The Functional Responses of *Stethorus punctum*[1] to Densities of the European Red Mite[2,3,4]

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ABSTRACT

The functional response of the predator *Stethorus punctum* (LeConte) was tested at various densities of the European red mite, *Panonychus ulmi* (Koch). Overwintered *S. punctum* adult females were tested at a range of densities from 4–30 mites/cage, whereas, the 2nd and 3rd generation larvae, female and male adults were tested at a range of densities from 4–80 mites/cage. Various types of mathematical models were fit to the data, using weighted regression analysis, to estimate the relationship between the number of prey eaten and prey density. Three types of functional response curves were exhibited by the different stages and sexes of *S. punctum*, a linear response, a negatively accelerated curve and an S-shaped rise to a plateau. Two factors partially responsible for these 3 types may be the different environmental conditions for each test and the replenishment of prey on an hourly basis.

S. punctum was found to stop feeding at dusk and to resume ca. 2 h after sunrise. The feeding of *S. punctum* increased as temperatures rose during the day with a maximum consumption occurring during the warm afternoon hours.

Chant (1964) stated that studies on factors regulating pest populations must be undertaken to select the influential ones and learn how to alter them in a way to reduce populations. In Pennsylvania apple orchards, these studies have been undertaken and the influential factors selected for further refinement and study. The Pennsylvania integrated pest management program for apples is based on the biological control of the European red mite, *Panonychus ulmi* (Koch), by the native predator *Stethorus punctum* (LeConte) integrated with chemical control of other pests (Mowery et al. 1975). If further refinement and improvement of this program is to be attained, a closer evaluation must be made of the predator, *S. punctum*.

In evaluating any predator, an examination must be made of the factors affecting predation. These factors are divided into 5 main groups by Leopold (1933): (a) prey density, (b) predator density, (c) characteristics of the environment, (d) characteristics of the prey, (e) characteristics of the predator. Holling (1961) stated that 2 of these factors, prey and predator density, are inevitable features of every predator-prey relationship. Two terms were acknowledged by Solomon (1949) to describe this relationship: the functional response, which refers to the destruction of more prey per individual predator as the prey's numbers increase, and the numerical response, which relates to an increase in the number of predators following an increase in prey density.

Research demonstrating functional responses of various insect predators to prey density exists (Debach and Smith 1941, Ullyett 1949, Burnett 1951, 1954, Miller 1959, 1960, Watt 1959, Holling 1966, and Messenger 1968). The genus *Stethorus* contains specialized predators of mites. The published research on *Stethorus* deals primarily with the prey consumption capacity when a surplus of prey is present (Fleschner 1950, Collyer 1953, 1964, Putman 1955, Kaylani 1967, Chazeau 1974). Colburn and Asquith (1971) demonstrated that *S. punctum* adults and larvae can, in the presence of an abundance of prey, consume an average of 9.75 and 9.67, respectively, immature and mature mites per hour. It seems logical, therefore, that within limits *Stethorus* would exhibit a functional response to prey density.

The experiment reported herein was designed to determine if *S. punctum* functionally responds to increases in density of its prey, the European red mite.

Materials and Methods

Colburn and Asquith (1971) found there were 3 generations a year of *S. punctum* in south-central Pennsylvania. The 1st feeding test was conducted in the spring to determine the functional response of the overwintered adults to mite density. The summer generations of *S. punctum* were also tested during July and August. *S. punctum* adults were collected from orchards surrounding Biglerville, Pa., and transported to the laboratory where they were sexed. The *S. punctum* male was identified by a small notch in the last abdominal sternite. The adults were placed in 12-oz styrofoam cups with a surplus of European red mites. Twelve hours before the beginning of the test the adults were transferred to other cups devoid of mites. The purpose was to maintain all adults at the same level of hunger.

All feeding trials were conducted in a specially

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[2] Acarina: Tetranychidae.

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Table 1.—Mean number of European red mite adult females eaten/hour (± standard error) by overwintered *S. punctum* adult females at a mean temperature of 26.22°C (range 13–33).

Prey density	Prey eaten/hour
4	1.38±0.16
12	2.92±0.21
16	4.42±0.36
20	4.63±0.47
30	5.32±0.23

designed cage similar to the one described by Colburn and Asquith (1971), with the following modifications. The cage was constructed from a 2×2×2-in. plastic box. The leaf to be used in the cage was cut to 1¼-in.^{2} and brushed free of mites or mite eggs. The total surface area in the cage for *S. punctum* and the European red mite to inhabit was 25.56-in.^{2}. A leaf petiole was inserted through a rubber stopper on one side of the cage and the cage rested in a vial of water with the leaf petiole submerged. The petiole was glued into place at the point of contact with the rubber stopper to prevent mite escape.

At the beginning of the test, only active adult female mites were transferred to the excised leaf using a camel's hair brush. One *S. punctum* female adult was placed in each cage and the test was started. Overwintered *S. punctum* adults were tested at the following densities: 4, 12, 16, 20 and 30 mites/cage. Each density level was started and observed on a staggered interval and the cages were checked every hour to record the number of mites eaten, to remove any mite eggs present, and to replenish the mites to the original density level. This was done to be representative of the orchard where *S. punctum* have a variable supply of mites available to them. Four replicates were started at each density level. Each *S. punctum* was assigned randomly to a cage. After an adult spent one hour in a cage, it was transferred by suction using a vacuum pump to a 2nd cage containing mites at the original density level. The number of mites eaten in the 1st cage was then recorded and the population replenished to the original density level. This method was used throughout the feeding test.

A screened insectary was used for the feeding trials. Small electric fans were located at each end of the table to circulate air through the cages. An identical cage with an inserted thermometer recorded the actual temperature within the cage. Temperature readings were taken every ½ hour.

The summer feeding tests were conducted similarly to the method described above except for minor changes. During these tests, 2nd and 3rd generation *S. punctum* larvae, female and male adults were tested. The larvae represented an age distribution of late 3rd and early 4th instars. The mite density levels were: 4, 8, 12, 16, 20, 50 and 80 mites/cage. Because of the nature of the test, the *S. punctum* adults were first tested at the lower densities (4, 8, 12 and 16) and then at a later date the higher densities (20, 50 and 80). Thus, for each feeding test, there was a different set of environmental conditions because the tests were run on different days.

Results and Discussion

Various mathematical models were fit to the data, using weighted regression analysis, to estimate the relationship between the number of prey eaten per hour and prey density for the different stages and generations of *S. punctum*. The purpose of testing various models was to find one that could adequately predict this relationship. The criteria used for evaluating each model was the residual sum of squares and the R-squared value.

In the spring test, the consumption rate of the overwintered *S. punctum* adult females increased as prey density increased from 4–30 (Table 1). Two

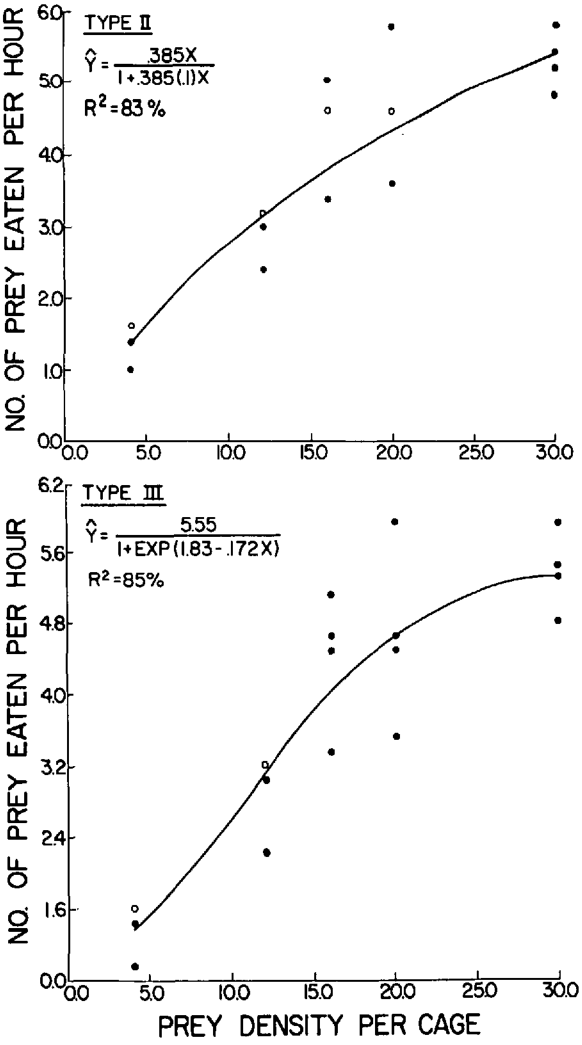

FIG. 1.—Top: Functional response of overwintered female *S. punctum* adults to increases in density of the European red mite using the Holling model; Bottom: using a logistic model. Open circles represent 2 data values at the same position.

Table 2.—Mean number of European red mite adult females eaten/hour (± standard error) by 2nd and 3rd generation *S. punctum* female and male adults and larvae at various prey densities and temperatures.

	Female adults			Male adults			Larvae		
Prey density	No. mites eaten	Mean temp. °C	Temp. range	No. mites eaten	Mean temp. °C	Temp. range	No. mites eaten	Mean temp. °C	Temp. range
4	1.39±0.13	27.70	15–35	1.12±0.47	27.74	18–32	1.13±0.39	29.95	16–37
8	2.00±0.57	27.70	15–35	1.68±0.11	27.74	18–32	2.41±0.61	29.95	16–37
12	3.56±0.26	27.70	15–35	1.73±0.52	27.74	18–32	2.25±0.48	29.95	16–37
16	4.13±0.24	27.70	15–35	2.45±1.36	27.74	18–32	2.58±0.44	29.95	16–37
20	2.69±0.33	26.96	15–34	2.35±0.16	28.31	19–33	3.63±0.58	26.96	15–34
50	7.12±1.11	26.96	15–34	4.42±0.47	28.31	19–33	4.42±0.61	26.96	15–34
80	10.44±1.09	26.96	15–34	5.52±0.26	28.31	19–33	7.10±0.86	26.96	15–34

models were found to fit the data, the one model being that of Holling (1959) describing a simple functional response or type II, the other a logistic model or type III response (Fig. 1). The type II response, which is a negatively accelerated rise to a plateau, is found to be common among insects (Pimentel and Cranston 1960, Morris 1963, Holling 1966). The type III response, which is an S-shaped rise to a plateau, has generally been found among small mammals (Holling 1959) but also has been reported by some workers using parasites (Burnett 1964, Takahashi 1968). Since the resulting R-squared values of both candidate models were nearly identical and each did not show any lack of fit, both models are presented and statistically either one can be used to explain this functional relationship. Possibly, with an increase in the number of replicates, one model would be dominant, however, due to the design of the experiment this was not possible to determine.

The first feeding test was conducted for 24 h to determine if *S. punctum* were also nocturnal in feeding. It was found that at approximately dusk all feeding activity ceased. *S. punctum* resumed feeding ca. 7:30 AM the following day. This type of feeding behavior was found to occur with both sexes and with larvae. Observation in the orchard at night further supported this finding. Thus, all subsequent feeding tests were started at 7:00 AM and continued until dusk.

The consumption rate of the 2nd and 3rd generation *S. punctum* increased with increasing prey density (Table 2). Since the low and high densities of prey for these individuals were run under different environmental conditions, each set of data was analyzed separately. A linear, or type I response (Holling 1959) fit the data best for *S. punctum* adult females and larvae at the lower densities with R-squared values of 91% and 33%, respectively (Fig. 2). The model of best fit for the adult male data was the type II with an R-squared value of 34%. Two possible explanations for the poor fits by both larvae and adult males to any model can be

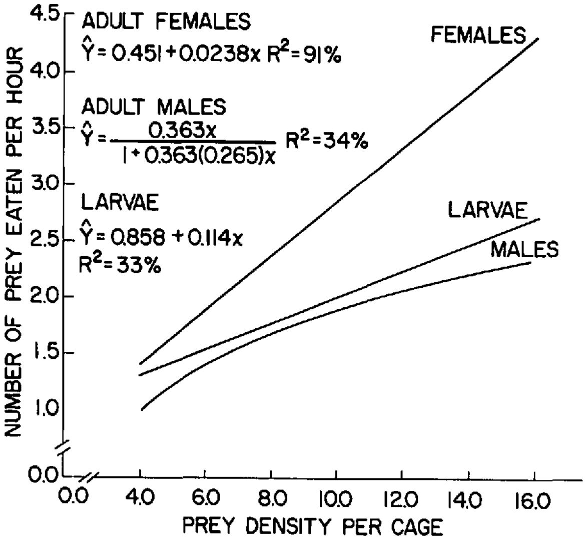

FIG. 2.—Functional responses of 2nd and 3rd generation *S. punctum* female and male adults and larvae to increases in density (4, 8, 12 and 16 mites/cage) of the European red mite.

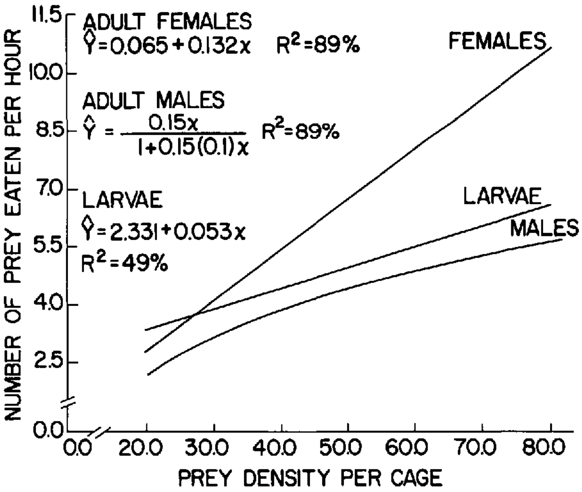

FIG. 3.—Functional responses of 2nd and 3rd generation *S. punctum* female and male adults and larvae to increases in density (20, 50 and 80 mites/cage) of the European red mite.

presented. In the case of the males, the poor fit could be attributed to a mixture of overwintered and summer generation adults. When the test was performed (early July) the overwintering generation was beginning to die off after having produced their progeny, thus any of these individuals selected could have been in poor physical condition. The poor fit of the larval data could be attributed to a few larvae beginning to pupate near the end of the feeding, thus causing some distortion in their functional response. Another possible contributing factor could be the amount of variability found in the feeding responses of both the adult males and larvae at the lower densities (Table 2).

At the higher prey densities the linear response (type I) provided the best fit to the data for *S. punctum* adult females and larvae producing R-squared values of 89% and 49%, respectively (Fig. 3). The response of the adult males was again found to be type II.

The above type I responses produced by *S. punctum* adult females and larvae have only been reported in a few experiments. Atival and Sethi (1963) reported that the coccinellid *Coccinella septempunctata* L. showed a type I response in attacking the cabbage aphid *Lipaphis erysimi* (Kalt). Also Chant (1961) demonstrated that the predatory mite, *Typhlodromus* (T.) *occidentalis* exhibited a type I response to various densities of *Tetranychus telarius.* In reality, a predator functionally responding to increases in prey density, must at some point reach a prey density where its rate of consumption can no longer increase. Holling (1959a) stated that the 2 simple time consuming behaviors—searching and handling of prey—are the basic components in any predator-prey system; therefore, at high prey densities the time required to handle and kill prey becomes limiting. In the *S. punctum* female and larval feeding studies this prey density was not attained. During one feeding test, however, when *S. punctum* adult females were being tested at densities of 20, 50 and 80 mites/cage, 2 replicates were maintained at 100 mites/cage. The number of mites consumed per hour decreased from 10.44 at 80 mites/cage to 8.44 at 100 mites/cage. It should be mentioned that replenishment of the mites was made every 2 h in-

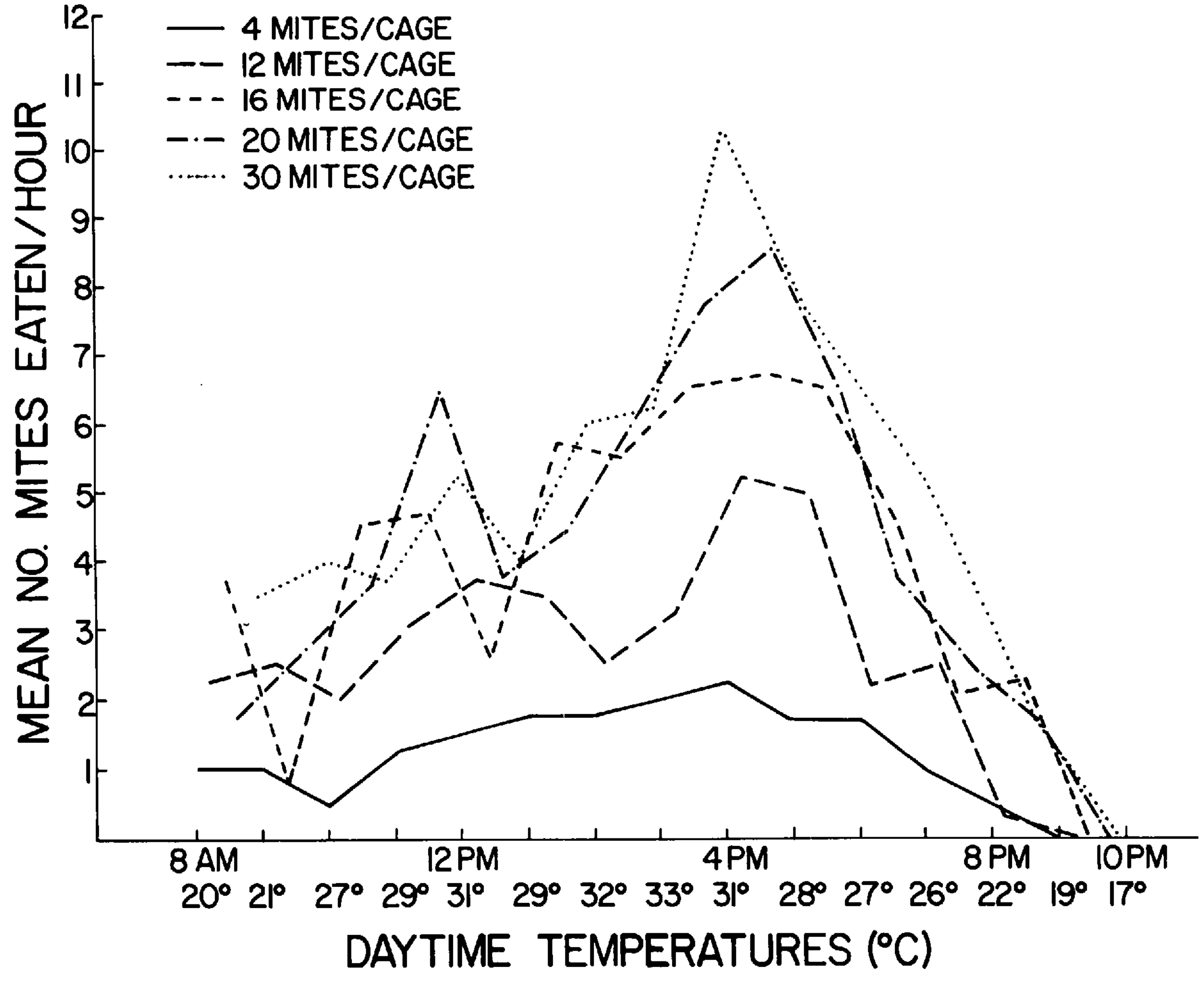

FIG. 4.—Relationship between the functional response of *S. punctum* to various densities of the European red mite and temperature during the spring.

stead of the normal one hour. This possibly presents evidence that as expected there is a leveling off point in the consumption rate of *S. punctum*.

The various types of responses to prey density exhibited by the different stages and generations of *S. punctum* may possibly be due to 2 factors. First, the experimental design in handling the replenishment of prey was different from other feeding experiments. The majority of feeding experiments provide for replenishment of the prey species every 24 hours. This design may influence the response of the predator because as the predator fed it decreased its food supply and thus had to spend more time searching for its prey. In this experiment replenishment of the prey was made hourly and there were no extended periods when the predator was without food. This design resembles more closely what occurs in the orchards. The predator upon consuming his food supply can move to another area and begin feeding again. This will depend greatly on the amount of food available and searching involved in finding that food. Secondly, the environmental conditions that exist for a particular day in the orchard may be responsible for different responses by *S. punctum*. There are physical and biotic factors in a natural environment that may influence the functional response of a predator to variation in prey density. Data from the spring test are presented to illustrate this point (Fig. 4). Early in the morning the feeding by *S. punctum* was slightly erratic. This may be attributed to the starvation period before the test. However, as the day progressed and temperatures rose the feeding of *S. punctum* increased at all prey densities. A similar pattern was found to occur in all feeding experiments. This finding seems to correlate well with other species of *Stethorus*. For example, Chazeau (1974) reported that the consumption rate of *S. madecassus* doubles with a temperature rise of 5°C.

These 2 factors (temperature and experimental design) whether acting individually or as an interaction between the two possibly explain the various responses of *S. punctum* to prey density. This raises some interesting questions concerning predation and merits further investigation in the future.

Acknowledgment

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ERRATUM

In December 1976 issue of ENVIRONMENTAL ENTOMOLOGY, in paper by Jeffrey K. Barnes on pages 1089–98, Abstract third sentence should read as follows: Total survival is greatest at 26°C.