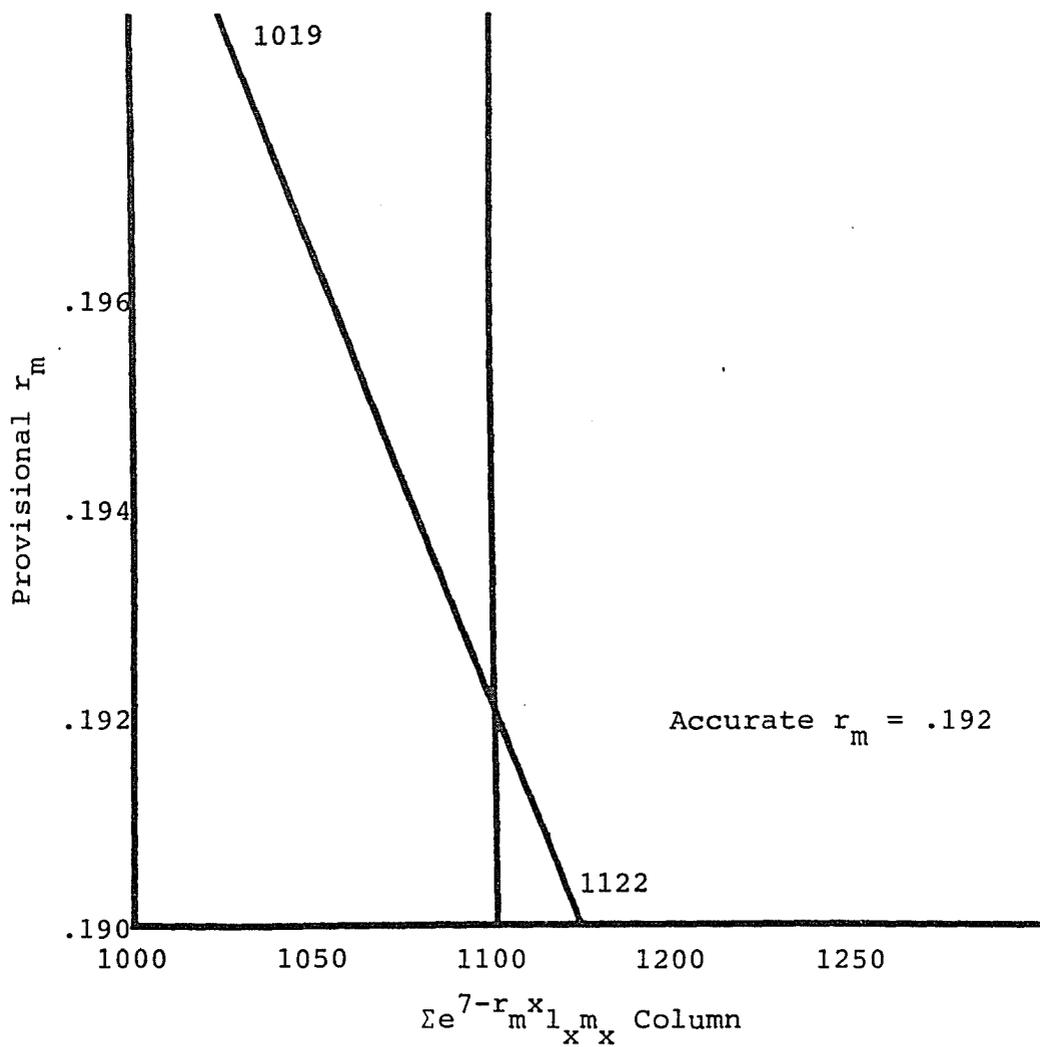


Figure 13. Determination of the Intrinsic Rate of Increase (r_m) for T. occidentalis at 26.6° C.

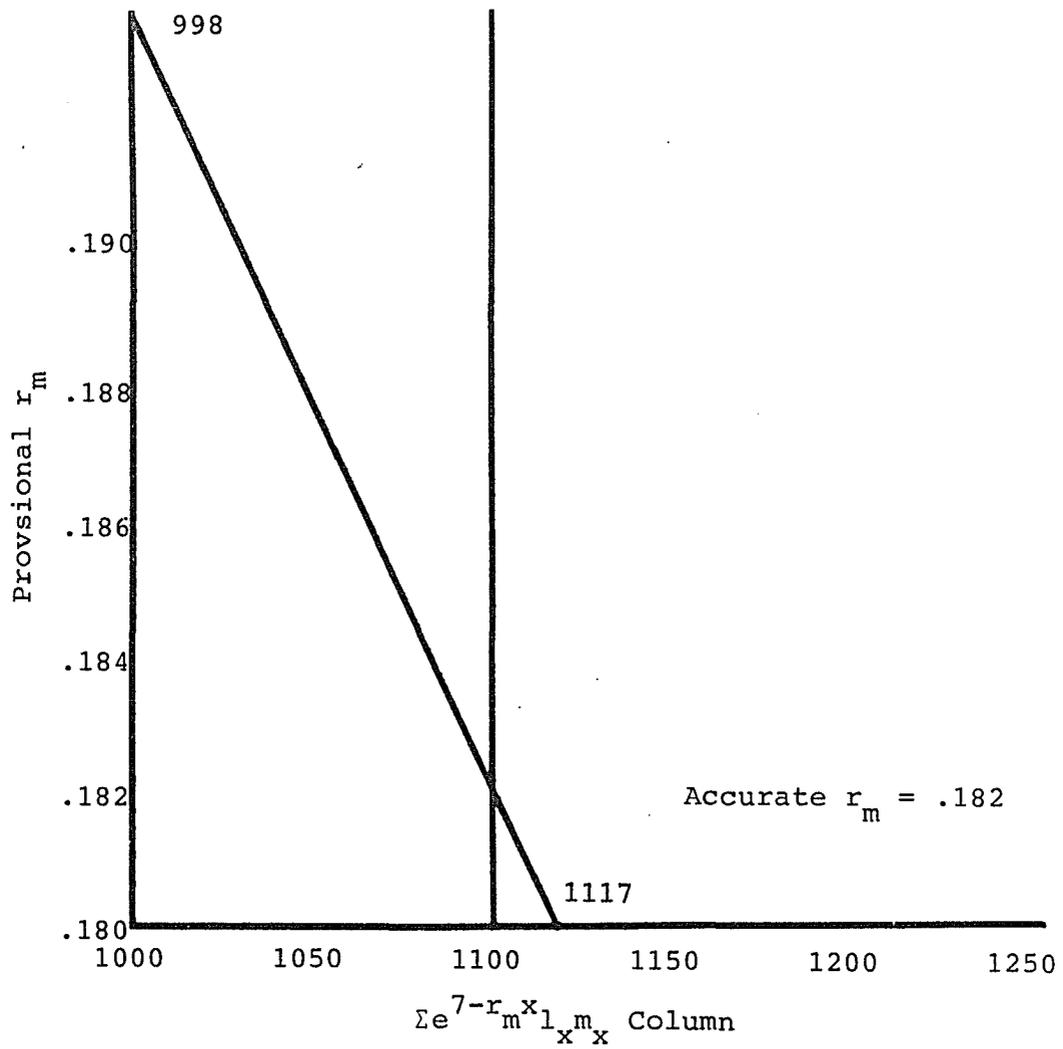


Figure 14. Determination of the Intrinsic Rate of Increase (r_m) for T. occidentalis at 30.5° C.

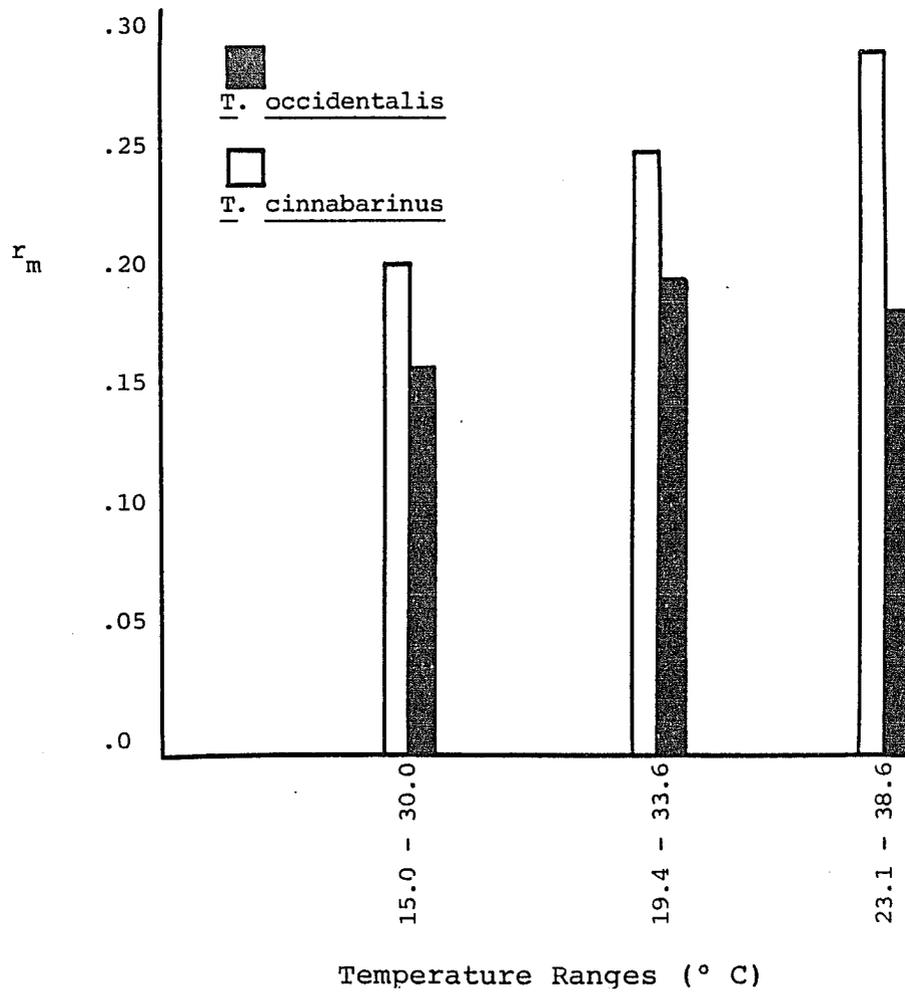


Figure 15. Comparison of Intrinsic Rate of Natural Increase (r_m) for T. cinnabarinus and its Predator T. occidentalis at Three Temperature Regimes.

T. cinnabarinus appears to have been at 22.7° C. Mean generation times were extremely close (Tables 14 and 15). R_0 values at the 22.7° C temperature regime were closest of the three temperatures. Most importantly, the r_m values were .196 for T. cinnabarinus and .158 for T. occidentalis at 22.7° C.

Figure 15, however, clearly shows that T. cinnabarinus responded more favorably to higher temperatures with increasing rates of population growth, while T. occidentalis showed a much lower potential than its prey. As a result, it would appear that T. occidentalis would not be able to effectively control T. cinnabarinus at higher temperatures. Furthermore, it would seem that, with a lower r_m value at high temperatures, when compared to T. cinnabarinus, T. occidentalis would not possess the necessary attribute to effect a rapid reduction of the mite pest at high prey densities.

Although intrinsic rates of increase can be compared for the prey and predator, these values do not allow for the effect of predation on the prey. Leopold (1933) proposed five factors that can affect predation: (1) prey density; (2) predator density; (3) characteristics of the environment; (4) characteristics of the prey; and (5) characteristics of the predator. These factors are beyond the scope of the

present study. In time, they should be investigated to help complete the study of the potential of T. occidentalis in southern Arizona's desert conditions.

Predator/Prey Ratio

Further data were collected in an attempt toward establishing an optimum predator/prey ratio in which neither population would be annihilated.

Starvation studies (Appendix G) indicated that, as the temperature increased, T. occidentalis was less able to withstand prolonged periods without nourishment. Over 50% of the predators had starved to death by the end of the third day at 30.5° C. It was not until the fifth and seventh days, respectively, that 50% of the mites died at 26.6° and 22.7° C. These data indicated that T. occidentalis would not be able to withstand long periods of extremely low prey densities. However, Chant (1960, 1961) observed that T. occidentalis may have the capacity to sustain itself on plants. Further, Kuenen (1947) reported that each predator has a minimum requirement for prey on which it can remain alive. Laing (1969b) also observed cannibalism, which allowed some predators to survive for considerable lengths of time without normal hosts. Therefore, it cannot be concluded that, under laboratory conditions, T. occidentalis will automatically starve to death in the absence of prey.

Studies were conducted to determine the predator's searching ability (Appendix H). As expected, the percent prey consumed increased with temperature, but decreased slightly with an increase in habitat complexity.

Attempts were made to increase the complexity of the search for host eggs. Eggs were placed on excised trifoliolate leaves which were floated on water in petri-dishes. However, over a 24-hour period, the petioles tended to become submerged in the water, and, therefore, did not allow the mite to pass freely from leaf to leaf. Consequently, studies were incomplete.

Further studies were conducted to determine a ratio in which neither population would be annihilated. The present study confirmed the findings of Sharma (1966), Chant (1963), and McClanahan (1968). A ratio of 1:10, predator to prey, adult gravid females was placed on a single excised leaf. Within 10-12 days, the host had been annihilated. To increase the complexity, a 1:10 ratio was placed on single, whole lima bean plants. Appendix I presents these results. At 22.7° C, after 28 days, the ratio had been reduced to almost 2:1. Therefore, it would seem that the 1:10 ratio at 22.7° C appeared to be headed toward annihilation within a few days. After 21 and 28 days, at 26.6° C, the populations present also seemed to be tending towards annihilation. Unfortunately, in the 30.5° C regime, the plants died from a

wilt disease in the environators, and counts had to be taken, then, at 7, 10, and 14 days. But, as indicated in Appendix I, it appears that the prey was increasing at a much greater pace than the predator. This would tend to confirm the findings in the present study of the respective r_m 's for T. cinnabarinus and T. occidentalis at 30.5° C regime.

Finally, a greenhouse study was conducted to help further determine the optimum predator/prey ratio in a more complex arena. Ratios of 0:10, 1:5, 1:10 and 1:20, T. occidentalis/T. cinnabarinus were studied. However, after the third week, it became apparent that the initial infestation of the predator had not been successful (see Appendices J and K).

A possible explanation was that the predatory mite was unable to find nourishment before starving to death.

A reinfestation of the predator took place in the fourth week, but sampling procedures did not indicate any predatory mite until the sixth week. By the sixth week, the host was in the second week of its crash phase, following the peak in the fifth week. Consequently, the greenhouse study did not accomplish its goal.

SUMMARY

In order to quantify population growth, the influence of temperature and its effects on T. cinnabarinus, a phytophagous mite, and its predator, T. occidentalis, were studied. Both mites were studied at three fluctuating regimes, which averaged 22.7°, 26.6°, and 30.5° C. Studies were conducted on: developmental time, daily fecundity and survival of individual adult females for each regime, consumptive capacity of the predator, predator/prey ratios, searching capacity and starvation tendencies of the predator.

Increasing temperatures caused mean longevity of the life cycles of both mites to decrease. Mean longevities for the adult female of T. occidentalis were highly significant between 22.7° and 26.6° C. Effect of temperature on adult female longevity of T. cinnabarinus was highly significant at each temperature regime.

Significant differences were observed in the reduction of mean pre-oviposition periods with each successively higher temperature regime for both predator and prey.

Mean number of days oviposition occurred for both mites decreased with an increase in temperature. Oviposition duration of T. cinnabarinus was only highly significant between 22.7° and 26.6° C.

Mean daily ovipositional rate of T. occidentalis decreased with each increase in temperature. However, it increased for T. cinnabarinus from 22.7° to 26.6° C by 2.07 egg/day, followed by a decline of 0.35 egg/day as the temperature is increased from 26.6° C to 30.5° C. The mean number of progeny from T. occidentalis also decreased with each increase in temperature. However, consistent with the mean daily oviposition rate, mean number of progeny of T. cinnabarinus increased by almost four eggs, from 22.7° to 26.6° C, and then decreased by almost 13 eggs from 26.6° to 30.5° C.

The mean total egg consumption by protonymphs, deutonymphs and adults of T. occidentalis increased with an increase in temperature. There was a highly significant difference in consumption of eggs between 22.7° and 26.6° C by the protonymphal stage. Differences in the consumptive capacity of the adult female were highly significant at all three temperature regimes. Total eggs consumed at 26.6° C doubled and then almost tripled at 30.5° C from the 7.88 eggs consumed at the 22.6° C temperature regime.

Life tables were constructed from life cycle data collected during the investigations to calculate: net reproduction rate (R_0), mean generation time (T), and the intrinsic rate of natural increase (r_m).

The mean generation time decreased with an increase

in temperature for both mite populations. Mean generation times for both mites were very close at each temperature regime.

Net reproduction rate of T. occidentalis decreased with a rise in temperature. However, the R_0 for T. cinnabarinus rose from 22.7° to 26.6° C and then fell from 33.0 to 27.3 with the increase in temperature from 26.6° to the 30.5° C regime.

The intrinsic rate of natural increase of T. cinnabarinus increased with the rise in temperature. However, r_m for T. occidentalis rose from the 22.7° regime to the 26.6° C temperature, but fell from the 26.6° to 30.5° C. Finally, the r_m for T. occidentalis showed that it does not respond to higher temperatures as well as does T. cinnabarinus.

Further data were collected in order to establish an optimum predator/prey ratio which would not result in annihilation of either population over time. However, data were inconclusive.

APPENDIX A

Life-fecundity Table with Calculations for Two Provisional r_m 's of T. cinnabarinus at 22.7° C.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | $r_m = .196$ | $R_o = 31.2$ | $T = 17.65$ |
|------------------|--|--|----------------------|---------|-----------|----------------|------------------------|---------|-----------|----------------|------------------------|--------------|-------------|
| | | | $r_m = .20$ | | | | $r_m = .19$ | | | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | | |
| 0-11 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |  |  |
| 12 | 1.00 | .827 | .827 | 2.4 | 4.6 | 99.48 | 82.27 | 2.28 | 4.72 | 112.17 | 92.76 | | |
| 13 | .98 | 2.4 | 2.35 | 2.6 | 4.4 | 81.45 | 191.41 | 2.47 | 4.53 | 92.76 | 217.99 | | |
| 14 | .98 | 2.7 | 2.64 | 2.8 | 4.2 | 66.69 | 176.06 | 2.66 | 4.34 | 76.71 | 202.51 | | |
| 15 | .95 | 2.8 | 2.66 | 3.0 | 4.0 | 54.6 | 145.24 | 2.85 | 4.15 | 63.43 | 168.72 | | |
| 16 | .90 | 3.0 | 2.7 | 3.2 | 3.8 | 44.7 | 120.69 | 3.04 | 3.96 | 52.46 | 141.64 | | |
| 17 | .86 | 3.0 | 2.58 | 3.4 | 3.6 | 36.6 | 94.43 | 3.23 | 3.77 | 43.40 | 109.80 | | |
| 18 | .81 | 2.32 | 1.87 | 3.6 | 3.4 | 29.97 | 56.04 | 3.42 | 3.58 | 35.87 | 67.08 | | |
| 19 | .74 | 2.6 | 1.92 | 3.8 | 3.2 | 24.53 | 47.1 | 3.61 | 3.39 | 29.67 | 56.97 | | |

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Appendix A Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|--|----------------------|---------|-----------|---------------|-------------------------|---------|-----------|---------------|-------------------------|
| | | | .20 | | | | | .19 | | | |
| x | l_x | m_x | $l_{x x}^m$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_{x x}^m$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_{x x}^m$ |
| 20 | .66 | 2.6 | 1.71 | 4.0 | 3.0 | 20.09 | 34.35 | 3.80 | 3.2 | 24.53 | 41.95 |
| 21 | .66 | 2.16 | 1.42 | 4.2 | 2.8 | 16.45 | 23.35 | 3.99 | 3.01 | 29.29 | 28.81 |
| 22 | .62 | 2.02 | 1.25 | 4.4 | 2.6 | 13.5 | 16.9 | 4.18 | 2.82 | 16.78 | 20.98 |
| 23 | .57 | 2.0 | 1.14 | 4.6 | 2.4 | 11.02 | 13.78 | 4.37 | 2.63 | 13.87 | 15.81 |
| 24 | .54 | 1.9 | 1.02 | 4.8 | 2.2 | 9.03 | 10.30 | 4.56 | 2.44 | 11.47 | 11.70 |
| 25 | .49 | 2.2 | 1.08 | 5.0 | 2.0 | 7.40 | 7.55 | 4.75 | 2.25 | 9.49 | 10.25 |
| 26 | .46 | 2.2 | 1.01 | 5.2 | 1.8 | 6.05 | 6.53 | 4.94 | 2.06 | 7.85 | 7.93 |
| 27 | .40 | 1.9 | .76 | 5.4 | 1.6 | 4.95 | 5.0 | 5.13 | 1.87 | 6.49 | 4.93 |
| 28 | .32 | 1.9 | .61 | 5.6 | 1.4 | 4.05 | 3.08 | 5.32 | 1.68 | 5.37 | 3.28 |
| 29 | .28 | 1.5 | .42 | 5.8 | 1.2 | 3.32 | 2.03 | 5.51 | 1.49 | 4.44 | 1.87 |
| 30 | .22 | 2.5 | .55 | 6.0 | 1.0 | 2.71 | 1.14 | 5.70 | 1.3 | 3.67 | 2.02 |
| 31 | .21 | 1.8 | .38 | 6.2 | .8 | 2.23 | 1.23 | 5.89 | 1.11 | 3.03 | 1.15 |
| 32 | .19 | 1.9 | .36 | 6.4 | .6 | 1.82 | .69 | 6.08 | .92 | 2.51 | .90 |

Appendix A Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Offspring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|---|----------------------|---------|-----------|----------------|------------------------|---------|-----------|----------------|------------------------|
| | | | .20 | | | | .19 | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ |
| 33 | .17 | 2.3 | .39 | 6.6 | .4 | 1.50 | .54 | 6.27 | .73 | 2.08 | .81 |
| 34 | .15 | 2.16 | .32 | 6.8 | .2 | 1.22 | .48 | 6.46 | .54 | 1.72 | .55 |
| 35 | .14 | 1.4 | .20 | 7.0 | .0 | 1.0 | .32 | 6.65 | .35 | 1.42 | .28 |
| 36 | .09 | 1.9 | .17 | 7.2 | -.20 | .82 | .16 | 6.84 | .16 | 1.17 | .20 |
| 37 | .09 | 1.7 | .153 | 7.4 | -.40 | .67 | .11 | 7.03 | -.3 | .74 | .11 |
| 38 | .06 | 2.0 | .12 | 7.6 | -.60 | .55 | .08 | 7.22 | -.22 | .80 | .10 |
| 39 | .05 | 1.8 | .09 | 7.8 | -.80 | .35 | .04 | 7.41 | -.41 | .66 | .60 |
| 40 | .05 | 1.8 | .09 | 8.0 | -1.00 | .37 | .03 | 7.60 | -.60 | .26 | .02 |
| 41 | .05 | 1.8 | .09 | 8.2 | -1.20 | .30 | .03 | 7.79 | -.79 | .34 | .03 |
| 42 | .05 | 2.25 | .11 | 8.4 | -1.40 | .25 | .02 | 7.98 | -.90 | .43 | .05 |
| 43 | .05 | 2.25 | .11 | 8.6 | -1.60 | .20 | .02 | 8.17 | -1.17 | .31 | .03 |

Appendix A Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | | |
|------------------|--|--|----------------------|---------|-------------|---------------|-----------------------|---------|-----------|---------------|-----------------------|--|
| | | | .20 | | | | .19 | | | | | |
| x | l_x | m_x | $l_{x,m}$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_{x,m}$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_{x,m}$ | |
| 44 | .02 | 2.5 | .05 | 8.8 | -1.80 | .17 | .02 | 8.36 | -1.36 | .26 | .01 | |
| 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Total | | | | 1041.03 | Total | | | | 1211.3 | | | |

APPENDIX B

Life-fecundity Table with Calculations for Two Provisional r_m 's of T. cinnabarinus at 26.6° C.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | $r_m = .244$ $R_o = 33.0$ $T = 14.34$ | |
|------------------|--|--|----------------------|---------|-----------|----------------|------------------------|---------|-----------|----------------|---|--|
| | | | .25 | | | | .24 | | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | |
| 0- 7 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |  |
| 8 | 1.0 | .02 | .02 | 2.00 | 5.00 | 148.4 | 2.97 | 1.92 | 5.08 | 160.77 | 3.22 | |
| 9 | 1.0 | .15 | .15 | 2.25 | 4.75 | 115.58 | 17.34 | 2.16 | 4.84 | 126.47 | 18.97 | |
| 10 | 1.0 | .69 | .69 | 2.50 | 4.50 | 90.02 | 62.11 | 2.4 | 4.6 | 99.5 | 68.65 | |
| 11 | .98 | 2.37 | 2.32 | 2.75 | 4.25 | 70.11 | 162.65 | 2.64 | 4.36 | 78.3 | 181.66 | |
| 12 | .97 | 3.44 | 3.34 | 3.00 | 4.00 | 54.6 | 182.36 | 2.88 | 4.12 | 61.56 | 205.6 | |
| 13 | .94 | 4.91 | 4.62 | 3.25 | 3.75 | 42.52 | 196.4 | 3.12 | 3.88 | 48.4 | 223.61 | |
| 14 | .90 | 4.58 | 4.12 | 3.30 | 3.50 | 33.12 | 136.45 | 3.36 | 3.64 | 38.1 | 156.97 | |
| 15 | .74 | 4.85 | 3.59 | 3.75 | 3.25 | 25.8 | 92.6 | 3.60 | 3.40 | 29.96 | 107.56 | |

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Appendix B Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|--|----------------------|---------|-----------|----------------|------------------------|---------|-----------|----------------|------------------------|
| | | | .25 | | | | .24 | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ |
| 16 | .65 | 4.59 | 2.98 | 4.00 | 3.00 | 20.09 | 59.86 | 3.84 | 3.16 | 23.57 | 70.24 |
| 17 | .53 | 4.77 | 2.53 | 4.25 | 3.75 | 15.69 | 39.69 | 4.08 | 2.92 | 18.54 | 46.91 |
| 18 | .46 | 4.69 | 2.16 | 4.50 | 2.50 | 12.18 | 26.31 | 4.32 | 2.68 | 14.6 | 31.54 |
| 19 | .37 | 4.38 | 1.62 | 4.75 | 2.25 | 9.49 | 15.37 | 4.56 | 2.44 | 11.47 | 18.58 |
| 20 | .35 | 4.3 | 1.51 | 5.00 | 2.00 | 2.4 | 11.17 | 4.80 | 2.20 | 9.03 | 13.63 |
| 21 | .28 | 3.72 | 1.04 | 5.25 | 1.72 | 5.8 | 6.03 | 5.04 | 1.96 | 7.1 | 7.38 |
| 22 | .21 | 3.05 | .64 | 5.50 | 1.50 | 4.5 | 2.88 | 5.28 | 1.72 | 5.58 | 3.57 |
| 23 | .14 | 3.13 | .44 | 3.75 | 1.25 | 3.5 | 1.51 | 5.52 | 1.48 | 4.4 | 1.96 |
| 24 | .13 | 2.29 | .3 | 6.00 | 1.00 | 3.7 | .81 | 5.76 | 1.24 | 3.5 | 1.05 |
| 25 | .09 | 2.5 | .23 | 6.25 | .75 | 2.1 | .48 | 6.00 | 1.00 | 2.72 | .63 |
| 26 | .06 | 2.16 | .13 | 6.50 | .50 | 1.65 | .21 | 6.24 | .76 | 2.14 | .64 |
| 27 | .03 | 2.3 | .07 | 6.75 | .25 | 1.28 | .08 | 6.48 | .52 | 1.7 | .09 |
| 28 | .03 | 1.6 | .05 | 7.00 | .0 | 1 | .05 | 6.72 | .28 | 1.3 | .06 |

Appendix B Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|--|----------------------|-------------|-----------|----------------|--------------------------|-------------|-----------|----------------|--------------------------|
| | | | .25 | | | | .24 | | | | |
| x | l_x | m_x | $l_{x m_x}$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_{x m_x}$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_{x m_x}$ |
| 29 | .01 | 2.0 | .02 | 7.25 | .25 | .79 | .02 | 6.96 | .04 | 1.04 | .02 |
| | | | | Total | 1017.35 | | | Total | 1162.74 | | |

APPENDIX C

Life-fecundity Table with Calculations for Two Provisional r_m 's of T. cinnabarinus at 30.5° C.

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| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | $r_m = .286$ | $R_o = 27.3$ | $T = 11.57$ |
|------------------|--|--|----------------------|---------|-----------|----------------|------------------------|---------|-----------|----------------|------------------------|--------------|-------------|
| | | | .29 | | | | .28 | | | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | | |
| 0- 7 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |  |  |
| 8 | 1.00 | 1.2 | 1.2 | 2.32 | 4.68 | 107.7 | 129.2 | 2.24 | 4.76 | 116.75 | 140.1 | | |
| 9 | 1.00 | 2.67 | 2.67 | 2.61 | 4.39 | 80.64 | 215.2 | 2.52 | 4.48 | 88.24 | 235.6 | | |
| 10 | .98 | 4.44 | 4.35 | 2.90 | 4.10 | 60.34 | 196.4 | 2.80 | 4.20 | 66.69 | 290.1 | | |
| 11 | .90 | 4.58 | 4.12 | 3.19 | 3.81 | 45.15 | 186.0 | 3.08 | 3.92 | 50.4 | 207.65 | | |
| 12 | .81 | 5.28 | 4.28 | 3.48 | 3.52 | 33.78 | 144.57 | 3.36 | 3.64 | 38.09 | 163.02 | | |
| 13 | .67 | 4.29 | 2.87 | 3.77 | 3.23 | 25.28 | 72.55 | 3.64 | 3.36 | 28.79 | 82.6 | | |
| 14 | .57 | 3.7 | 2.11 | 4.06 | 2.94 | 18.92 | 39.9 | 3.92 | 3.08 | 21.76 | 45.9 | | |
| 15 | .45 | 2.74 | 1.23 | 4.35 | 2.65 | 14.15 | 17.4 | 4.2 | 2.80 | 16.45 | 20.23 | | |

Appendix C Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Offspring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|---|----------------------|---------|-----------|----------------|------------------------|---------|-----------|----------------|------------------------|
| | | | .29 | | | | .28 | | | | |
| x | l_x | m_x | $l_{x x}$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_{x x}$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_{x x}$ |
| 16 | .36 | 3.59 | 1.30 | 4.64 | 2.36 | 10.6 | 13.8 | 4.48 | 2.52 | 12.43 | 16.16 |
| 17 | .26 | 2.17 | .56 | 4.93 | 2.07 | 7.92 | 4.43 | 4.76 | 2.24 | 9.4 | 5.26 |
| 18 | .21 | 2.65 | .55 | 5.22 | 1.78 | 5.93 | 3.26 | 5.04 | 1.96 | 7.09 | 3.89 |
| 19 | .18 | 2.0 | .36 | 5.51 | 1.49 | 4.43 | 1.59 | 5.32 | 1.68 | 5.36 | 1.93 |
| 20 | .16 | 2.27 | .36 | 5.80 | 1.2 | 3.3 | 1.18 | 5.6 | 1.4 | 4.05 | 1.46 |
| 21 | .15 | 1.4 | .31 | 6.09 | .91 | 2.5 | .53 | 5.88 | 1.12 | 3.06 | .64 |
| 22 | .16 | 2.14 | .34 | 6.38 | .62 | 1.86 | .63 | 6.16 | .84 | 2.32 | .78 |
| 23 | .15 | 2.33 | .35 | 6.67 | .33 | 1.39 | .48 | 6.44 | .56 | 1.75 | .61 |
| 24 | .09 | 2.66 | .24 | 6.96 | .04 | 1.04 | .25 | 6.72 | .28 | 1.32 | .32 |
| 25 | .06 | 3.0 | .18 | 7.25 | .25 | .77 | .14 | 7.00 | 0 | 1.0 | .18 |

Appendix C Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Offspring Produced per Female | Provisional r_m 's | | | | | | | | | | |
|------------------|--|---|----------------------|---------|-----------|--------------|----------------|---------|-------------|--------------|----------------|--|---------|
| | | | .29 | | | | .28 | | | | | | |
| x | l_x | m_x | $l_{x,x}$ | r_m^x | $7-r_m^x$ | $e^{-r_m^x}$ | $e^{-7-r_m^x}$ | r_m^x | $7-r_m^x$ | $e^{-r_m^x}$ | $e^{-7-r_m^x}$ | | |
| 26 | .01 | 1.0 | .01 | 7.54 | .54 | .58 | .05 | 7.28 | -.28 | .75 | .01 | | |
| 27 | .01 | 0 | 0 | 7.38 | .83 | .43 | 0 | 0 | 0 | 0 | 0 | | |
| Total | | | | | | | | 1027.66 | Total | | | | 1216.43 |

APPENDIX D

Life-fecundity Table with Calculations for Two Provisional r_m 's of T. occidentalis at 22.7° C.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | $r_m = .158$ $R_0 = 17.31$ $T = 18.03$ |
|------------------|--|--|----------------------|---------|-----------|---------------|---------------------|---------|-----------|---------------|--|
| | | | $r_m = .15$ | | | | $r_m = .16$ | | | | |
| x | l_x | m_x | l_x^m | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_x^m$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_x^m$ |
| 0- 9 | .... | .... | .... | .... | .... | ..... | ..... | .... | .... | ..... | ..... |
| 10 | 1.00 | .21 | .21 | 1.50 | 5.50 | 244.69 | 51.39 | 1.60 | 5.40 | 221.41 | 46.50 |
| 11 | 1.00 | .71 | .71 | 1.65 | 5.35 | 210.61 | 149.53 | 1.76 | 5.24 | 188.67 | 133.96 |
| 12 | 1.00 | .76 | .76 | 1.80 | 5.20 | 181.27 | 137.77 | 1.92 | 5.08 | 160.77 | 122.19 |
| 13 | 1.00 | .57 | .57 | 1.95 | 5.05 | 156.02 | 88.93 | 2.08 | 4.92 | 137.00 | 78.09 |
| 14 | .95 | 1.02 | .97 | 2.10 | 4.90 | 134.29 | 130.26 | 2.24 | 4.76 | 116.75 | 113.25 |
| 15 | .95 | 1.15 | 1.09 | 2.25 | 4.75 | 115.58 | 125.90 | 2.40 | 4.60 | 99.48 | 108.43 |
| 16 | .93 | 1.12 | 1.04 | 2.40 | 4.60 | 99.48 | 103.46 | 2.56 | 4.44 | 84.76 | 88.15 |
| 17 | .90 | 1.16 | 1.04 | 2.55 | 4.45 | 83.63 | 86.98 | 2.72 | 4.28 | 72.24 | 75.13 |

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Appendix D Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|--|----------------------|---------|-----------|---------------|-----------------------|---------|-----------|---------------|-----------------------|
| | | | .15 | | | | .16 | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_x m_x$ |
| 18 | .86 | 1.05 | .90 | 2.70 | 4.30 | 73.70 | 66.33 | 2.88 | 4.12 | 61.56 | 55.40 |
| 19 | .86 | .92 | .80 | 2.85 | 4.15 | 63.43 | 50.74 | 3.04 | 3.96 | 42.46 | 41.97 |
| 20 | .86 | 1.19 | 1.02 | 3.00 | 4.00 | 54.60 | 53.70 | 3.20 | 3.80 | 44.70 | 44.79 |
| 21 | .83 | 1.03 | .85 | 3.15 | 3.85 | 47.00 | 39.95 | 3.36 | 3.64 | 38.09 | 32.38 |
| 22 | .81 | .94 | .76 | 3.30 | 3.70 | 40.45 | 30.74 | 3.52 | 3.48 | 32.46 | 24.67 |
| 23 | .79 | .84 | .66 | 3.45 | 3.55 | 34.81 | 22.98 | 3.68 | 3.32 | 27.66 | 18.26 |
| 24 | .74 | .87 | .64 | 3.60 | 3.40 | 29.96 | 19.17 | 3.84 | 3.16 | 23.57 | 15.09 |
| 25 | .71 | .93 | .66 | 3.75 | 3.25 | 25.79 | 17.02 | 4.00 | 3.00 | 20.09 | 13.26 |
| 26 | .57 | .88 | .50 | 3.90 | 3.10 | 22.20 | 11.10 | 4.16 | 2.84 | 17.17 | 8.59 |
| 27 | .52 | 1.00 | .52 | 4.05 | 2.95 | 19.11 | 9.94 | 4.32 | 2.68 | 14.59 | 7.59 |
| 28 | .52 | 1.32 | .68 | 4.20 | 2.80 | 16.45 | 11.19 | 4.48 | 2.52 | 12.43 | 8.45 |
| 29 | .52 | 1.09 | .57 | 4.35 | 2.65 | 14.15 | 8.07 | 4.64 | 2.36 | 10.59 | 6.04 |

Appendix D Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Offspring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|---|----------------------|---------|-----------|----------------|------------------------|---------|-----------|----------------|------------------------|
| | | | .15 | | | | .16 | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ |
| 30 | .50 | .66 | .33 | 4.50 | 2.50 | 12.18 | 4.02 | 4.80 | 2.20 | 9.03 | 2.98 |
| 31 | .50 | .76 | .38 | 4.65 | 2.35 | 10.49 | 3.99 | 4.96 | 2.04 | 7.69 | 2.92 |
| 32 | .48 | .70 | .34 | 4.80 | 2.20 | 9.03 | 3.07 | 5.12 | 1.88 | 6.55 | 2.23 |
| 33 | .48 | .50 | .24 | 4.95 | 2.05 | 7.77 | 1.87 | 5.28 | 1.72 | 5.59 | 1.34 |
| 34 | .40 | .35 | .14 | 5.10 | 1.90 | 6.69 | .94 | 5.44 | 1.56 | 4.76 | .67 |
| 35 | .33 | .43 | .14 | 5.25 | 1.75 | 5.76 | .81 | 5.60 | 1.40 | 4.06 | .57 |
| 36 | .31 | .38 | .12 | 5.40 | 1.60 | 4.95 | .59 | 5.76 | 1.24 | 3.46 | .42 |
| 37 | .31 | .46 | .14 | 5.55 | 1.45 | 4.26 | .60 | 5.92 | 1.08 | 2.95 | .41 |
| 38 | .24 | .40 | .09 | 5.70 | 1.30 | 3.67 | .33 | 6.08 | .92 | 2.51 | .23 |
| 39 | .19 | 1.00 | .19 | 5.85 | 1.15 | 3.16 | .60 | 6.24 | .76 | 2.14 | .41 |
| 40 | .16 | 1.10 | .17 | 6.00 | 1.00 | 2.72 | .46 | 6.40 | .60 | 1.82 | .31 |
| 41 | .14 | .30 | .04 | 6.15 | .85 | 2.34 | .09 | 6.56 | .44 | 1.55 | .06 |

Appendix D Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | | |
|------------------|--|--|----------------------|---------|-----------|----------------|--------------------------|-------------|-----------|----------------|--------------------------|---------|
| | | | .15 | | | | .16 | | | | | |
| x | l_x | m_x | $l_{x m_x}$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_{x m_x}$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_{x m_x}$ | |
| 42 | .09 | .50 | .04 | 6.30 | .70 | 2.01 | .08 | 6.72 | .28 | 1.32 | .05 | |
| 43 | .09 | 0 | 0 | 6.45 | .55 | 1.73 | 0 | 6.56 | .12 | 1.13 | 0 | |
| 44 | .09 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 45 | .09 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 46 | .04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 47 | .04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Total | | | | 1054.79 | | | | Total | | | | 1234.68 |

APPENDIX E

Life-fecundity Table with Calculations for Two Provisional r_m 's of T. occidentalis at 26.6° C.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | $r_m \doteq .192$ $R_0 = 12.3$ $T = 13.07$ | |
|------------------|--|--|----------------------|---------|-----------|---------------|-----------------------|---------|-----------|---------------|--|--|
| | | | .20 | | | | .19 | | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_x m_x$ | |
| 0- 7 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |  |
| 8 | 1.00 | .75 | .75 | 1.60 | 5.40 | 221.40 | 166.05 | 1.52 | 5.48 | 239.85 | 179.88 | |
| 9 | 1.00 | 1.15 | 1.15 | 1.80 | 5.20 | 181.27 | 208.46 | 1.71 | 5.29 | 198.34 | 228.09 | |
| 10 | .98 | 1.09 | 1.07 | 2.00 | 5.00 | 148.4 | 158.78 | 1.90 | 5.0 | 148.41 | 158.79 | |
| 11 | .91 | 1.19 | 1.08 | 2.20 | 4.80 | 121.5 | 131.2 | 2.09 | 4.91 | 135.14 | 146.49 | |
| 12 | .91 | 1.09 | .99 | 2.40 | 4.60 | 99.48 | 98.48 | 2.28 | 4.72 | 112.17 | 111.04 | |
| 13 | .91 | .88 | .80 | 2.60 | 4.40 | 81.45 | 65.16 | 2.47 | 4.53 | 92.75 | 74.02 | |
| 14 | .87 | .95 | .83 | 2.80 | 4.20 | 66.68 | 55.34 | 2.06 | 4.34 | 76.7 | 63.66 | |

Appendix E Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Offspring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|---|----------------------|---------|-----------|---------------|-----------------------|---------|-----------|---------------|-----------------------|
| | | | .20 | | | | .19 | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_x m_x$ |
| 15 | .83 | .95 | .79 | 3.00 | 4.00 | 54.59 | 43.12 | 2.85 | 4.15 | 63.43 | 50.11 |
| 16 | .80 | .68 | .54 | 3.20 | 3.80 | 44.7 | 24.14 | 3.04 | 3.96 | 52.45 | 28.32 |
| 17 | .66 | .80 | .53 | 3.40 | 3.60 | 36.59 | 19.39 | 3.23 | 3.77 | 43.38 | 22.99 |
| 18 | .62 | .75 | .46 | 3.60 | 3.40 | 29.96 | 13.96 | 3.42 | 3.58 | 35.87 | 16.5 |
| 19 | .58 | .63 | .36 | 3.80 | 3.20 | 24.53 | 8.83 | 3.61 | 3.39 | 29.66 | 10.67 |
| 20 | .58 | .70 | .40 | 4.00 | 3.00 | 20.08 | 8.03 | 3.80 | 3.19 | 24.28 | 9.7 |
| 21 | .55 | .65 | .36 | 4.20 | 2.80 | 16.45 | 5.92 | 3.99 | 3.01 | 20.29 | 7.30 |
| 22 | .51 | .58 | .30 | 4.40 | 2.10 | 13.46 | 4.04 | 4.18 | 2.82 | 16.78 | 5.03 |
| 23 | .40 | .68 | .27 | 4.60 | 2.40 | 11.02 | 2.98 | 4.37 | 2.63 | 13.87 | 3.75 |
| 24 | .34 | .44 | .15 | 4.80 | 2.20 | 9.03 | 1.36 | 4.56 | 2.44 | 11.47 | 1.72 |
| 25 | .32 | .40 | 1.28 | 5.00 | 2.00 | 7.39 | .96 | 4.75 | 2.25 | 9.49 | 1.23 |
| 26 | .30 | .50 | .15 | 5.20 | 1.80 | 6.05 | .91 | 4.94 | 2.06 | 7.86 | 1.18 |

Appendix E Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|--|----------------------|---------|-----------|----------------|------------------------|---------|-----------|----------------|------------------------|
| | | | .20 | | | | .19 | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ |
| 27 | .21 | .60 | .13 | 5.40 | 1.60 | 4.95 | .59 | 5.13 | 1.87 | 6.49 | .84 |
| 28 | .21 | .20 | .04 | 5.60 | 1.40 | 4.05 | .16 | 5.32 | 1.68 | 5.37 | .22 |
| 29 | .17 | .12 | .02 | 5.80 | 1.20 | 3.32 | .07 | 5.51 | 1.49 | 4.44 | .10 |
| 30 | .13 | 0 | 0 | 6.00 | 1.00 | 2.72 | 0 | 5.70 | 1.30 | 3.67 | 0 |
| 31 | .08 | 0 | 0 | 6.20 | .80 | 2.23 | 0 | 5.89 | 1.11 | 3.03 | 0 |
| 32 | .08 | 0 | 0 | 6.40 | .60 | 1.82 | 0 | 6.08 | .92 | 2.51 | 0 |
| 33 | .08 | 0 | 0 | 6.60 | .40 | 1.49 | 0 | 6.27 | .73 | 2.08 | 0 |
| 34 | .08 | 0 | 0 | 6.80 | .20 | 1.22 | 0 | 6.46 | .64 | 1.90 | 0 |
| 35 | .08 | 1.25 | .1 | 7.00 | 0 | 1.0 | .1 | 6.65 | .35 | 1.42 | .14 |
| 36 | .08 | 1.25 | .1 | 7.20 | -.20 | .82 | .08 | 6.84 | .16 | 1.17 | .09 |
| 37 | .08 | 1.75 | .14 | 7.40 | .40 | .67 | .09 | 7.03 | .03 | .97 | .09 |
| 38 | .08 | 2.0 | .16 | 7.60 | -.60 | .55 | .09 | 7.22 | .22 | .80 | .07 |

Appendix E Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | | |
|------------------|--|--|----------------------|---------|-------------|----------------|------------------------|---------|-----------|----------------|------------------------|--|
| | | | .20 | | | | .19 | | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | |
| 39 | .08 | 1.0 | .08 | 7.80 | -.80 | .45 | .04 | 7.41 | .41 | .66 | .03 | |
| 40 | .08 | 1.0 | .08 | 8.00 | -1.00 | .37 | .03 | 7.60 | .60 | .55 | .02 | |
| 41 | .08 | .75 | .06 | 8.20 | 1.20 | .30 | .02 | 7.79 | .79 | .45 | .01 | |
| 42 | .08 | .50 | .04 | 8.40 | 1.40 | .25 | .01 | 7.98 | .98 | .38 | .004 | |
| 43 | .08 | 1.75 | .14 | 8.60 | 1.60 | .20 | .03 | 8.17 | 1.17 | .31 | .009 | |
| 44 | .04 | 1.25 | .14 | 8.80 | 1.80 | .17 | .02 | 8.36 | 1.36 | .26 | .005 | |
| 45 | .0002 | 0 | 0 | 9.00 | 2.00 | .14 | 0 | 8.55 | 1.55 | 0 | 0 | |
| 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Total | | | | 1018.95 | Total | | | | 1122.09 | | | |

APPENDIX F

Life fecundity Table with Calculations for Two Provisional r_m 's of T. occidentalis at 30.5° C.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | $r_m = .182$ $R_o = 9.97$ $T = 12.64$ | |
|------------------|--|--|----------------------|---------|-----------|---------------|-----------------------|---------|-----------|---------------|---|--|
| | | | .19 | | | | .18 | | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{7-r_m^x}$ | $e^{7-r_m^x} l_x m_x$ | |
| 0- 6 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |  |
| 7 | 1.00 | .11 | .11 | 1.33 | 5.67 | 2.88 | 31.68 | 1.26 | 5.74 | 314.19 | 34.56 | |
| 8 | 1.00 | .51 | .51 | 1.52 | 5.48 | 239.85 | 122.32 | 1.44 | 5.56 | 257.24 | 131.19 | |
| 9 | .94 | 1.14 | 1.07 | 1.71 | 5.29 | 198.34 | 212.22 | 1.62 | 5.38 | 217.02 | 23.22 | |
| 10 | .91 | 1.12 | 1.02 | 1.90 | 5.10 | 164.02 | 167.30 | 1.80 | 5.20 | 181.27 | 18.49 | |
| 11 | .86 | .93 | .79 | 2.09 | 4.91 | 135.64 | 107.15 | 1.98 | 5.02 | 151.41 | 119.14 | |
| 12 | .81 | 1.03 | .83 | 2.28 | 4.72 | 112.17 | 93.10 | 2.16 | 4.84 | 126.47 | 104.97 | |
| 13 | .81 | 1.0 | .81 | 2.47 | 4.53 | 92.76 | 75.14 | 2.34 | 4.66 | 105.64 | 85.56 | |
| 14 | .78 | .96 | .74 | 2.66 | 4.34 | 76.71 | 56.77 | 2.52 | 4.48 | 88.23 | 65.29 | |

Appendix F Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|---------------------------------------|----------------------|---------|-----------|----------------|------------------------|---------|-----------|----------------|------------------------|
| | | | .19 | | | | .18 | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ |
| 15 | .73 | .88 | .64 | 2.85 | 4.15 | 63.43 | 40.60 | 2.70 | 4.30 | 7.37 | 47.17 |
| 16 | .70 | .76 | .53 | 3.04 | 3.96 | 52.46 | 27.80 | 2.88 | 4.12 | 6.15 | 32.6 |
| 17 | .45 | 1.11 | .49 | 3.23 | 3.77 | 43.38 | 21.26 | 3.06 | 3.94 | 51.41 | 25.19 |
| 18 | .40 | 1.0 | .40 | 3.42 | 3.58 | 35.87 | 14.35 | 3.24 | 3.76 | 42.95 | 17.18 |
| 19 | .40 | .46 | .18 | 3.61 | 3.39 | 29.67 | 5.34 | 3.42 | 3.58 | 35.87 | 6.46 |
| 20 | .32 | .58 | .18 | 3.80 | 3.20 | 24.53 | 4.42 | 3.60 | 3.40 | 29.96 | 5.39 |
| 21 | .27 | 1.0 | .27 | 3.99 | 3.01 | 20.29 | 5.48 | 3.78 | 3.22 | 25.03 | 6.76 |
| 22 | .24 | 1.0 | .24 | 4.18 | 2.82 | 16.78 | 4.03 | 3.96 | 3.04 | 29.91 | 7.18 |
| 23 | .24 | .88 | .21 | 4.37 | 2.63 | 13.87 | 3.33 | 4.14 | 2.86 | 17.46 | 3.67 |
| 24 | .24 | .88 | .21 | 4.56 | 2.44 | 11.42 | 2.41 | 4.32 | 2.08 | 14.59 | 3.06 |
| 25 | .21 | .63 | .13 | 4.25 | 2.25 | 9.49 | 1.23 | 4.50 | 2.50 | 12.18 | 1.58 |
| 26 | .19 | .57 | .10 | 4.94 | 2.06 | 7.85 | .78 | 4.68 | 2.32 | 10.18 | 1.02 |

Appendix F Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Off-spring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|--|----------------------|---------|-----------|----------------|------------------------|---------|-----------|----------------|------------------------|
| | | | .19 | | | .18 | | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ |
| 27 | .16 | .66 | .10 | 5.13 | 1.87 | 6.49 | .65 | 4.86 | 2.14 | 8.60 | .85 |
| 28 | .14 | .2 | .02 | 5.32 | 1.68 | 5.37 | .11 | 5.04 | 1.96 | 7.10 | .14 |
| 29 | .08 | .66 | .05 | 5.51 | 1.49 | 4.44 | .22 | 5.22 | 1.78 | 5.93 | .30 |
| 30 | .08 | .66 | .05 | 5.70 | 1.30 | 3.67 | .18 | 5.40 | 1.60 | 4.95 | .25 |
| 31 | .05 | 1.0 | .05 | 5.89 | 1.11 | 3.03 | .15 | 5.58 | 1.42 | 4.14 | .21 |
| 32 | .05 | 1.0 | .05 | 6.08 | .92 | 2.51 | .11 | 5.76 | 1.24 | 3.46 | .17 |
| 33 | .05 | .5 | .02 | 6.27 | .73 | 2.08 | .04 | 5.94 | 1.06 | 2.89 | .06 |
| 34 | .05 | .5 | .02 | 6.46 | .54 | 1.72 | .03 | 6.12 | .88 | 2.41 | .05 |
| 35 | .05 | 1.0 | .02 | 6.65 | .35 | 1.42 | .07 | 6.30 | .70 | 2.01 | .10 |
| 36 | .05 | 1.0 | .05 | 6.84 | .16 | 1.17 | .06 | 6.48 | .52 | 1.68 | .08 |
| 37 | .05 | 1.0 | .05 | 7.03 | .03 | .97 | .05 | 6.66 | .34 | 1.40 | .67 |
| 38 | .05 | 0 | 0 | 7.22 | .22 | .80 | 0 | 6.84 | .16 | 1.17 | 0 |

Appendix F Cont'd.

| Adult Age (days) | Proportion of Individuals Still Alive at Age X | Number Female Offspring Produced per Female | Provisional r_m 's | | | | | | | | |
|------------------|--|---|----------------------|---------|-----------|----------------|------------------------|---------------------|-----------|----------------|------------------------|
| | | | .19 | | | | .18 | | | | |
| x | l_x | m_x | $l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ | r_m^x | $7-r_m^x$ | $e^{-7-r_m^x}$ | $e^{-7-r_m^x} l_x m_x$ |
| 39 | .02 | 0 | 0 | 7.41 | .41 | .66 | 0 | 7.02 | .02 | .98 | 0 |
| 40 | 0 | 0 | 0 | 7.60 | .60 | .55 | 0 | 7.20 | .20 | .82 | 0 |
| Total | | | | 998.38 | | | | Total 1117.26 | | | |

APPENDIX G

Starvation of *T. occidentalis* Gravid Females Held on Bean Leaves at Three Temperature Regimes.

| Number Days To Starvation | Percent to Total | | |
|------------------------------|---|---|---|
| | 15.0-30.0° C $\bar{X} = 22.7^\circ \text{C}$ | 19.9-33.6° C $\bar{X} = 26.6^\circ \text{C}$ | 23.1-38.6° C $\bar{X} = 30.5^\circ \text{C}$ |
| 1 | 0.00 | 3.33 | 6.66 |
| 2 | 0.00 | 3.33 | 23.33 |
| 3 | 0.00 | 6.66 | 40.00 |
| 4 | 6.66 | 13.33 | 20.00 |
| 5 | 13.33 | 26.66 | 10.00 |
| 6 | 20.00 | 20.00 | 0.00 |
| 7 | 23.33 | 13.33 | 0.00 |
| 8 | 16.66 | 10.00 | 0.00 |
| 9 | 10.00 | 3.33 | 0.00 |
| 10 | 6.66 | 0.00 | 0.00 |
| 11 | <u>3.33</u> | <u>0.00</u> | <u>0.00</u> |
| | 100.00 | 100.00 | 100.00 |

APPENDIX H

Percent of T. cinnabarinus Eggs Consumed by Adult Female T. occidentalis on 5.1 cm² Leaf Discs at Three Temperature Regimes Within 24 Hours.

Percent Eggs Consumed

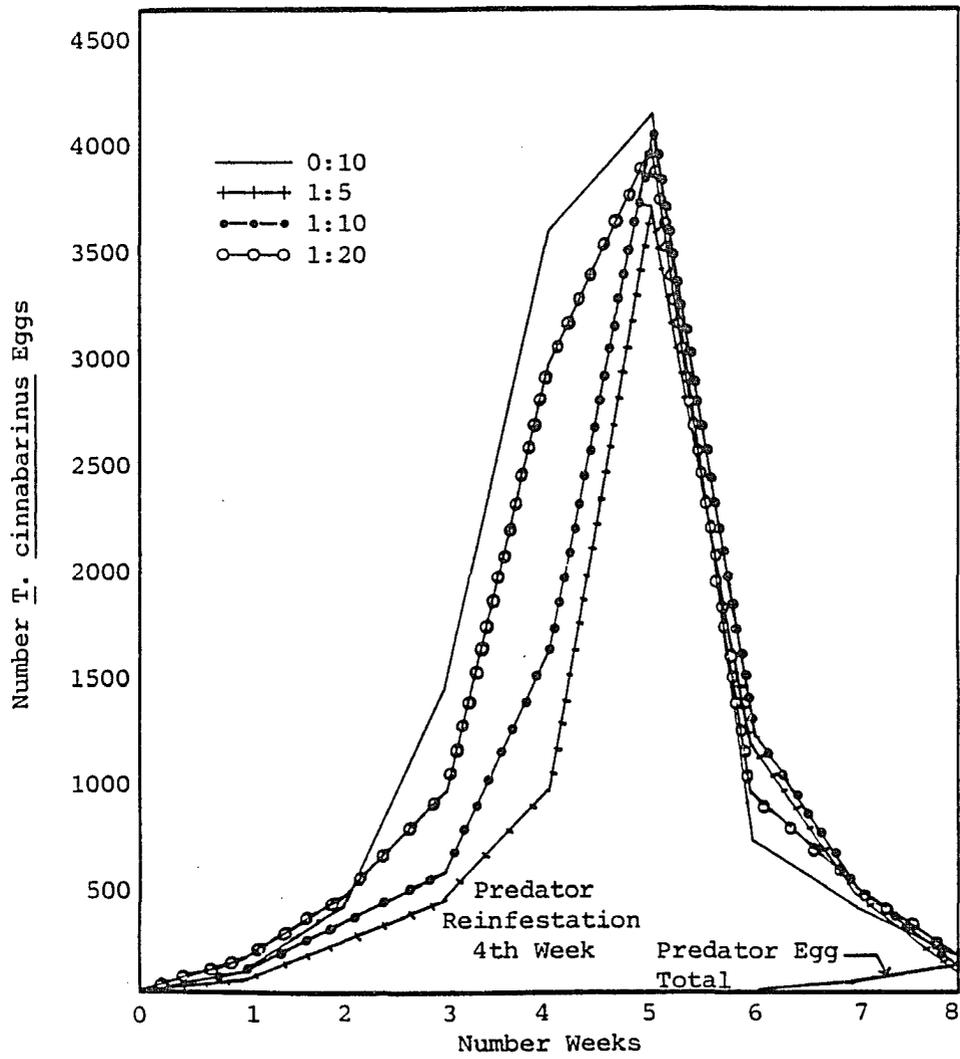
| ° C | No. Replications | No. Eggs Offered | Egg Placement | | |
|------|------------------|------------------|----------------|-----------------------|--------------|
| | | | Center of Disc | Dispersed from Center | Edge of Disc |
| 22.7 | 32 | 3 | 86 | 76 | 64 |
| 26.6 | 40 | 5 | 91 | 86 | 75 |
| 30.5 | 38 | 7 | 97 | 84 | 82 |

APPENDIX I

Effect of Three Temperature Regimes on 10:1 Ratio of T. cinnabarinus and T. occidentalis After 7, 10, 14, 21, and 28 Days on Bean Plants.

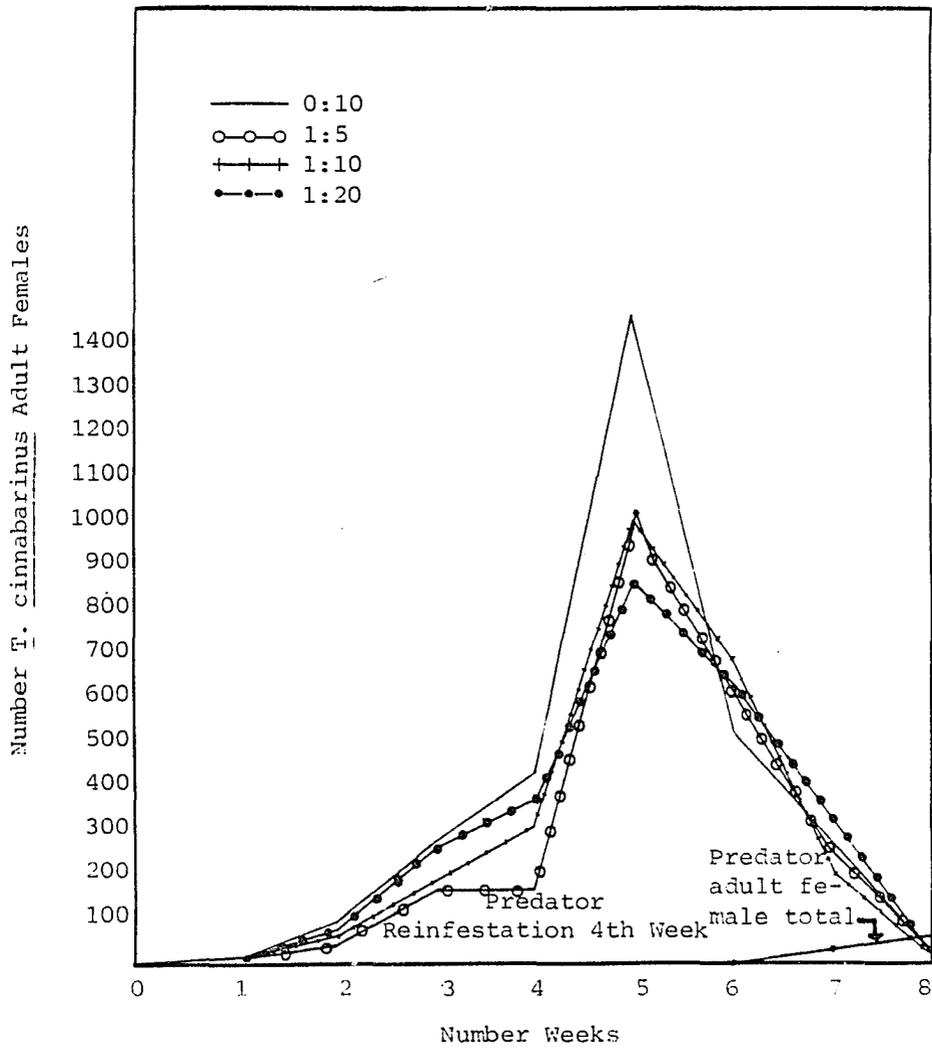
| °C | No. Replications | No. Days | Life Stage Present | | |
|------|------------------|----------|------------------------|------------------------|-----------|
| | | | Eggs | Immatures | Females |
| | | | <u>T. cinnabarinus</u> | <u>T. occidentalis</u> | |
| | | | \bar{X} | \bar{X} | \bar{X} |
| 22.7 | 9 | 14 | 26.5:43 | 12.7:5.5 | 9.3:1.6 |
| | 8 | 28 | 13.8:5.5 | 11.6:5.3 | 5.3:2.1 |
| 26.6 | 2 | 7 | 47:1 | 34:5 | 10:0 |
| | 2 | 10 | 17:2 | 6:6 | 2.5:2 |
| | 5 | 21 | 15.6:5.6 | 2.6:3.2 | 2.6:1.4 |
| | 3 | 28 | 5.3:1 | 5.3:4.3 | 1.6:.6 |
| 30.5 | 4 | 7 | 11:4 | 8:15 | 5:2 |
| | 4 | 10 | 12:3 | 7:1 | 2:2.5 |
| | 4 | 14 | 83:6 | 43:5 | 10:6 |

APPENDIX J



Number of Predator and Prey Eggs from 0:10, 1:5, 1:10, 1:20 *T. occidentalis*/
T. cinnabarinus Ratios on Bean Plants.

APPENDIX K



Number of Predator and Prey Adult Females from 0:10, 1:5, 1:10, 1:20 T. occidentalis/ T. cinnabarinus Ratios on Bean Plants.

LIST OF REFERENCES

- Andrewartha, H. G. and L. C. Birch. 1954. The Distribution and Abundance of Animals. Chicago: The University of Chicago Press. 782 pp.
- Ballard, R. C. 1953. The biology of the predaceous mite, Typhlodromus fallacis at 78° F. Ohio J. Sci. 54: 175-179.
- Birch, L. C. 1948. The intrinsic rate of natural increase of an insect population. J. Anim. Ecol., 17: 15-26.
- Boudreaux, H. B. and G. Dosse. 1963. Concerning the names of some common spider mites. Adv. Acarol. 1: 350-364.
- Bursell, E. 1970. An Introduction to Insect Physiology. New York: Academic Press. 276 pp.
- Carey, J. R. and J. W. Bradley. 1982. Developmental rates, vital schedules, sex ratios, and life tables for Tetranychus urticae, T. turkestanii and T. pacificus (Acarina: Tetranychidae) on cotton. Acarol. 23: 333-344.
- Chant, D. A. 1959. Phytoseiid mites (Acarina: Phytoseiidae). Part I. Bionomics of seven species in southeastern England. Can. Entomol. 91: 1-44.
- Chant, D. A. 1960. Phytoseiid mites. Parts I and II. Can. Entomol., 91, suppl. 12: 1-166.
- Chant, D. A. 1961. The effect of prey density on prey consumption and oviposition in adults of Typhlodromus (T.) occidentalis (Acarina: Phytoseiidae) in the laboratory. Can. J. Zool. 29: 311-315.
- Chant, D. A. 1963. Some mortality factors and the dynamics of orchard mites. Mem. Entomol. Soc. Can. 32: 33-40.
- Davis, D. W. 1961. Biology of Tetranychus multisetis the polychaetous form of T. cinnabarinus. Ann. Entomol. Soc. Amer. 54: 30-34.

- Flaherty, D. L. and C. B. Huffaker. 1970. Role of Metaseiulus occidentalis. *Hilgardia*, 40: 267-308.
- Force, D. C. and P. S. Messenger. 1964. Duration of development, generation time, and longevity of three hymenopterous parasites of Therioaphis maculata, reared at various constant temperatures. *Ann. Entomol. Soc. Amer.* 54: 405-413.
- Gunther, F. A. and L. R. Jeppson. 1960. *Modern Insecticides and World Food Production*. London: Chapman and Hill. 284 pp.
- Harcourt, D. G. 1969. The development and use of life tables in the study of natural insect populations. *Ann. Rev. Entomol.* 14: 175-196.
- Harrison, R. A. and A. G. Smith. 1961. The influence of temperature and relative humidity on the development of eggs and on the effectiveness of ovicides against Tetranychus telarius. *New Zealand J. Sci.* 4: 540-549.
- Hazan, A., U. Gerson and A. S. Tahori. 1974. Life history and life tables of the carmine spider mite. *Acarol.* 15: 414-440.
- Herbert, H. J. 1956. Laboratory studies on some factors in the life history of the predaceous mite Typhlodromus tiliae Oudms. *Can. Entomol.* 88: 701-704.
- Howe, R. W. 1953. The rapid determination of the intrinsic rate of increase of an insect population. *Ann. Appl. Biol.* 40: 134-151.
- Hoy, M. A., W. W. Barnett and W. D. Reil. 1982. Large scale releases of pesticide resistant spider mite predators. *Calif. Agr.* Jan-Feb, Vol. 35, Nos. 1 and 2: 8-10.
- Hoy, M. A., D. L. Flaherty, W. Peacock and D. Culver. 1979a. Vineyard and laboratory evaluation of methomyl dimethoate, and permethrin for a grape pest management program in the San Joaquin Valley of Calif. *J. Econ. Entomol.* 72: 250-255.
- Hoy, M.A., R. T. Roush and K. B. Smith. 1979b. Spider mites and their predators in San Joaquin Valley almond orchards. *Calif. Agri.* 33(10): 11-13.

- Hoyt, S. C. 1969. Integrated chemical control of insects and biological control of mites on apples in Washington. *J. Econ. Entomol.* 62: 74-86.
- Hoyt, S. C. and L. E. Caltagirone. 1970. The developing programs of integrated control of pests of apples in Washington and peaches in California. *Biological Control*, ed. C. D. Huffaker. New York: Plenum Publishing Corp. 395-421.
- Huffaker, C. B. and D. L. Flaherty. 1966. Potential of biological control of two-spotted spider mites on strawberries in California. *J. Econ. Entomol.* 59: 786-792.
- Huffaker, C. B. and C. E. Kennett. 1953. Developments toward biological control of cyclamen mite on strawberries in California. *J. Econ. Entomol.* 46: 802-812.
- Huffaker, C. B., M. van de Vrie and J. A. McMurtry. 1969. The ecology of tetranychid mites and their natural control. *Ann. Rev. Entomol.* 14: 125-174.
- 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(11): 291-458.
- Iglinsky, W. and C. F. Rainwater. 1954. Life history and habits of Tetranychus desertorium and T. bimaculatus on cotton. *J. Econ. Entomol.* 74: 1084-86.
- Jeppson, L. R., H. H. Keifer and E. W. Baker. 1975. *Mites Injurious to Economic Plants*. Berkeley, California: Univ. of Calif. Press. 614 pp.
- Klostermeyer, E. C. 1959. Insecticide-induced population changes in four mite species on alfalfa. *J. Econ. Entomol.* 52: 991-994.
- Kono, T. and C. S. Papp. 1977. *Handbook of agricultural pests*. Sacramento, California: State of California Dept. of Food and Agriculture. 134-180.
- Kuenen, D. J. 1947. On the ecological significance of two predators of Metatetranychus ulmi. C. L. Koch (Acari, Tetranychidae). *Tijdschr. Entomol.* 88: 303-312.

- Laing, J. E. 1969a. Life history and life table of Tetranychus urticae Koch. *Acarol.* 11: 32-42.
- Laing, J. E. 1969b. The life history and life table of Metaseiulus occidentalis. *Ann. Entomol. Soc. Amer.* 61(5): 978-982.
- Laing, J. E. and J. A. L. Osborn. 1974. The effect of prey density on the functional and numerical responses of three species of predatory mites. *Entomophaga.* 19: 267-277.
- Lee, M. S. and D. W. Davis. 1968. Life history and behavior of the predatory mite Typhlodromus occidentalis in Utah. *Ann. Entomol. Soc. Amer.* 61: 251-257.
- Leopold, A. 1933. *Game Management*. New York: Charles Scribner's Sons. 481 pp.
- Little, T. M. and F. J. Hills. 1978. *Agricultural Experimentation Design and Analysis*. New York: John Wiley and Sons, Inc. 350 pp.
- McLanahan, R. J. 1968. Influence of temperature on the reproductive potential of two mite predators of the two-spotted spider mite. *Can. Entomol.* 100: 549-556.
- McMurtry, J. A., C. B. Huffaker and M. van de Vrie. 1970. I. Tetranychus enemies: their biological characters and the impact of spray practices. *Hilgardia.* 40 (11): 331-390.
- Nickel, J. L. 1960. Temperature and humidity relationships of Tetranychus desertorium Banks with special reference to distribution. *Hilgardia.* 30(2): 41-100.
- Oatman, E. R., J. A. McMurtry, F. E. Gilstrap, and V. Voth. 1977. Effect of releases of Amblyseius californicus, Phytoseiulus persimilis, and Typhlodromus occidentalis on the two-spotted spider mite on strawberry in southern California. *J. Econ. Entomol.* 70: 45-47.
- Pringle, K. L. 1975. The seasonal occurrence of phytophagous mites and their predators on apple tress in the Elgin area. *Proc. I Congr. Entomol. Soc. Southern Africa.* 131-140.

- Putnam, W. L. 1962. Life-history and behavior of the predaceous mite Typhlodromus (T.) caudiglans Schuster in Ontario, with notes on the prey of related species. *Can. Entomol.* 94: 163-177.
- Roush, R. T. and F. W. Plapp. 1982. Biochemical genetics of resistance to aryl carbamate insecticides in the predaceous mite Typhlodromus occidentalis. *J. Ann. Soc. Amer.* April: 304-307.
- Sharma, N. 1966. Factors influencing the effectiveness of Typhlodromus occidentalis Nesbitt as a predator of Tetranychus urticae Koch. Unpublished M.S. thesis. University of California, Berkeley. 169 pp.
- Shih, C. T., S. L. Poe and H. O. Cromroy. 1975. Biology, life table, and intrinsic rate of increase of Tetranychus urticae. *Ann. Entomol. Soc. Amer.* 69: 362-364.
- Smith, J. C. 1965. A laboratory and greenhouse evaluation of Typhlodromus fallacis as a predator of Tetranychus spp. Ph.D. dissertation. Louisiana State University. 93 pp.
- Smith, C. and E. W. Baker. 1968. Names of the two-spotted mite and the carmine mite to be redesignated. U. S. Dept. Agr. Coop. Econ. Ins. Rept. 18(47): 1080.
- Solomon, M. E. 1957. Dynamics of insect populations. *Ann. Rev. Entomol.* 2: 121-142.
- Southwood, T. R. E. 1966. *Ecological Methods with Particular Reference to the Study of Insect Populations*. London: Methuen and Co., Ltd. 391 pp.
- Tahori, A. S. and B. Raccah. 1970. Resistance to acaricides in the carmine spider mite in Israel. *J. Econ. Entomol.* 63: 545-548.
- Tuttle, D. M. and E. W. Baker. 1968. Spider mites of southwestern United States and a revision of the family Tetranychidae. Tucson: Univ. of Arizona Press. 143 pp.
- Tuttle, D. M. and M. H. Muma. 1973. Phytoseiidae (Acarina: Mestogimata) inhabiting agricultural and other plants in Arizona. *Ariz. Agr. Exp. Sta. Bull.* 208. 55 pp.

- Waters, N. 1955. Biological and ecological studies of Typhlodromus mites as predators of the six-spotted spider mite. Unpublished Ph.D. dissertation. Univ. of California, Berkeley. 169. pp.
- Watson, T. F. 1964. Influence of host plant condition on population increase of Tetranychus telarius (Linnaeus) (Acarina: Tetranychidae). Hilgardia. 35 (11). 273-322.
- Werner, F. G., L. Moore and T. F. Watson. 1979. Arizona Cotton Insects. Cooperative Extension Service, Tucson: University of Arizona Bulletin, A23R. 38 pp.