THE LIFE HISTORY AND HABITS OF THE PREDACIOUS MIRID

HYALIODES HARTI KNIGHT

By

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I. INTRODUCTION

The annual apple production of the world has increased immensely during the last two decades and parallelled with this there has been an increase in the number and complexity of chemical treatments to combat the various pests attacking this fruit. Spraying is now an accepted, though not welcome, practice and it is becoming increasingly evident that the desired control can not be attained at this time through the use of chemicals alone. Arthropod pests "resistant" to chemicals have been observed in numerous instances. Suppression of one pest only to allow another to increase is a common result of disturbing nature's natural balance. Largely for these reasons no chemical has adequately controlled any pest for a long period of time. These principles were known long before post World War II discoveries of more powerful insecticides but even with these recent wide spectrum chemicals the insects and related arthropods still survive and cause heavy losses each year.

Entomologists in various parts of the world are becoming increasingly aware of the value of natural and biological agents in insect control. There are many examples of biological control in which the controlling agents have been introduced by man. This type of control is very similar to controls effected when native biological control agents are manipulated through the selected use of spray chemicals as well as other cultural practices. Apple growers in the Annapolis Valley of Nova Scotia have been utilizing such an integrated program with success for the past 15 years.

This modified or integrated program is the result of ecological investigations on the fauna of apple orchards and the determination of the influence of chemical sprays on the interactions of pests and beneficial arthropods. This study, initiated about 1945 (Pickett *et al.*, 1946), has been carried on by the staff of the Entomology Section of the Research Station, Canada Department of Agriculture, Kentville, Nova Scotia. As a part of these investigations the writer has studied the life histories and habits of the predacious Miridae found on apple trees. This group constitutes a large portion of the total predator complex.

The predacious mirid *Hyaliodes harti* Knight was the first species to be studied in detail because of its importance as a predator of noxious orchard insects. This importance has been indicated by the observations of workers in Nova Scotia (Gilliatt, 1935; Lord, 1949; MacLellan, 1954; MacPhee and Sanford, 1954; and Stultz, 1955). Gilliatt first discussed *H. harti* under the name

Hyaliodes vitripennis (Say) but subsequent examination of his specimens by officers of the Systematics Unit, Ottawa, indicate the species was harti. No specimens of vitripennis have been identified from Nova Scotia.

H. harti was described by Knight (1941) from specimens collected mainly in Illinois but also from Georgia, Iowa, Missouri, New York, North Carolina, North Dakota and Wisconsin. In Canada the predator has been collected from Ontario (Knight 1941), Quebec (LeRoux 1960), New Brunswick (Maxwell, 1961, personal communication) and Nova Scotia. There is no record that it occurs on the West Coast of North America or in other parts of the world.

The results obtained from studies, during the period 1956-1960, on the life history and bionomics of H. harti are presented in this thesis. Each stage in the development of H. harti is described in detail. Data, gathered on related predacious mirids, are included for comparison with H. harti. The descriptions of the eggs of other species of mirids are given to demonstrate the obscure differences between this stage of each species. The status of H. harti as a predator is substantiated from records on long term predator-prey relationships and feeding tests.

II. GENERAL METHODS AND PROCEDURES

A. EGG STUDIES

When this investigation started there was little or no information on where the eggs of the predacious mirids were laid or what they looked like. The presence of first stage nymphs on the trees in the spring suggested that the winter was passed in the egg stage on the tree. Workers examining apple wood, while counting European red mite eggs and oystershell scale for a number of years at Kentville, did not notice or record having seen eggs that might have belonged to this group. This indicated that these eggs must be obscured by the bark. Dr. A. M. Massee, East Malling Research Station, East Malling, Kent, England, while visiting Kentville in 1956 was able to suggest what to look for. Descriptions of the eggs and oviposition sites of Blepharidopterus angulatus (Fall) (Collyer 1952) was of considerable help in the initial searches.

Two procedures were eventually used to identify the eggs and oviposition sites. Collections of apple wood were made and searched with a binocular microscope. All swellings or "bumps" on the bark and visible egg caps on the twigs were marked, photographed and incubated. When the egg hatched the nymph was identified or reared to a larger stage if the early form was unidentifiable.

High concentrations of eggs were obtained by caging adults of individual species on apple limbs in the autumn. After eggs were identified by this method a search of wood from the orchard was made to determine the normal oviposition site.

The removal of eggs from the bark for measurement and examination required considerable care. A small block of bark and wood containing separate eggs was first removed from the twig. A cut was made on each side of the block as near to the egg as possible. The egg was removed by holding one side of the block and tearing the other side away with forceps. The block usually separated around the egg leaving it exposed.

Measurements of exposed eggs were made with a micrometer-measuring eyepiece calibrated on a Leitz Ortholux microscope. The photographs were made through microscopes. Lord (1957) described one method using a speed flash for light and a 35 mm Alpa reflex camera mounted on a microscope with additional magnification obtained by the use of extension tubes. Another method utilized sheet film in the Leitz Aristophot camera attachment mounted on a Leitz Ortholux microscope equipped for incident light. This type of lighting coupled with the higher magnification of the compound microscope provided more detailed pictures than the first method.

B. LABORATORY INCUBATION AND REARING

Considerable difficulty has been experienced in attempts to hatch and rear specimens of Hyaliodes harti in captivity. Eggs of this species hatch late in June in the field. Because this time is later than the bloom period in Nova Scotia it is almost impossible to keep twigs, containing the eggs, alive long enough for the eggs to hatch under ordinary conditions in the greenhouse. Only a few nymphs have been obtained by taking twigs containing eggs from the orchard and allowing them to develop inside. Usually the twigs leaf out and dry up very soon after being cut. Nymphs of many other species have been obtained by this practice but these are species that normally hatch earlier than H. harti. Small numbers of nymphs were obtained from overwintering eggs by placing short twigs with the eggs on them in water and changing the water daily. The twigs were enclosed in glass with prehumidified air (75% R.H. and 80° F.) passed through the enclosure. This humidity, together with a 16-hour day provided by fluorescent light kept the twig fresh long enough and increased the rate of development of the eggs sufficiently to allow them to hatch in a relatively short time.

Several methods of rearing the nymphs that were obtained from laboratory hatching and field collections have been tried with varying success. Very few specimens have been reared from the egg through all stages to adult. Often nymphs could be kept alive for one to three stages. In order to study all stages additional nymphs had to be brought in from the orchard. This procedure required that feeding tests, measurements, and other observations be carried on during the active stages of the predator in the orchard.

The first type of rearing cage used was of the type described by Huffaker (1948). Phytophagous mites and eggs on apple leaves were put into the cage daily for food. The nymphs remained alive for periods of up to a week and records for an entire instar could be obtained. Changing the leaf daily did not sustain the life of the mirids for longer periods.

A more successful method of rearing was to keep the nymphs in the presence of succulent terminal apple growth. The bases of short lengths of these shoots were wrapped with moist absorbent cotton and placed in small round or rectangular transparent plastic cages. Leaves with prey were added to each cage and replenished when necessary. The terminal shoots were renewed approximately every second day. Glass-topped metal pill box type cages were also used but the greater transparent areas of the plastic were useful for microscope examination of the contents. Nymphs stayed alive in both types of cages for comparatively long periods but not long enough for rearing individual specimens through all stages.

The most successful means of rearing nymphs of _H. harti_ in the laboratory lay in a system developed by Specht (1963) at Kentville for rearing European red mite (_Panonychus ulmi_) on individual leaves. With this apparatus humidified air (75% R.H.) at a temperature of 80° F. was passed over apple shoots that were standing in water and enclosed within glass cylinders. The water was changed daily. The shoots stayed alive for periods up to two weeks and were changed when signs of wilting occurred. The nymphs were transferred to the new shoots. Food was provided for the nymphs by placing a twig with overwintering red and/or brown mite eggs on it in the cage. New twigs were put in as the eggs were consumed. Up to six nymphs were reared on single shoots in cylinders about eight inches long and two inches in diameter. Undoubtedly mass rearings could be made with larger capacity equipment but would be limited by the difficulty of transferring the nymphs to new shoots. If the nymphs were too numerous the chances of escape would be greater.

III. DESCRIPTION OF EACH STAGE

A. EGG STAGE

The eggs of several mirid species were identified during the search for and identification of eggs of _Hyaliodes harti_. A similarity between the eggs of all species and the generalized type of mirid egg was noted but the differences were great enough to make it possible to distinguish each species _in situ_. The shape, size, and color of the egg cap, position on branch, age of wood, type of bark, and numbers in one position were characters used to separate eggs of each species. Further differences in shape and size of the egg were noted after dissection from the wood.

1. HYALIODES HARTI EGG

Eggs of H. harti in situ (Plate I - A) are not clearly distinct from the surrounding bark. The only external feature is an elliptical operculum with an outside amber region around a narrow dark center region. This egg cap is usually flush with the bark surface and may be obscured by pubescence on the twig. There is not a distinct swelling or "bump" associated with the egg as is found with many mirid species, for example, B. angulatus (Collyer 1952) or Diaphnidia pellucida (unpublished notes). H. harti females always insert their eggs on or near a bud swelling on new terminal growth. No eggs are laid on wood older than the current season's growth. They are placed with the posterior end of the egg towards the distal end of the twig, just under the bark (Plate I - B). Normally one egg is laid at each position but occasionally two to six eggs may be found near a single bud (Plate I - C).

The chorion of the exposed egg (Plate I - D) is smooth, dull white and opaque in color with a thick amber operculum. The egg is slightly curved, wider at the posterior end and narrowing to form a neck. Thirty-one eggs dissected from apple twigs from commercial orchards were measured (Table 1), the average dimensions being: overall length 0.958 mm.; greatest width 0.263 mm.; greatest width of egg cap 0.198 mm.; thickness of egg cap 0.05 mm.

2. EGGS OF OTHER PREDACIOUS MIRIDS

Eggs of several species were compared with those of *H. harti*. These all show certain differences in their general appearance which, with some experience, makes it possible to identify them in the wood. Brief descriptions of the known eggs are included here to show how eggs of *H. harti* and other species differ. These eggs are illustrated *in situ*, and after removal from the bark, on Plates II - IX. Measurements are listed in Table 1.

a. *Atractotomus mali* (Meyer)

Eggs of *A. mali* are laid early in the season on new wood, mostly on fruit spurs. The egg is generally placed between the leaf stem and the twig near the abscission layer. When the leaf breaks off, the eggs can be found in the resulting scar (Plate II - A). The cap is orange in color and when seen from an end view appears pinched together, resembling the thin edge of a wedge (Plate II - B). The egg caps may be partly exposed but often are obscured by bark growing over them later in the season. Generally more than one egg is deposited in one site. The egg is white in color with an orange

Table 1. Measurements of mirid eggs.

Length of egg	Greatest width of egg	Thickness of cap	Greatest width of cap
H. harti			
M = .958 mm.	M = .263 mm.	.05	M = .198 mm.
N = 31	N = 31		N = 31
S.D. = .035	S.D. = .057		S.D. = .012
A. mali			
M = 1.083 mm.	M = .225 mm.		M = .215 mm.
N = 31	N = 31		N = 31
S.D. = .063	S.D. = .009		S.D. = .015
D. fasciolus			
M = 1.446 mm.	M = .303 mm.	.194	M = .249 mm.
N = 8	N = 8		N = 8
S.D. = .085	S.D. = .036		S.D. = .024
C. verbasci			
M = .830 mm.	M = .204 mm.		M = .156 mm.
N = 7	N = 7		N = 7
S.D. = .098	S.D. = .015		S.D. = .037
P. perplexus			
M = 1.213 mm.	M = .285 mm.		M = .196 mm.
N = 8	N = 8		N = 8
S.D. = .106	S.D. = .034		S.D. = .022

opercular end, very slightly curved, broad posteriorly, narrowing to form a neck with a wider wedge shaped cap (Plate II - C). The average measurements of the 31 eggs observed were: length 1.083 mm.; greatest width 0.225 mm.; greatest width of the operculum 0.215 mm.

b. Deraeocoris fasciolus Knight

The adult D. fasciolus inserts its eggs in creases where the bark is incurved at the twig axils (Plate III - A). The egg is characterized by a prominent white waxy collar with a projecting hairlike process near one edge (Plate III - B). This projection and collar are exposed when the egg is in position (Plate III - C). The egg is white and curved similarly to that of A. mali having a wide posterior end narrowing to the neck and only slightly wider at the operculum (Plate III - D). The average overall length is 1.446 mm.; greatest width .303 mm.; greatest width of the operculum .024 mm.; thickness of egg cap 0.94 mm.

c. Campylomma verbasci (Meyer)

Eggs of this species are invariably deposited in lenticles but not necessarily on new growth. If the egg is near the edge of the lenticle a small swelling may be noticeable but if in the center no "bump" is evident (Plate IV - A). The egg cap is about the same color as the lenticle and often obscured by the growth of the lenticle, making these eggs very difficult to locate (Plate IV - B). When exposed, the eggs show little or no curvature and are very short and stout (Plate IV - C). The average overall length of seven eggs was 0.830 mm.; greatest width, 0.204 mm.; and the greatest width of the cap 0.156 mm.

d. Pilophorus perplexus D. & S.

Eggs of P. perplexus are laid deeply imbedded in the wood of branches of all ages, even large limbs (Plate V - A). The adults prefer hard rough bark, often associated with injuries or lenticles, as oviposition sites (Plate V - B). The egg is long and nearly straight and it is inserted directly in towards the center of the branch with no external "bump" indicating the site (Plate V - C). Only the cap is exposed when the egg is in position, this being very white, waxy, sharply elliptical in shape, and with a dark center (Plate V - B). These eggs occur singly. The average length is 1.213 mm.; greatest width 0.285 and greatest width of cap 0.196 mm.

e. Diaphnidia pellucida Uhler

The eggs of D. pellucida are situated at right angles to the longitudinal axis of the twig. They are deposited on one and two year wood just under the bark. A distinct "bump" is found with the egg cap visible at one end (Plate VI-A). The cap is white with a distinct rim. The center portion under high magnification is seen to contain a number of small projections with cavities between (Plate VI - B). These eggs are laid singly on smooth succulent bark, and also frequently in the edge of lenticles where the ovipositor can penetrate easily (Plate VI - C). The egg is almost straight with a pearly white chorion and a slightly lighter operculum (Plate VI - D).

f. Blepharidopterus angulatus (Fall.)

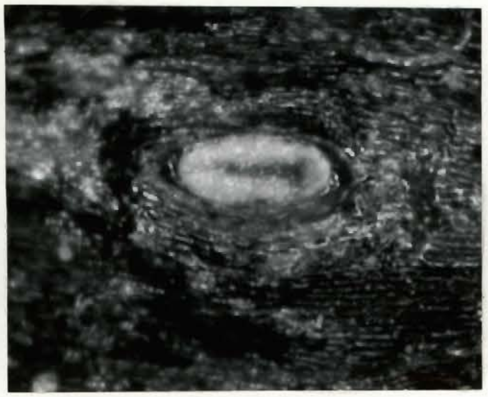
The eggs of this species (Plate VII - A & B) have been found and identified from one orchard. The characteristics of these eggs are similar to those reported by Collyer (1952) for eggs of this species in England. The eggs are very similar to those of D. pellucida but can be distinguished in situ by differences in the visible operculum. The outer rim of the cap in B. angulatus is more distinct with the center darker (Plate VII - C). Further characteristics may be found in Collyer's paper.

g. Phytocoris conspurcatus Knight

Eggs of P. conspurcatus are found in places similar to those of Deraeocoris fasciolus, that is in the creases of the twig axils of fruit spurs (Plate VIII - A). Several are usually found in each position. The visible egg cap is typically elliptical, similar in color to the bark and, therefore, difficult to see (Plate VIII - B). The cap is nearly the same color without the degree of distinction between the rim and center of the operculum found in *B. angulatus*. It is composed of a honeycomb type of structure which shows under high magnification (Plate VIII - C).

h. *Psallus* spp.

Specimens of *Psallus* species have been found recently on apple trees. Preliminary indications are that it is predacious. By caging adults on limbs, eggs were obtained and photographed. The egg cap *in situ* (Plate IX - A) is typically elliptical with a white outer rim and slightly darker center. The exposed egg has a light colored chorion with a typical mirid shape, wider posteriorly, curving slightly to form a narrow neck and cap (Plate IX - B). These eggs were found inserted in rough crevices but because the adults were caged and eggs were not found in the orchard, it is not known whether or not this is the normal location.



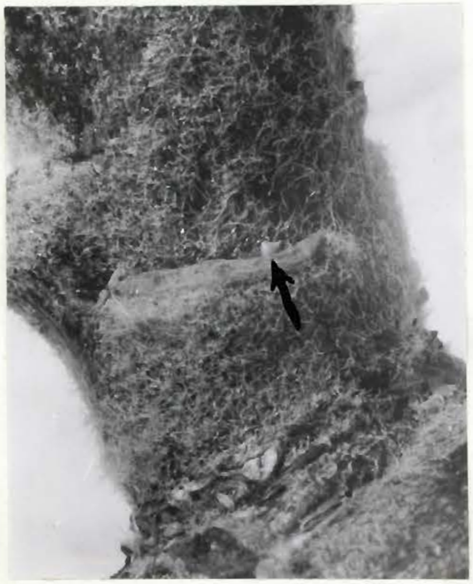
A. Egg cap <u>in situ</u>. X 110

B. Exposed egg showing relation to bark surface. X 35

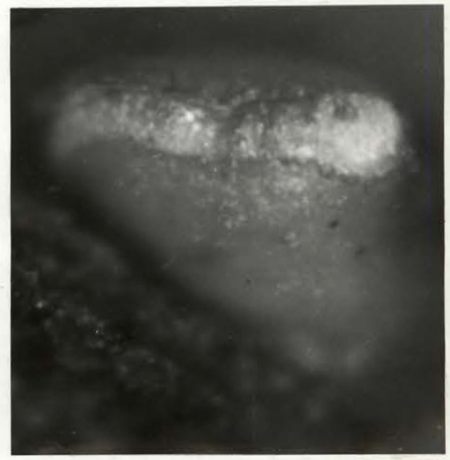
C. Position of eggs in relation to bud. X 10

D. Egg exposed. X 60

Plate I. <u>Hyaliodes harti</u> Knight eggs.



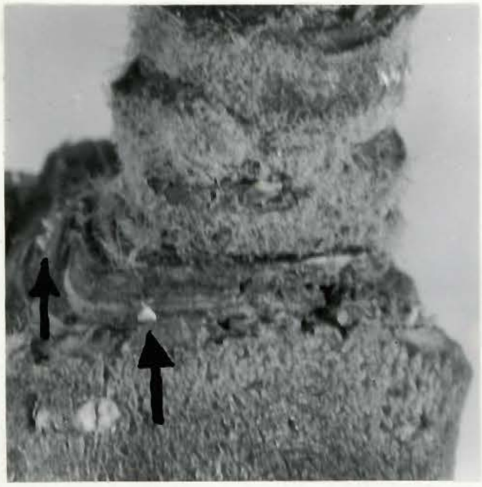
A. Egg in leaf scar.
X 11



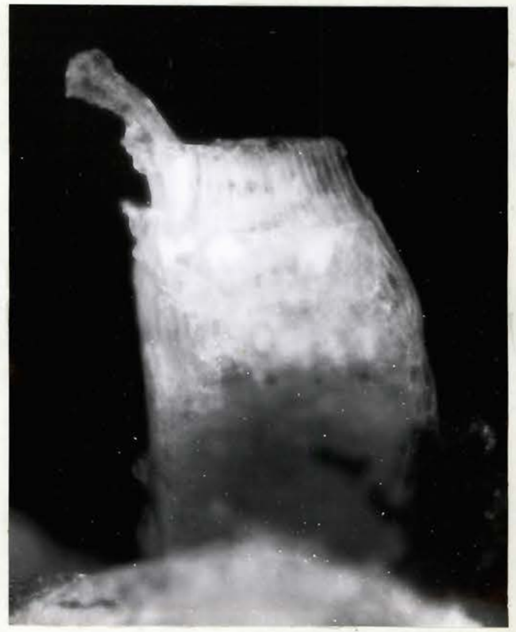
B. Opercular end of
the egg. X 240

C. Exposed egg dissected from the wood. X 55

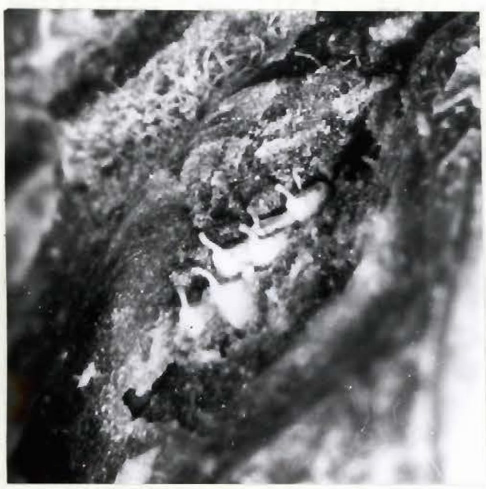
Plate II. Atractotomus mali (Meyer) eggs.



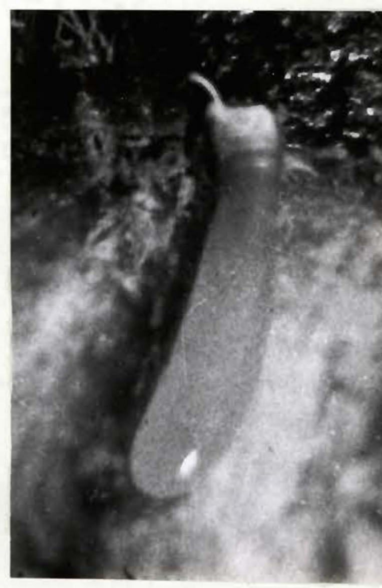
A. Eggs in bark creases.
X 10



B. Egg cap highly
magnified. X 130



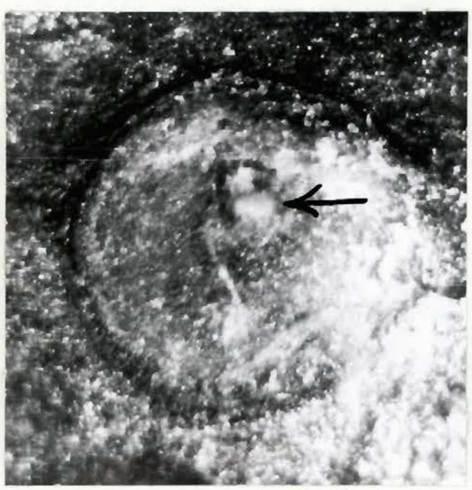
C. Group of eggs in
bark. X 20



D. Egg dissected from
the wood. X 43

Plate III. <u>Deraeocoris fasciolus</u> Knight eggs.

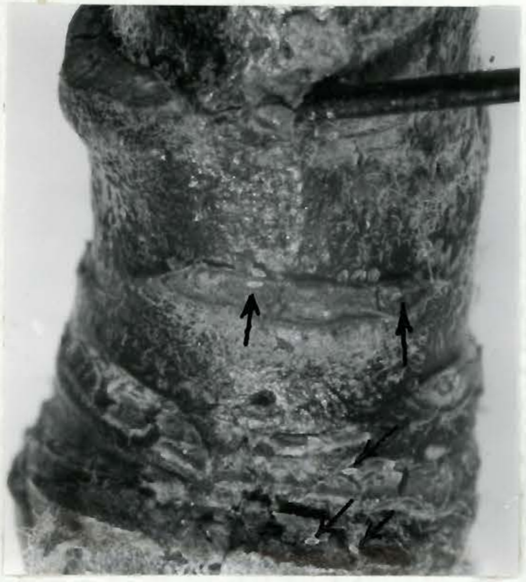
A. Eggs in lenticles. Very obscure. X 9



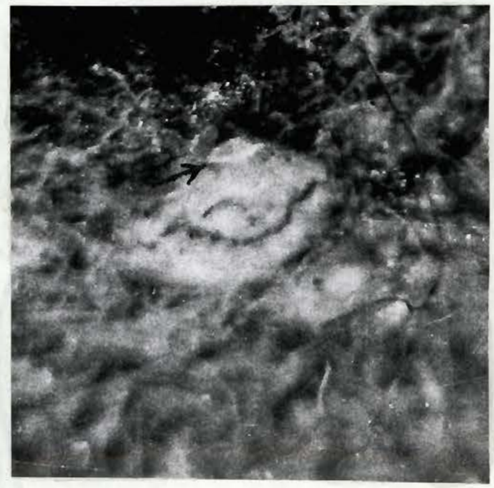
B. Egg cap slightly visible in center of lenticle. X 40

C. Egg exposed by dissection. X 24

Plate IV. Campylomma verbasci (Meyer) eggs.



A. Eggs imbedded in leaf scar. X 10



B. Egg inserted in edge of lenticle with cap showing. X 30

C. Egg exposed by dissection of the wood. X 25

Plate V. Pilophorus perplexus D.& S. eggs.

A. Egg "bump" on twig.

B. Egg cap highly magnified.

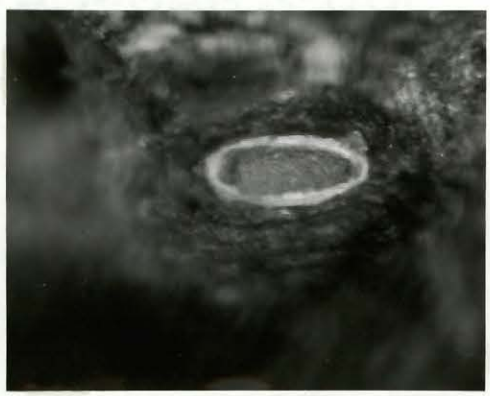
C. Egg deposited at the edge of a lenticle.

D. Egg exposed.

Plate VI. Diaphnidia pellucida Uhler eggs.

A. Eggs on twig. Not typical position. X 10

B. Exposed egg. X 58



C. Egg cap on egg in wood. X 90

Plate VII. Blepharidopterus angulatus (Fall.) eggs.

A. Eggs in the twig axil of a fruit spur. X 8

B. Egg cap. X 107

C. Egg cap highly magnified showing honey-comb type of structure. X 300

Plate VIII. Phytocoris conspurcatus Knight eggs.

A. Egg cap in situ.

B. Egg exposed.

Plate IX. Psallus spp.

B. NYMPHAL STAGES

There are five nymphal instars of *Hyaliodes harti* which can be distinguished from each other by size and wing bud development (Plate X). The instars were first separated by measuring the head capsules of specimens from three localities, randomly collected for three years, (1955-1957) and plotting the results. The frequency distribution of the measurements are plotted in Figure 1 with the number of variates and means given in Table 2 for each year and the average for three years. The mean measurements of each antennal segment, width of the pronotum, and the overall length of the same specimens are given in Table 3. The nymphs of *H. harti* are basically white in color and are characterized by a distinctly red last abdominal segment which has led to the popular colloquial use of the name "Red-tailed mirid". Additional red markings are found on the legs, antennae, and eyes.

A straight line relation between instars is shown by the width of the head capsule, width of the pronotum, and overall body length (Figure 5). The ratios of measurements of each instar to the preceding instar calculated from data given in Tables 2 and 3 are reasonably constant. The average ratio for the head capsule is 1.23, the pronotum 1.28 and the body length 1.27. The application of Dyar's rule might be useful in mirid studies to determine the size of structures or the number of instars of an incomplete series of nymphs. These ratios of linear measurements may agree with the growth hypothesis of Przibram and Megusar (1912) but the weights of each instar are not known; the weight, according to the rule, should double at each instar. If it is assumed that the nymph is a cylinder, the diameter of which is an average of the head and pronotum width, a hypothetical volume may be calculated from this diameter and the body length. The calculated hypothetical volumes in cubic mm. for H. harti nymphs are as follows: instar 1, .096; 2, .222; 3, .452; 4, .766; 5, 1.286.

These suggest agreement with Przibram's rule in that they approximately double at each instar. It appears, therefore, that the structures and overall size of the nymphs increase in geometrical progression.

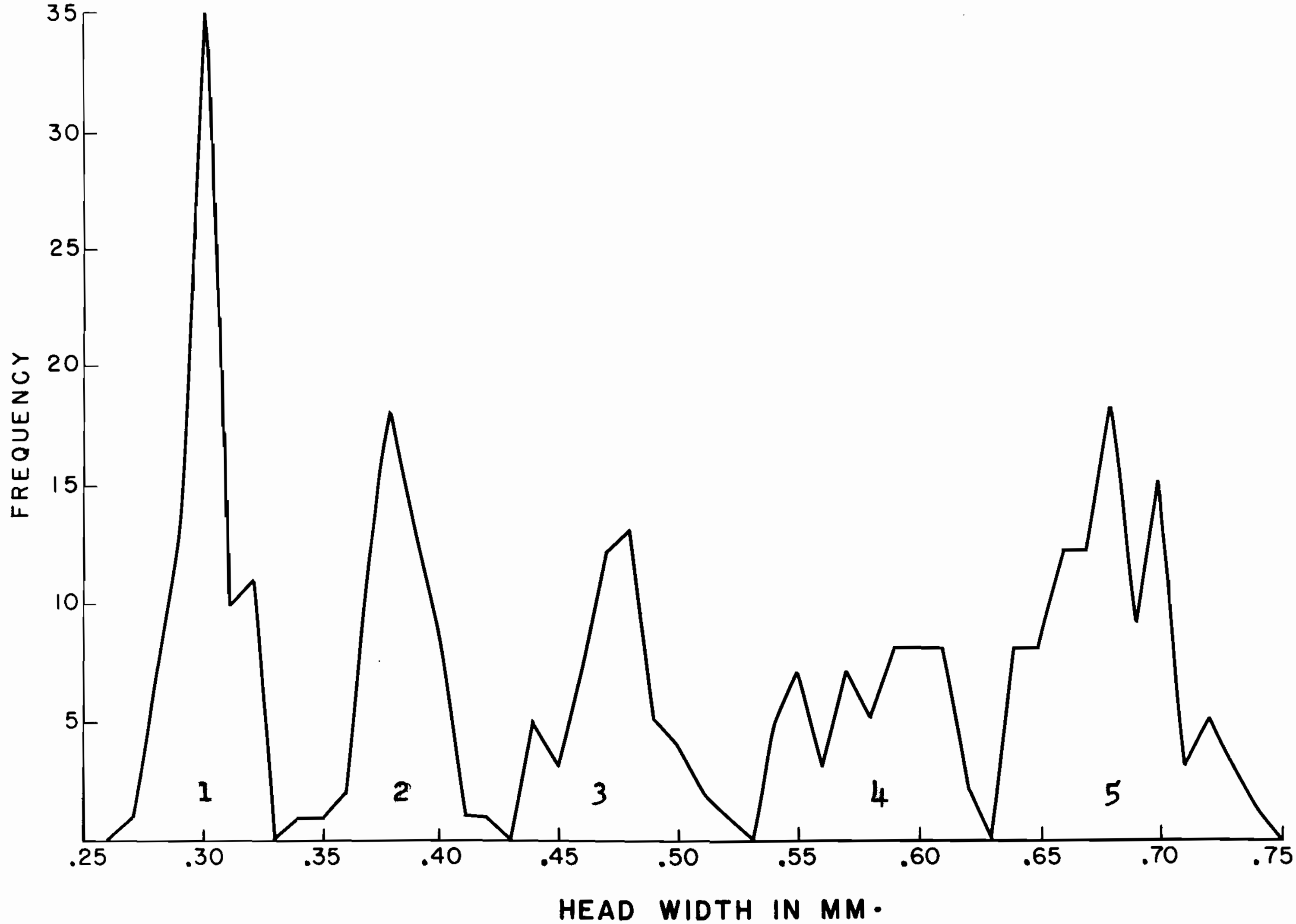


Figure 1. *Hyaliodes harti* Knight. Frequency distribution of head capsule widths of immature specimens.

Table 2. Head capsule measurements of randomly collected _H. harti_ nymphs.

Instar	Number variates				Means (mm.)			Mean for three years
	1955	1956	1957	Total	1955	1956	1957	
I	20	18	39	77	.3020	.2967	.2980	.2957
II	17	28	13	58	.3881	.3800	.3805	.3829
III	20	20	13	53	.4785	.4665	.4905	.4751
IV	18	23	9	50	.5867	.5735	.5968	.5824
V	42	27	18	87	.6707	.6893	.6956	.6816
Adults		13				.7438		

Table 3. Mean measurements and standard errors of the means of antennal segments, pronotum and overall length of H. harti nymphs.

Instar	No. specimens measured 1955-1957	Antennal segments								Total length
		1	SE	2	SE	3	SE	4	SE	
I	77	.25	.001	.39	.005	.39	.009	.38	.003	1.40
II	58	.37	.007	.60	.013	.56	.010	.46	.006	1.99
III	53	.52	.011	.87	.016	.74	.012	.55	.014	2.68
IV	50	.69	.010	1.18	.017	.97	.010	.62	.008	3.46
V	87	.88	.005	1.47	.011	1.18	.008	.70	.007	4.23

(cont'd)

Table 3. (cont'd)

Instar	No. specimens measured 1955-1957	Width of pronotum	SE	Overall length	SE
I	77	.25	.003	1.56	.031
II	58	.34	.004	2.14	.028
III	53	.41	.006	2.92	.026
IV	50	.50	.007	3.35	.037
V	87	.61	.005	4.00	.032

1. FIRST INSTAR

First instar nymphs, Plate X - A, average 1.56 mm. in length and .29 mm. in head capsule width. All thoracic segments are of similar size. Red markings are visible on the distal ends of the first three antennal segments, the proximal end of the first and second tibia, and the distal end of the third femur. The eyes and the last abdominal segment are also red in color. All other parts of the body are white.

2. SECOND INSTAR

Morphological differences are shown between the first and second stage nymphs (Plate X - B). The latter are larger in size, the average length being 2.14 mm. and the head capsule width 0.39 mm. The mesothorax is longer and wider than the metathorax. The color is similar to that of the first instar.

3. THIRD INSTAR

This instar (Plate X - C) is distinguished by the first appearance of small wing pads on the mesothorax. The average length is 2.92 mm. and width of head capsule is .475 mm. The overall body color is white with some red markings. These include a red line on the outer margin of the first antennal segment and the distal ends of segments two and three.

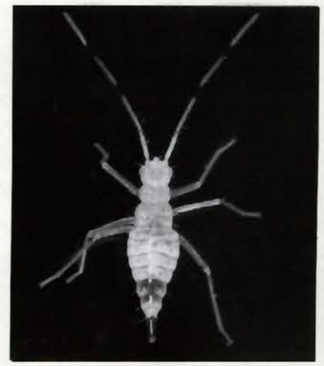
4. FOURTH INSTAR

This instar (Plate X - D) is easily recognized by the wing pads which extend to the second abdominal segment. The average overall length and head capsule width are 3.35 and .58 millimeters respectively. The antennae are marked with a black line on the outer margin of the first and part of the second segments and the distal end of the second and third segments are red in color.

5. FIFTH INSTAR

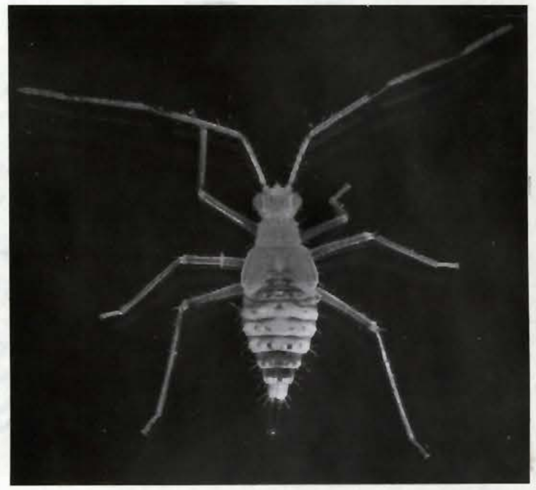
In the fifth instar the wing pads extend to the fifth abdominal segment (Plate X - E). Early in this stage the pads are entirely white but as the adult stage approaches (last 24 hours) they become more colored with a red area developing on each pad about one-quarter the distance from the posterior end. The antennae are marked with a black line on the outer margin of the first segment with the distal ends of the first three segments red. The femur and tibia of all legs have a dark line on the posterior margins with dark markings on the proximal ends of all tibiae. The eyes are somewhat darker than the generally white color of the head capsule and body. A distinct dark glandular spot shows through the dorsal body wall of the third abdominal segment.

A. First instar.
X 12



B. Second instar.
X 11

C. Third instar.
X 12



D. Fourth instar.
X 10

E. Fifth instar. X 10.5

Plate X. Hyaliodes harti Knight. Five nymphal stages.

C. ADULT STAGE

Knight (1941) described the adult male and female _H. harti_ as follows: "General color pale, translucent; head and body yellowish; calli, collar, scutellum except apex, mesoscutum, and inner margin of clavus, black; apex of scutellum white; apex of corium, and tip of embolium, red; cuneus and membrane clear, anal angles fuscous. Legs pale to yellowish". Average measurements in mm. made by the writer from specimens collected in Kings County, N. S., compared with those given by Knight (1941) are as follows:

	Male		Female	
	Knight	Author	Knight	Author
Length	4.40		4.90	
Width	1.40		1.60	
Head width	0.73	0.75	0.71	0.75
Vertex	0.26		0.32	
Rostrum length	1.20		-	
Antennal segment 1	1.10	1.13	1.08	1.09
" " 2	1.69	1.82	1.77	1.76
" " 3	1.12	1.19	-	1.24
" " 4	0.60		-	0.74
Pronotum length	0.82	0.84	-	0.93
Pronotum width at base	1.12	1.22	-	1.40

There are slight differences in the two sets of measurements. Differences in the two sexes were noted from Nova Scotia specimens and can be used to sex live adults where examination of the genital segments is not easy, such as in cages. The white mark on the apex of the scutellum is usually small in the male and much larger in the female (Plate XI). The general head color of the male is slightly orange while that of the female is pale yellowish. Both these differences can be seen from a convenient dorsal view.

A. Female. X 11.5

B. Male. X 11.5

Plate XI. Hyaliodes harti. Adult female and male.

IV. LIFE HISTORY

Great difficulty has been experienced in rearing species of predacious Miridae in the laboratory, with the result that most observations on the life history of _H. harti_ were obtained from the field. Recently (1961) some success has been obtained rearing this species in the laboratory by maintaining control of humidity and length of day. This method is described in Section II and promises to be useful for further studies. The laboratory observations made in this study are included in the following sections.

H. harti develops from the egg through five nymphal instars to the adult stage in about five weeks. There is one generation a year. The rate of development is determined to some extent by temperature. This temperature influence is shown by the different stage of nymphal development, at any one date, in early and late seasons and in early and late areas in the Annapolis Valley within a single season. Gilliatt (1935) gave a brief outline of the active period for the year 1932, the dates of which coincide closely with observations made by the writer. The duration of each stage in the years 1955 to 1960 is shown in Figure 2, and is based on specimens taken at various localities thus representing the periods of occurrence of each stage in all the orcharding areas of the Annapolis Valley. The specimens were obtained by periodic collections from study orchards and in the course of regular orchard sampling for other purposes. The extreme limits of each stage may be in error by a few days due to the intervals between collection dates or the locality of the final collection, but the similarity between the years indicates that this error is not large. The seasonal differences shown in Figure 2 are reflected in the different bloom dates and the dates *H. harti* nymphs first occur. The same climatic factors affecting the bloom development apparently have similar effects on the development and hatching of the mirid eggs. Because of this relationship it is possible to predict the approximate hatching date after bloom has occurred.

A. EGGS

1. FIELD

H. harti overwinters as an egg on apple shoots. Oviposition occurs during the last half of August and the eggs remain embedded in the bark until they hatch during the latter part of June of the following year. Most of the eggs hatch within 2-4 days of each other in any one locality, with small numbers hatching up to eight days after the first eggs hatch. The cap of the newly hatched egg remains on the bark beside the egg until it is dislodged by wind or rain. Oviposition punctures or egg cavities soon heal over with no resulting scar. Often eggs are found incompletely inserted in the wood. These dry out and do not hatch.

2. LABORATORY HATCHING

Two lots of eggs brought from the orchard on January 10 and February 8, 1961, were subjected to 75° F. and 75 per cent relative humidity with a day length of 16 hours. Four nymphs were obtained from the first lot after an average of 24.5 days incubation. The second lot produced seven nymphs and an average incubation period of 23 days. On the assumption that eggs start to develop at 43° F. the number of "day degrees" required to hatch these eggs in the laboratory was calculated as 784 and 736 respectively. This difference in incubation time had been observed previously in eggs brought from the orchard during the winter and spring. Less time was required for incubation of eggs collected nearest to the normal orchard hatching date.

The peak hatching date in the field in 1960 was near June 15. From meteorological records the number of "day degrees" accumulated in 1960, above the threshhold of development of 43° F., was 702 to June 15 and 749 to June 17. The only records available for calculating the number of "day degrees" in the field were from records of mean daily temperatures but mean hourly temperatures would be more accurate. It appears that the relationship between the field and laboratory egg development was very close requiring nearly the same number of heat units. Knowledge of the heat units required to hatch eggs of _H. harti_ could be useful in predicting the approximate hatching date of the eggs in the field. Seasonal differences in temperature that influence this date would be included in calculating the accumulation of heat units. The practical use of this would be in timing spray treatments of detrimental chemicals to avoid killing the nymphs.

B. NYMPHS

The nymphal stages of H. harti occur somewhat later than the other predacious mirids in Nova Scotia orchards. This difference in occurrence allows the early stages of H. harti to be vulnerable to attack by the larger nymphs of other species such as D. fasciolus. An indication of the period of occurrence of nymphs of H. harti in relation to other species is given in Table 4. These periods were estimated by determining instars of specimens collected randomly during regular orchard sampling. Observations made during regular orchard sampling on species other than those given in Table 4 indicate that H. harti hatches later than the species C. verbasci and D. pellucida. These two species have two generations a year and thus are active over longer periods than H. harti. The mirid Deraeocoris nebulosis (Uhl.) overwinters as an adult. Eggs are laid during June so that the nymphs from these eggs occur later than H. harti nymphs.

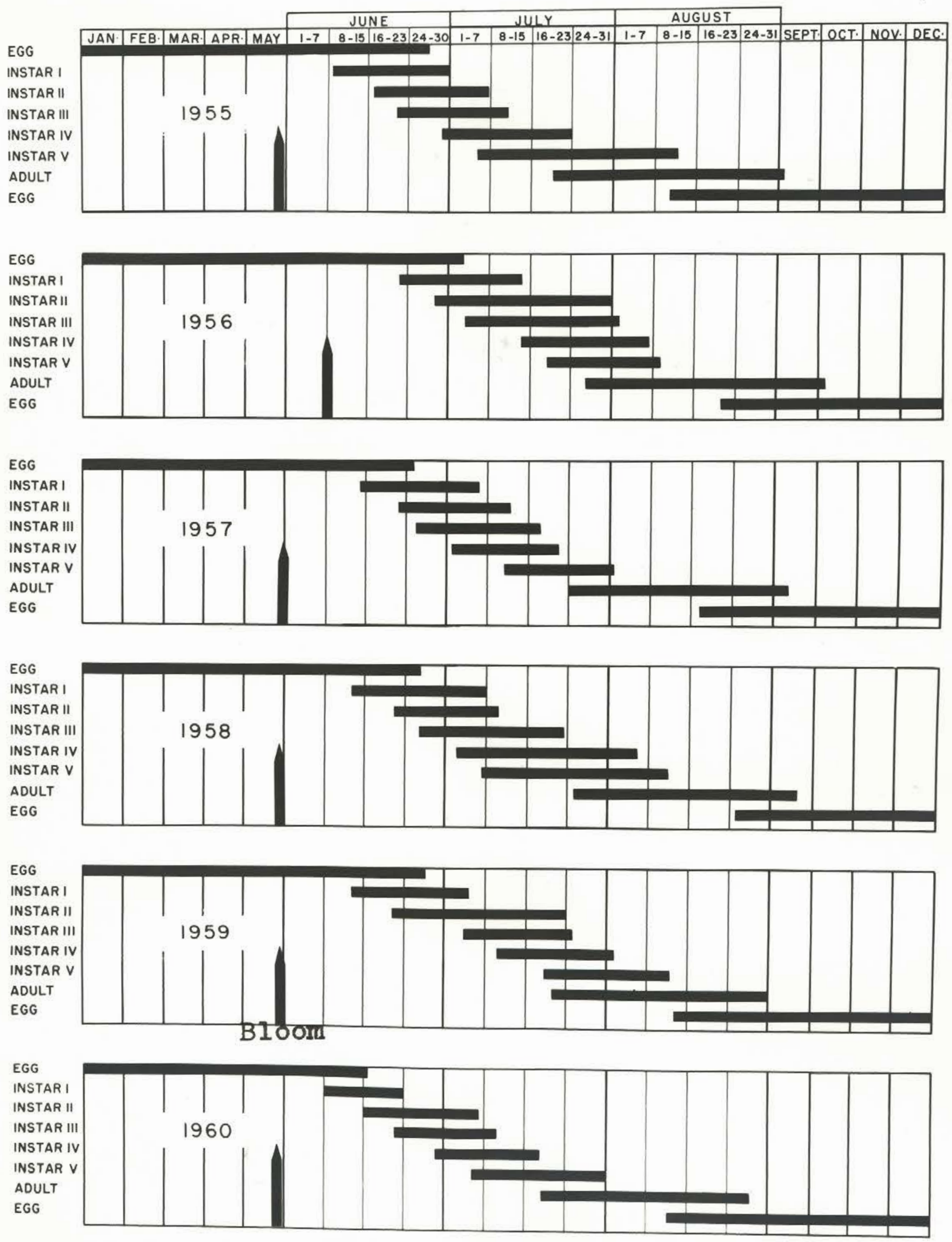


Figure 2. Periods of occurrence of each stage of *H. harti* for the years 1955-1960 and their relation to full bloom.

In the following discussion on each instar of H. harti the period of occurrence of the nymphs in the field and the mean number of days in each instar of laboratory reared individuals are given in Figure 2 and Table 5. The number of days in each instar of individuals in the field is not known but it is suspected the time would be longer than laboratory reared individuals because of the variable field temperatures. This field period of individuals would be considerably shorter than the total period of occurrence in the field of each instar because of different hatching dates in various localities of Nova Scotia and also the rate of development within instars may differ with the locality.

1. FIRST INSTAR

The first instar nymph moves about actively searching for food very shortly after emerging from the egg. They are difficult to see because of their small size and their location. When the mirid hatches the phytophagous mites are all on the leaves. The nymphs very shortly move back on the limb to find leaves infested with the mites. The nymphs occur over a fairly long period because of the temperature influence on the hatching dates in various localities of Nova Scotia. Eggs generally hatch later in orchards near tidal waters due to the cooling influence of

Table 4. Period of occurrence of each stage of some predacious mirids 1958 and 1959.

Species	First instar	Second instar	Third instar	Fourth instar	Fifth instar
Hyaliodes harti	Jn.12-Jl. 7	Jn.21-Jl.23	Jn.27-Jl.25	Jl.2-Ag. 4	Jl. 7-Ag. 9
Atractotomus mali	May22-Jn.16	Jn. 1-Jn.23	Jn. 5-Jn.25	Jn.13-Jl. 3	Jn.13-Ag. 7
Deraeocoris fasciolus	Jn. 3-Jn.23	Jn. 5-Jn.30	Jn.15-Jl. 7	Jn.16-Jl.13	Jn.29-Ag. 7
Pilophorus perplexus	Jn.10-Jl.31	Jn.10-Ag. 7	Jn.15-Ag. 8	Jn.30-Ag.14	Jl. 7-Ag.29
Phytocoris conspurcatus	Jn.12-Ag. 4	Jn.26-Ag. 8	Jn.30-Ag.14	Jl. 2-Ag.27	Jl. 7-Ag.27
Blepharidopterus angulatus	Jn.12-Jl. 7	Jn.12-Ag. 4	Jl. 7-Ag. 4	Jl.10-Ag. 4	Jl.21-Ag.27
Plagiognathus obscurus	Jn. 5-Jn.25	Jn.15-Jn.22	Jn.15-Jn.29	Jn.26-Jn.29	Jn.29-Jl.15

(cont'd)

Table 4. (cont'd)

Species	Adult females	Adult males	Total adults	Total active period
Hyaliodes harti	Jl. 21- Ag. 27	Jl. 21- Ag. 13	Jl.21- Ag.27	Jn. 12- Ag. 27
Atractotomus mali	Jn. 30- Ag. 14	Jn.29- Ag.14	Jn.29- Ag.14	May 22- Ag. 14
Deraeocoris fasciolus	Jn. 29- Ag. 29	Jl. 9- Ag. 26	Jn.29- Ag.29	Jn. 3- Ag. 29
Pilophorus perplexus	Jl. 16- Sep.22	Jl. 11- Sep.15	Jl.16- Sep.22	Jn. 10- Sep.22
Phytocoris conspurcatus	Jl. 28- Ag. 27	Jl.27- Ag.28	Jl.27- Ag.28	Jn. 12- Ag. 28
Blepharidopterus angulatus	Jl. 27- Ag. 27	Jl. 27- Ag. 18	Jl.27- Ag.27	Jn. 12- Ag. 27
Plagiognathus obscurus	Jl. 20- Ag. 11	Ag. 7-	Jl.20- Ag.11	Before Jn.15- Ag. 11

the water. Figure 2 and Table 5 show that the average duration of occurrence in the field for the six year period 1955-1960, of first instar nymphs was 19.5 days. The difference in dates when they were first collected each year is due to the differences in the seasons. The average period in the first instar of laboratory reared individuals was 4.7 days (Table 5).

2. SECOND INSTAR

Second instar nymphs in the field appear about one week after the eggs hatch. Because these nymphs are larger and more widely distributed, this is the first stage usually noticed. The dark red ingesta showing through the abdominal wall makes this stage easier to spot on leaves than the first instar nymphs. The numbers of H. harti obtained by sampling are highest at this period because losses from the trees are at a minimum. In the field second instar nymphs were found over an average period of 23.2 days (Figure 2). In the laboratory individuals remained in the second instar for an average of 4.6 days (Table 5).

3. THIRD INSTAR

The third instar nymphs appear less than a week later than the first individuals of the second instar (Figure 2). They occur in the field over an average of 4.5 days. This instar is easily recognized and obtained readily by sampling.

4. FOURTH INSTAR

Fourth instar nymphs first occur in the early part of July, about three weeks after the first hatching and can be found over an average period of 24.2 days. Nymphs reared in the laboratory remained in the fourth instar an average of five days (Figure 2 and Table 5). Nymphs in this stage are easily obtained by sampling. They fall more readily than earlier instars when the branches are jarred over cloth trays.

5. FIFTH INSTAR

The last nymphal stage occurs during an average period of 26.0 days in the field (Table 5). Individuals reared in captivity required an average of 6.3 days to pass through this stage. The field population starts during the second or third week of July depending on the season and lasts through the first week of August when the adults begin to appear.

C. ADULT

The adults of *Hyaliodes harti* occur first about mid-July and are most numerous until mid-August when the numbers fall off rapidly. The occasional specimen is taken in late September or even October but this is not

Table 5. The mean number of days over which *H. harti* nymphs of each instar were observed in the field during the years 1955 to 1960 and the duration in each instar of individuals reared in the laboratory.

Instar	Mean number of days nymphs were found in the field six consecutive years		Mean number of days individuals lived in the laboratory in each instar		
	Mean	SE	No. of individuals	Mean	SE
I	19.5	1.2	7	4.7	0.4
II	23.2	2.9	16	4.6	0.3
III	21.8	2.0	17	4.5	0.3
IV	24.2	2.1	15	5.0	0.2
V	26.0	2.5	21	6.3	0.2
Adults	48.0	4.7	Total	25.1	

common. Figure 2 and Table 5 indicate that adults occur over a 48 day period but the majority of them live for about four weeks. The females have a pre-oviposition period of 10-20 days, the first eggs usually appearing in the third week of August. Slight differences may occur due to the season but it has been noted that the adults appear at about the same time each year regardless of the season or hatching date. It is thought the temperatures in July bring about faster growth of individuals that hatched late so that egg laying occurs about the same time each year. Females die shortly after depositing their eggs. The first adults found are usually males, but soon the numbers of males to females becomes equal. Because the males are active for a shorter period than the females, the females are predominant near the end of the season.

Oviposition is executed in a typical mirid manner. The female selects current years' growth and places her eggs in the bud swellings. During oviposition she stands facing the base of the shoot so that after the egg is inserted its posterior end is towards the distal end of the shoot. One egg is deposited in each position although up to six eggs have been found near a single bud. Often two eggs are deposited near one bud but the eggs never are positioned side by side. It is not known how many eggs each female deposits but dissections of gravid females have shown up to 30 eggs each, some of which were not as fully developed as others. One female had 25 fully developed eggs. It is thought that on the basis of twig examinations that 30-40 eggs would be near the number deposited per female. Dead females have been found containing eggs so possibly not all eggs are deposited before the mirid dies.

V. DISTRIBUTION

Insects belonging to the family Miridae are noted as being active in their movements. Throughout this study it has been evident that available food and the physical characteristics of the host plants play the dominant roles in determining their distribution. This is particularly true of the mirid *H. harti* because, unlike some species of predacious mirids, *H. harti* cannot exist solely on a plant diet. These movements in relation to food both within and between apple trees as well as other vegetation and the resulting distributions have been studied in some detail. The results of this study are presented in the following sections.

A. DISTRIBUTION AND MOVEMENT WITHIN THE APPLE TREE

1. EGGS

The eggs of *H. harti* have been discussed in previous sections. The type of wood containing the eggs and the position of the eggs on this wood was described. Because they are found only in new growth these eggs are distributed largely according to the previous season's growth. This in turn is determined by the tree vigor and the pruning that the tree received. A tree with new wood evenly distributed on all branches will, if the mirid population is heavy enough, have eggs more or less uniformly distributed. Trees where the vigorous growth is only in certain limbs, will have eggs distributed accordingly.

New growth in one orchard was examined systematically to determine if the eggs were more concentrated on shoots from the tops or from the lower levels of the trees. Counts were also made to determine near which bud on the new growth the eggs were most frequently found. The buds were numbered from the tip of the shoot. The shoots examined were all terminal growths, some being the distal ends of limbs and others the new growth on the shorter laterals. Collections of twigs were made randomly in the areas indicated.

The distribution of mirid eggs in relation to the buds on the twigs is shown in Table 6. Regardless of the number of buds on the shoot, most of the eggs are found on the first six to ten buds from the tip. In most trees examined 80-90 per cent of the total number of eggs were found near these buds. Occasionally an egg was found on the longer shoots beyond the tenth bud. Although these records were made from one orchard, similar observations have been made in other orchards when collecting eggs of this species. Pruning practices which remove water sprouts, also destroy large numbers of H. harti eggs commonly found on them. Where this is the case the following year's population must come from terminal growth only.

The number of eggs from the tops and bottoms of six trees are given and compared in Table 7. The comparison is made on three bases, i.e., eggs per shoot, eggs per bud, and eggs per inch of shoot. According to the "t" test for paired data (Cox. 1954) the differences between the means of all three sets of data are not significant. This suggests that there is no difference in numbers from the top or bottom of the trees, and thus the eggs are distributed at random over the tree. Since the eggs are only laid on new wood the distribution of eggs is associated with the occurrence of new growth. The number of eggs per shoot is considered the most representative data because the numbers of eggs between long shoots and short shoots are not different and apparently the adult is not attracted to one type more than the other. This is also indicated by the fact that the number of eggs per bud and per inch of shoot were similar for both the tops and bottoms of the six trees.

2. NYMPHAL STAGES

When the eggs of *H. harti* hatch the nymphs are not usually on a part of the tree where food, particularly in the form of phytophagous mites, is readily available. At this time of the year the mites are located on leaves nearer the center of the tree and in order to reach this source of food the newly hatched nymph must move from the terminal growth, where it emerged, towards the base of the branch to clusters where food is available. If sufficient numbers of phytophagous mites are on the outer portions of the limbs then this inward movement of the mirid nymphs is not necessary. Thus the first stages of the nymphs are usually found on leaves on the inner regions of the trees. Other species of predators which are active earlier in the season in some orchards remove the phytophagous mites on the outer branches before the *H. harti* nymphs emerge. This contributes to the necessity of young nymphs moving inwards in search of food.

The nymphs are usually found on the under surfaces of the leaves both when at rest and when feeding. Probably the main reason for this is that this is where most of the mites are located but shade or temperature may also be factors contributing to this habit. Occasionally

Table 6. The total number and accumulated percentage of <u>H. harti</u> eggs in relation to buds from the tops and bottoms of six trees.

Bud Numbered from tip	Total 6 trees Top N	%	Bottom N	%
1	12	10.1	16	10.8
2	7	15.9	22	25.8
3	22	34.5	29	45.6
4	14	46.2	21	59.9
5	25	67.2	15	70.1
6	11	76.5	14	79.6
7	13	87.4	6	83.7
8	2	89.1	6	87.7
9	3	91.6	10	94.5
10	3	94.1	0	
11	3	96.6	1	95.2
12	1	97.5	4	97.9
13	1	98.3	0	
14	0		1	98.6
15	0		0	
16	0		0	
17	1	99.2	0	
18	0		0	
19	0		1	99.3
20	0		1	100.0
21	0			
22	1	100.0		

Table 7. Numbers of *H. harti* eggs on terminal growth from the tops and bottoms of apple trees.

Tree	Eggs per shoot		Eggs per bud		Eggs per inch of shoot	
	Top	Bottom	Top	Bottom	Top	Bottom
1	.32	.29	.05	.03	.05	.01
2	.84	.97	.01	.03	.01	.05
3	.61	.15	.07	.11	.08	.20
4	.47	.34	.03	.03	.04	.04
5	.71	1.52	.04	.04	.04	.05
6	.23	.81	.05	.13	.05	.20
Total	3.18	4.08	.25	.37	.27	.55
Mean	.53	.68	.04	.06	.045	.091
Student's "t" test for paired data	.775		1.33		.62	

$t_{.05} = 2.571$

$t_{.01} = 4.032$

DF = 5

nymphs are found moving on the wood from one cluster to another. When disturbed the nymphs may move from one leaf surface to the other or along the petiole. The tendency is for them to hide if they are aware of some danger such as other insects or even the close presence of other H. harti nymphs. Individuals seem to avoid one another, never coming in contact with each other, although two or more may be on the same leaf. The most that has been recorded is ten individuals on a single leaf and 25 on a single cluster. The nymphs rest for long periods on the under side of the leaf when not feeding. During these periods the proboscis is pulled up between the forelegs. The earlier stages move about with the tip of the abdomen turned up at right angles, a characteristic that is not as evident in the later stages.

The numbers of H. harti nymphs on the apple trees decrease as the season progresses. This was first observed when sampling nymphs on spray plots and was confirmed in tests in two separate orchards on different varieties during different years. A series of one yard square cloth trays was placed under representative apple trees, one tray per tree; under the variety Ben Davis in the Boyle orchard at Aldershot in 1958, and 1959, and under Delicious trees in the Melvin orchard at Pereaux in 1959.

The trays were ringed on the edges with tanglefoot and placed on supports driven in the ground. A band of tanglefoot was put around the trunk of each tree 2-3 feet above the ground. Periodic counts were made of nymphs on the trays and on the trunks above and below the tanglefoot. These records are given in Table 8 and show by the numbers taken on the trays that nymphs fall or are blown from the trees. The nymphs have a strong tendency to move up the tree trunk from the ground and not down the trunk from the branches. This was indicated by the considerable numbers of nymphs found below the band compared to no nymphs found above the band. Nymphs were also found in the grass under the trees. This movement partly explains the reduction in numbers of nymphs in the trees between early and late counts.

In addition to dropping to the ground, the apparent reduction in numbers of nymphs in the trees may be caused by movement from a high concentration in the tree centers to the outer portions of the tree. To prove or disprove this, a test to obtain the total numbers of H. harti nymphs on a tree was carried out on Delicious trees in 1959 in the Melvin orchard, Pereaux. Nine trees were selected and sprayed with a high concentration of Parathion 15% w.p., three on each of the dates July 9, July 22 and August 3. All the H. harti mirids that fell were collected from paper trays covering the area under the trees. The numbers of H. harti nymphs on 100 clusters were obtained by visual counts on each of the nine study trees on each spray date. Table 9 gives the record of the counts made by the two methods and the percentage of the total count obtained by the visual count is included. The numbers of H. harti became less on both the total tree counts and the visual counts as the season advanced. The ratio of visual to total count remained reasonably constant for all three trees in the first two sampling dates but on the August 3 count the percentage dropped considerably. This was apparently due to H. harti being mostly in the adult stage at this time. These adults were able to fly readily making the numbers obtained by visual counts low, while the total number for the tree was not influenced by the mobility of the adults. The numbers given for the whole tree are probably not the actual total for the tree due to losses during sampling but they would be comparative to others on the same date and probably represent at least 80 per cent of the actual number on the tree.

During the course of sampling orchards for H. harti nymphs and other predators, by the tapping method and by visual examination of clusters in situ, differences in numbers in various parts of the tree have been noticed. Numbers of H. harti nymphs tapped from the outer branches were low initially but increased as the season progressed

Table 8. Numbers of *H. harti* nymphs taken on banded trees and trays, Boyle orchard, 1958.

Tree	Date	Above band	Below band	On tray
1	July 17	0	6	6
2	do	0	8	2
3	do	0	0	4
4	do	0	1	2
5	do	0	4	6
Totals		0	19	20
1	July 21	0	20	6
2	do	0	24	4
3	do	0	4	2
4	do	0	10	3
5	do	0	7	2
Totals		0	65	17
1	July 31	0	0	2
2	do	0	2	0
3	do	0	1	1
4	do	0	0	2
5	do	1	1	0
Totals		1	4	5
1	August 5	0	0	0
2	do	0	0	0
3	do	0	0	0
4	do	0	0	0
5	do	0	0	0
Totals		0	0	0

(cont'd)

Table 8. (cont'd)

Tree	Date	Above band	Below band	On tray
Numbers of *H. harti* nymphs taken on banded trees and trays, Melvin and Boyle orchards, 1959.				
Total six (6) trees	July 9	0	0	0
	15	0	2	5
	17	0	0	2
	20	0	4	9
	24	0	3	11
	28	0	2	10
	30	0	0	4
	Aug. 3	0	0	0
Numbers of *H. harti* nymphs taken on banded trees and trays, Boyle orchard, 1959.				
Total five (5) trees	July 16	0	1	12
	27	0	14	13
	29	0	7	3
	30	0	1	0

Table 9. H. harti nymphs. Total number per tree and visual counts per 100 clusters from sprayed trees, Melvin orchard.

	Sprayed July 9			Sprayed July 22			Sprayed August 3			
Tree No.	1	2	3	4	5	6	7	8	9	
Total numbers from sprayed trees	1746	940	1026	600	485	511	154	120	207	
Visual count per 100 clusters										
July 9	119	109	67	85	77	115	142	130	119	Ny.
" 22	0	0	0	45	30	34	22	27	25	Ny.
Aug. 3	0	3	1	3	0	0	2	1	11	Ad.
Per cent visual of spray count*	6.8	11.6	6.5	7.5	6.2	6.7	1.3	.83	5.3	

*Figures based on visual counts taken just previous to spraying.

whereas numbers of nymphs, estimated by visual counts, on the inner parts of the tree were initially high and increased with each succeeding count. This indicated considerable redistribution within the tree. To show this, six trees in the Melvin orchard, Pereaux, were sampled periodically for H. harti nymphs throughout July and part of August, 1959. The counts were visual, based on 100 clusters taken inside (within 4' of the trunk) and outside (within the first 3' from the terminal ends of the branches). The phytophagous mites were also counted in the two regions with the aid of a mite brushing machine (Henderson and McBurnie 1943). The mite counts were based on samples of 20 leaves for each date and each location. These counts are summarized in Table 10.

The numbers of H. harti nymphs on the inside clusters were significantly greater than numbers on outside clusters during the early part of the season. The counts, of nymphs that were concentrated near the center of the trees early in the season, became progressively less with each succeeding count. The July 7 outside count was low and the July 15 outside count was significantly greater than the earlier one. This increase in numbers was the result of an outward distribution of nymphs from the center of the trees which was the only source from which the nymphs could come. The total number of mirids

Table 10. Mean numbers of phytophagous mites and H. harti nymphs from the inside and outside of six apple trees (Melvin orchard, 1959).

Date	H. harti nymphs per 100 clusters		
	Inside	Outside	Student's "t"
July 7	113	14[1]	4.72[2]
July 15	62	29[1]	4.02[2]
July 24	28	29	0.22
July 30	11	9	0.48
Aug. 5	8	7	0.45
	Mean phytophagous mites for all dates per 10 leaves		
	25.4	54.1	3.68[3]

1 Numbers of H. harti on the outside of the trees on July 7 and July 15 are significantly different at the 0.05 level. t= 2.66, Df = 10.

2 Numbers of H. harti from the inside and outside of apple trees are significantly different at the 0.01 level. Df = 10.

3 Numbers of phytophagous mites from the inside and outside areas of apple trees are significantly different at the 0.01 level. Df = 28.

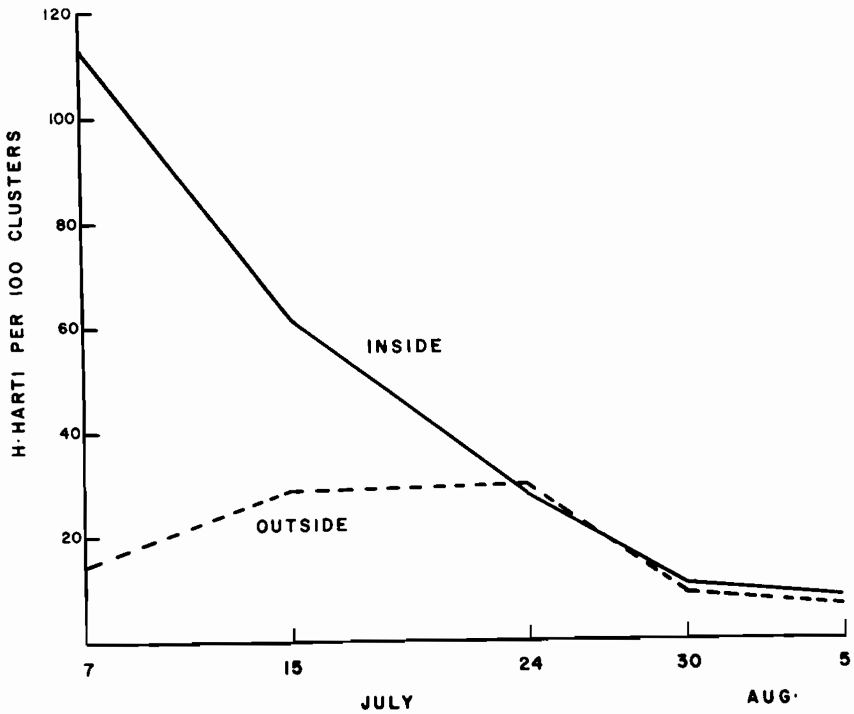


Figure 3. Seasonal relationship between numbers of H. harti nymphs on the inside and outside regions of apple trees.

counted on inside and outside clusters became less with succeeding counts. This was expected as similar losses were shown to occur on the banded and sprayed trees discussed above. The total numbers of phytophagous mites were greater on the outside than on the inside, which may account for the outward movement of some _H. harti_ nymphs. The numbers on the inside, however, were not eliminated so they maintained part of the _H. harti_ population. Reduction in numbers of nymphs from these trees was apparently not due to lack of food because mites were present in sufficient numbers to maintain the population. Probably factors such as wind, rain or excessive competition by other insects contribute to this loss.

The seasonal movements of _H. harti_ nymphs in apple trees indicated by the above tests and observations may be summarized as follows. The nymphs hatch on terminal wood and move to the bases of the branches to leaves where phytophagous mites are most abundant at this time of year. The predacious nymphs tend to follow the mites as they spread outward to new locations. In addition to this outward movement of _H. harti_ nymphs there is also considerable loss in numbers from the tree. This loss is not necessarily due to lack of food but can be caused by other unknown factors.

3. ADULTS

Adults, like nymphs, require prey but because the adults are able to fly they can explore larger areas. In some cases the mite populations are extremely low due to predation by the nymphs so that when the adults emerge they must move considerable distances in search of food. Failure to find adequate prey may occasionally cause considerable mortality of adults.

In each of the years 1956 and 1957 four trees were treated with DDT to remove all predators and thus increase the phytophagous mite population. These trees were in a block of orchard that had been regularly treated with sulphur and supported a moderate population of H. harti. The initial DDT treatment removed practically all the H. harti nymphs but the year after treatment all trees again supported considerable numbers. In order for nymphs to be on these trees adults must have been attracted by the mites during the previous August at oviposition time. The counts made from these trees are shown graphically (Figure 6) and discussed in Section V1-B-1.

The average mite counts for August (per cluster) and the H. harti nymphs (per 100 clusters) for the whole season on the DDT treated and check trees are as follows:

	Average counts 1956 treated trees		Average counts 1957 treated trees	
	Mites	*H. harti*	Mites	*H. harti*
			Sulphur + DDT	
Year of treatment	544	0.1	2413	.1
Year after "	143	10.3	111.6	7.1
			Sulphur alone	
Similar counts on trees adjacent to those treated				
Year of treatment	6.0	17.4	40.0	5.0
Year after "	52.5	5.2	93.4	5.1

The knowledge that adults oviposit on trees, to which they are attracted by prey, led to attempts to correlate numbers of phytophagous mites one year with numbers of *H. harti* nymphs the following year. Existing predator-prey records for the years 1957-1960 were used. Figure 4 shows the relations between the predator and phytophagous mites from records taken in the North Sawler orchard during the years 1957-1960. The predator count was the peak one for each season and the corresponding mite count was the one taken on August 7 of the preceding year. These times were used because the peak record of *H. harti* is more indicative of the number of eggs laid and the mite date is approximately the time when the adult mirids are in the pre-oviposition stage. The correlation coefficients shown are both significant which adds evidence to the observation that H. harti adults are attracted to trees supporting phytophagous mite populations.

Each of the plotted points are the means of three mite counts grouped according to increasing value with corresponding predator counts. A better relation showed between the European red mite (broken line) alone and the predator than between the European red mite and brown mite together (solid line) and the predator even though both species are known prey. This is probably due to an inadequate sampling technique for the brown mite. Many of the brown mites were on the woody parts of the tree when the samples were taken and thus were not included. The correlation coefficient was not significant between brown mite alone and H. harti due probably to the sampling. The records were obtained from eleven different treatment blocks in the same orchard. This resulted in very different prey populations between blocks but the blocks were sufficiently close to allow the predator to fly to areas containing sufficient food. The fact that there were some mites on all blocks would reduce the incentive of the predators to move to areas where there were more mites. Also, the fact that some mortality occurs to the mirid eggs during winter and to nymphs early in the summer of each season would contribute to a poorer record of the predator numbers which would result in a lower correlation calculated from such records.

B. OBSERVATIONS ON OTHER HOST PLANTS

Very few specimens of *H. harti* have been found on plant hosts other than apple in Nova Scotia. Adults have been taken on maple and oak, and numerous specimens have been found on the vegetation under apple trees but these may have come from the trees. Dogbane, *Apocynum* sp., often harbours many specimens especially when mites such as the two-spotted species, *Tetranychus telarius* (L.), and the clover mite, *Bryobia praetiosa* Koch, are present. In bushes near the edges of orchards both nymphs and adults of *H. harti* have been found on alder, *Alnus* sp. These appeared in the presence of alder aphids and it is presumed the aphids were being used as food. These predator nymphs may have crawled to the bushes from the orchard but the presence of large numbers indicated that the eggs had been laid on the alder and the nymphs hatched on this host.

This species was reported by Knight (1941) as having been found on maple, and "in woods" in Illinois. Froeschner (1949) reports it in Missouri as "usually swept from weedy fields but some specimens were taken from wild grape, black locust and oaks".

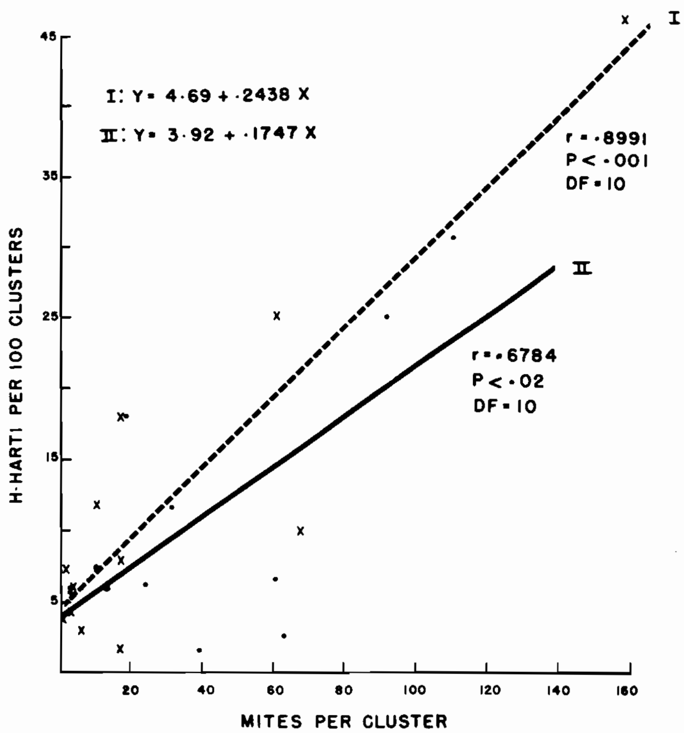


Figure 4. Relation between numbers of phytophagous mites in early August and the peak numbers of <u>H. harti</u> the following season.

VI. STATUS AS A PREDATOR IN APPLE ORCHARDS

The fauna of apple trees is always undergoing fluctuations, sometimes simple and often very complex, depending on the factors and forces involved. To determine the role of each species in the faunal population and show how any one species is coordinated with other species requires detailed knowledge of each and of the interactions within the environment. That this is a monumental task is a foregone conclusion but by elucidating small facets of the whole complex and eventually combining all the accumulated knowledge, the overall complexities will eventually be understood.

Attempts have been made to determine under what conditions the predator H. harti is an important factor affecting the fauna of the apple tree and how H. harti numbers may be manipulated to provide maximum predation effect. In some orchards numbers of H. harti are high, in others low, and the species is almost non-existent in some. It is obvious that some spray chemicals directly influence the numbers but other factors such as amounts or type of food are more often the regulating force. These may also be influenced directly or indirectly by spray chemicals.

Sufficient data are now available to enable manipulation of numbers of this predator through the application of certain chemicals. This has proved useful in studying this species in relation to its food hosts. A prerequisite to determining the value of this species as a predator is the determination of the amount and kind of food it requires. The following sections include a discussion of the species of prey and amount of food this predator will consume and also some predator-prey relationships in orchard blocks.

A. FOOD AND FOOD PREFERENCES

H. harti is known to be one of the more effective predators on orchard pests in Nova Scotia. It kills large numbers of some species, e.g. phytophagous mites, but does not attack others. Reasons for these preferences are unknown. Furthermore, only certain stages of some species are preyed on. Prey that is not available during the active stages of *H. harti* has been fed to them in captivity. This indicates that they will accept a large number of different species of orchard arthropods for food. A list of the species and stages of each species, in order of suspected preference, that *H. harti* is known to attack in Nova Scotia orchards is as follows:

Species	Stage attacked
Panonychus ulmi (Koch)	Egg Nymph Adult
Typhlodromus spp. (15 species)	Egg Nymph Adult
Vasates schlechtendali (Nal.)	Nymph Adult
Bryobia arborea Morgan	Egg Nymph Adult
Tetranychus telarius (L.)	Egg Nymph Adult
Carpocapsa pomonella (L.)	Egg Larva (small)
Spilonata ocellana (D. & S.)	Egg Larva (small)
Aphis pomi (DeG.)	Nymph Adult
Sappaphis roseus (Baker)	Nymph Adult
Lecanium corni Bouche	Nymph
Typhlocyba pomaria McA.	Nymph
Chrysopa sp.	Egg

1. FEEDING TESTS

Feeding tests were conducted in the laboratory at temperatures similar to those occurring in the field. Individuals of each instar were collected in the orchard, placed in plastic cages, and fed mites and eggs or combinations of both. The prey was put on single leaves, the petioles of which were wrapped in moist cotton. An attempt was made to provide an excess of food each day so that the maximum number they would destroy could be determined. The number of mites consumed was determined as frequently as possible, usually every day. If a mirid was found dead the count for that day was not included when computing the average consumed per day.

The European red mite, P. ulmi, was used as the prey in most of the tests. The average number of mites and eggs of P. ulmi consumed by each instar of H. harti in a 24-hour period are recorded in Table 11. The linear regression of the amount eaten on stage of development for all instars was significant indicating an increase in food consumption with each new instar.

The regression lines shown in Figure 5 are for the number of mites consumed, the body length, and the pronotum width each plotted against instar number. Correllation coefficients indicate that each of these is significantly related to instars and also the relationship between the size of the structures and the food consumed is significant. These correlation coefficients are as follows:

	Correlation coefficient r*
Instar with number eaten	.9783
Instar with body length	.9983
Instar with pronotum width	.9943
Body length with number eaten	.9772
Pronotum width with number eaten	.9763

*All r values are significant, $P < .01$, with 3 degrees of freedom.

Table 11. Numbers of European red mite, *P. ulmi*, destroyed per 24-hour period by *H. harti* nymphs.

Instar or number of moults	Number periods fed	Average number mites consumed	
		Laboratory feeding	Calculated from regression line
1	15	55	52
2	49	67	76
3	34	94	102
4	45	110	125
5	48	153	152

Analysis of variance

	DF	SS	MS	F
Linear regression	1	221,685.33	221,685.33	65.99**
Deviation from regression	3	5,916.17	1,972.05	
Error	186	624,849.71	3,359.41	
Total	190	852,451.21		

** Significant $P < .001$

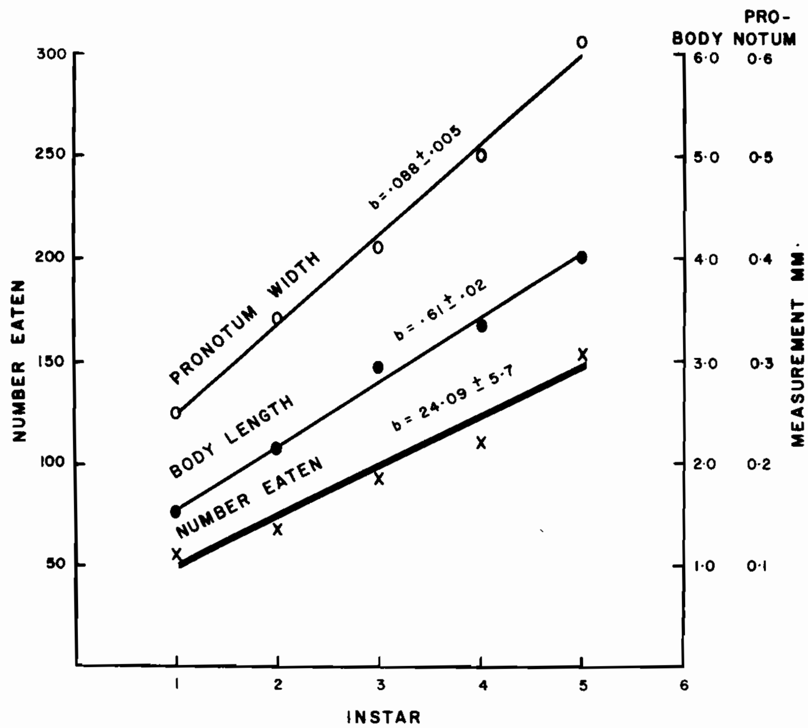


Figure 5. Relation between numbers of P. ulmi eaten per day, body length and pronotum width.

B. VALUE AS A PREDATOR

Extensive long term field studies were conducted to assess the role of H. harti as a predator of several important orchard pests. Spray chemicals were utilized in a selective manner to create certain combinations and densities of predators and pests for study in the natural environment of the orchard.

1. EUROPEAN RED MITE, PANONYCHUS ULMI (KOCH)

(a) Preliminary test

Numbers of H. harti are more closely related to numbers of phytophagous mites than to any other food host. The European red mite, because it is preferred and generally available, is the most important. Because of this, most of the work was carried out on the relationship between the predator and this host.

It was shown (MacPhee and Sanford 1956) that sulphur and perthane were largely innocuous to H. harti, while eliminating other species of predators, and DDT eliminated all species of predators. With this knowledge three plots were set up in 1956 and a similar series in 1957, in an orchard treated with sulphur fungicide in all the regular sprays for the years 1956-1959. One block of each series was left treated with the sulphur alone. A second block in the 1956 series was treated with one application of perthane (50% w.p.) 3 lb. per 100 gal. on June 28, 1956. The second block in the 1957 series was treated with perthane on May 28, June 12 and July 29 in 1957; on May 27, June 13 and July 17 in 1958, and on May 15, June 11 and August 13 in 1959. The third block in each series was treated with one application of DDT (50% w.p.) 2 lb. per 100 gal. on July 6, 1956 and July 5, 1957.

Phytophagous mites and _H. harti_ predators were counted periodically on trees in both series of plots for three years. _H. harti_ counts were made visually on 100 clusters per sample and mite counts, by the method described by Henderson and McBurnie (1943), on ten clusters per sample. All counts were taken in an area defined as being about half-way between the trunk and the circumference of the tree, i.e., standing on the ground and searching or collecting clusters in this region. New growth or terminal clusters over two inches in length were not classed as clusters. Records were made of additional predators by sampling trees adjacent to the test trees by the tapping method as described by MacPhee (1953).

The predator and mite records for both series of plots are shown graphically in Figure 6. Tapping records for 1956 are given in Table 12. The effect of continued spraying with sulphur is the reduction in numbers of some predator species accompanied by an increase in numbers of

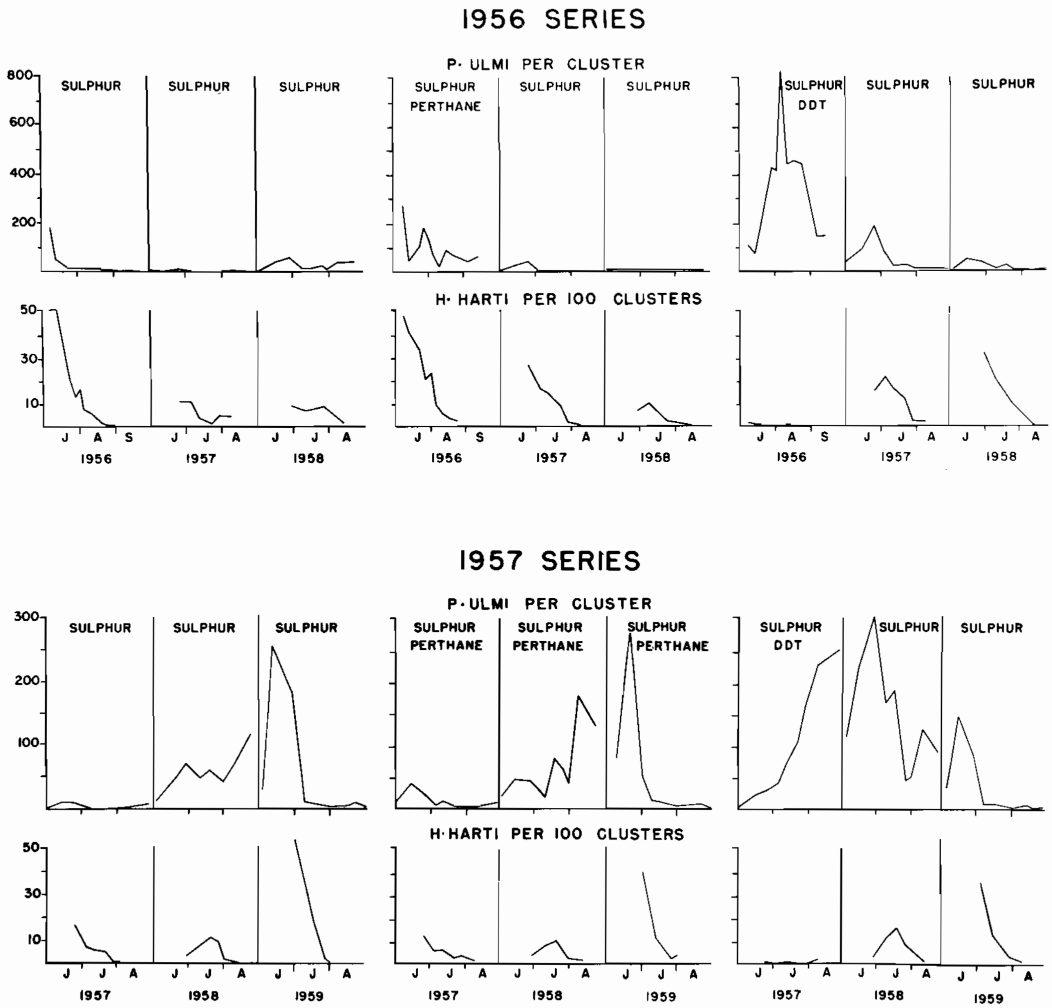


Figure 6. Relation between numbers of <u>H. harti</u> and European red mite, <u>P. ulmi</u>, in sulphur, Perthane and DDT treated trees.

European red mite. Other species of phytophagous mites, e.g., brown mite, **Bryobia arborea** M. & A., are eliminated by sulphur leaving only the European red mite. The use of perthane has a much more drastic effect on predators but has little effect on numbers of H. harti and DDT practically eliminates all predators. Perthane and DDT do not affect numbers of red mite directly. These effects occurred in the plots described above, indicated by the numbers of predators taken by tapping in the three plots, during the first year of treatment (Table 12).

The predator-prey relation followed for three years in both series (Figure 6) showed trends that indicate the effectiveness of H. harti against the European red mite, the only species of mite present. This simplified situation of one main predator and one food host does not often occur in commercial orchards but the results from such a synthetic relationship is a start towards understanding the predator-prey relations in more natural complex situations.

A cyclic relation between the European red mite and predators occurred under continued treatments with sulphur. In 1956, when records were started, the mite population was apparently decreasing due to high numbers of predators, of which H. harti constituted a large part (Table 12). Numbers of predators decreased as the food disappeared. The mites

Table 12. Summary of tapping record of test and adjacent trees in the 1956 series of DDT, perthane and sulphur treatments.

Predators (Numbers per tree)	DDT	Perthane	Sulphur
H. harti	0.0	5.33	21.6
Other mirids	0.25	0.0	18.3
Anthocoridae	2.5	0.0	1.0
Thrips	0.0	0.0	4.0
Anystis agilis	0.75	3.0	45.6
Coccinellidae	0.0	0.3	0.2
Chrysopidae	0.25	0.6	0.2
Nabidae	0.0	0.3	1.0
Pentatomidae	0.0	0.0	1.0
Spiders	1.25	3.3	8.5

and predators remained low through 1957, and in 1958 started to increase. Accordingly the numbers of predators increased with the increased food until soon after the time *H. harti* hatched in 1959. This species, which by this time constituted about 90 per cent of the total predators due to the continued use of sulphur for several years, apparently reached high enough numbers to cause the crash in numbers of European red mite in early July (Figure 6 sulphur). If these records had been continued several more years it is predicted this cycle would have been repeated.

A single application of perthane, superimposed on the sulphur treatments in the 1956 series, (Figure 6) had only a slight effect on mite numbers in the following years. The year perthane was applied mites were not reduced as rapidly because the chemical reduced the numbers of all predators except *H. harti* (Table 12), but other than this the three year record of mites on the perthane treatment in the 1956 series was very similar to that on the sulphur plot. In the years 1957 and 1958 numbers of *H. harti* steadily declined due to lack of food. The continued applications of perthane in the 1957 series (Figure 6) caused somewhat different relations. All predators except *H. harti* were eliminated which resulted in a mite increase because *H. harti* was not present in sufficient numbers to control it. However during 1958 because of increased food the predator population increased in numbers to the point where the mites were greatly reduced. Undoubtedly the predator numbers would decline the following year from lack of food. This would reduce the predation pressure and result in an increase in prey thus starting the fluctuation over again. Unfortunately records are not available to show this.

The effect of a single application of DDT superimposed on the sulphur schedule was similar in both series. Initially it killed all predators which resulted in a rapid upsurge in mite numbers. Winter mortality due to low temperatures in January, 1957 caused a large reduction (up to 80% by actual count) in the numbers of mites hatching in the spring of 1957 in this orchard (MacPhee 1961). This reduction is reflected in the numbers of mites recorded in the 1957 counts on the 1956 series compared to the number in the 1958 counts on the 1957 series both of which were taken the year following the DDT treatment. The numbers of mites in the other plots in 1957 were also low which is partly due to winter killing of the eggs. The effect of winter killing and the buildup of H. harti caused the mites to decrease rapidly in the 1956 series. Adults of H. harti moved in and oviposited on the trees that had been treated in 1956 with DDT because there was a high concentration of food (see distribution of adults, V - 3 above). This provided an impetus for an increase in predator numbers. In the 1957 series the mites were not influenced by winter mortality with the result they remained high during the year following the DDT treatment, but were eventually reduced by the predator in July, 1959. Here also the cyclic relation between mites and the predator *H. harti* is indicated.

From these preliminary tests it is concluded that *H. harti* is capable of becoming numerous enough, when it is the only predator present, to eventually destroy a population of phytophagous mites. A minimum of three years is required, although this could be influenced greatly by spray programs and how quickly the predator can become established from low levels. In these series the surrounding trees sprayed with sulphur provided a reservoir of *H. harti* but even in the trees sprayed with sulphur only, it appeared to take at least three years before the predator was completely effective. Some predation pressures were being applied during the buildup period which would slow the rate of mite increase. The population fluctuation occurs over a longer period and is of greater amplitude when *H. harti* is the only predator present. More effective predation is achieved when a number of predator species exist together rather than when only one predacious species is active.

b. North Sawler experiment

On the basis of the early results in the tests described in the previous section, similar experiments were initiated in order to study the predator-prey relationships in a more intensive manner for several years. Larger blocks were deemed necessary to eliminate the border effects of predators moving from a low to higher density of food and also the effectiveness of the predator could be evaluated at different host levels if a series of blocks were treated to establish these levels.

The experiment was carried out in the North Sawler orchard, Aldershot, N. S., utilizing fungicide plots first treated in 1956. These treatments were on five blocks of approximately 50 trees each, treated regularly throughout the season with captan, glyodin, ferbam, dichlone or sulphur (Magnetic 70). An additional block was left unsprayed as a check. Previous records on phytophagous mites and predacious insects and mites indicated that different levels of each existed in the various blocks. In order to evaluate the effectiveness of *H. harti* at different host levels and in the presence or absence of competing predators, the fungicide plots were further divided. Perthane (50% w.p.) at 3 lb. per 100 gal. was applied to the south four trees in each row of each block, except the check, three times during each season. Single trees were selected for record taking, one tree in each side of each block, i.e., one without and one with perthane superimposed on the regular treatments. This arrangement provided two trees for record taking in each block, of which the ones without perthane had a "normal" number and variety of predators present while the trees treated with perthane had most predator species removed with the exception of H. harti.

Periodic counts were made on clusters; phytophagous mites were counted on a ten-cluster sample, using the mite brushing machine while H. harti numbers were obtained by a visual search on 100 clusters per sample. These counts were taken in a region similar to those discussed in the previous experiment, i.e., about halfway between the trunk and the outer circumference of the tree. These permanent trees for annual records were not disturbed by tapping or other form of mechanical sampling. Visual counts were made which did not alter the numbers of predators present, but ten clusters were removed each sampling date for mite counts. This removed some of the mite population but was not considered of any significance. Additional predator records were obtained by periodic tapping of trees adjacent to the test trees.

The fungicides were applied at approximately ten-day intervals throughout the regular spray season. Perthane was applied on the following dates:

1957 - May 28, June 12, July 29.

1958 - May 27, June 13, July 17.

1959 - May 15, June 11, August 13.

1960 - June 8 only.

The results from four seasons of periodic record taking on the permanent test trees are shown graphically in Figure 7. In addition to the phytophagous mite and the visual H. harti counts, the periodic tapping results are given. The total numbers of predators per tray are shown with the numbers of H. harti (dotted line) included. This indicates the portion of the total that is made up by numbers of this species. The graphs showing the total mite numbers are plotted from the total numbers of European red mite and brown mite; both the eggs and active stages.

The cyclic type of fluctuation between numbers of predators and food hosts, suggested in the previous section, is more pronounced in this series of observations where records were obtained for four seasons (Figure 7). The effect of perthane on predator populations has been previously stated in this thesis and the effect of this chemical in these plots was the basis of a paper by Sanford and Lord (1962). The overall effect of perthane applications in these plots was the reduction of predators other than H. harti, with an accompanying increase in phytophagous mites. The mite numbers were higher each year of the experiment in all the perthane treated plots compared to the corresponding plots treated only with the fungicide. This was noticeable for the different mite densities; whether mite numbers were low or high the numbers were greater on the perthane treated sides. The numbers of _H. harti_ obtained by tapping built up from low numbers to a peak and then declined each year, whereas the numbers obtained by visual counts started at a peak and declined as the season progressed (Figure 7). This variation is probably caused by the different sampling methods. The distribution of _H. harti_ nymphs discussed in Section V - 2 is such that when they first hatch they are not located on the outer portions of the limbs where they can be removed by tapping. As they move outwards they become more vulnerable to the tapping. This results in a peak in the numbers collected. Progressively fewer individuals are obtained in the later samples because, as was shown previously, there is a steady loss from the tree as the season advances and also the nymphs become adults and are not taken by tapping. Visual counts in the center of the tree show in most cases the peak numbers of _H. harti_ nymphs as soon as they emerge. Distribution and loss from the tree provides smaller numbers in succeeding samples from this area.

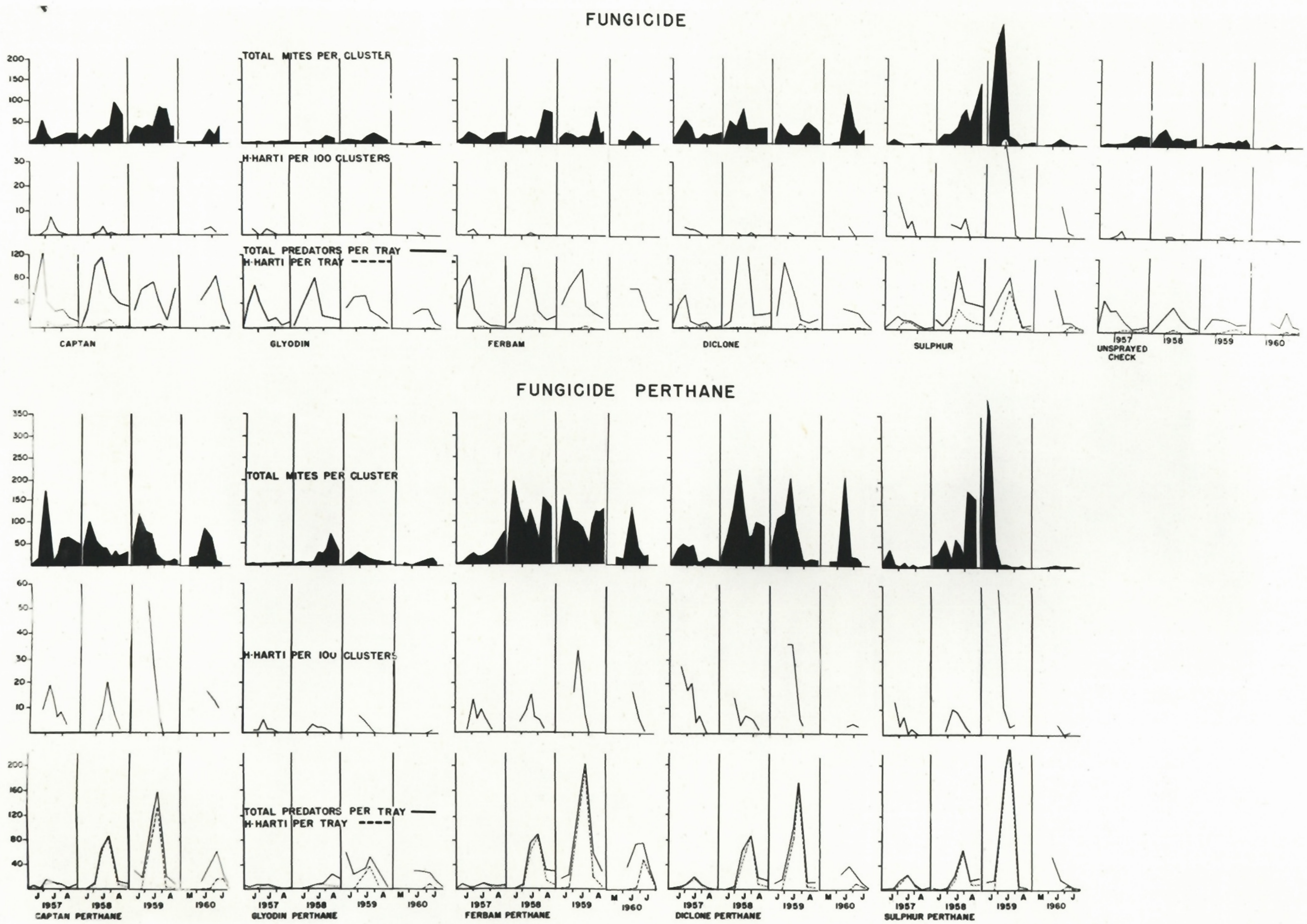


Figure 7. Predator and prey relationships in plots treated with several fungicides and fungicides plus Perthane. North Sawler orchard.

The phytophagous mite complex varies under the different treatments. In some plots Bryobia arborea is the more prevalent species while in others P. ulmi is more numerous. Counts of these species have been totalled on the graph because both are prey of H. harti. Tables of the actual mite numbers are not included but Table 13 gives an indication of the proportion of each species represented by the graphs for each plot.

The cause of these different mite complexes under different fungicide treatments is not clear. It cannot be attributed to the presence or absence of certain predators in these plots because no consistent relation can be found. For instance Typhlodromus spp. were present in the captan and glyodin plots with very small numbers present in the captan-perthane, glyodin-perthane, ferbam, dichlone, and unsprayed check plots. No typhlodromids were taken in the ferbam-perthane, dichlone-perthane, sulphur and sulphur-perthane plots. The presence or absence of these predacious mites did not coincide in every plot with high or low numbers of either species of phytophagous mite. The reason for the different mite complexes is thought to be the fungicide, but it is not clear what part of the fauna is affected.

A brief explanation of what changes occurred in the mite and predator populations in each plot (Figure 7)

Table 13. Per cent red mite and brown mite present in all counts for each year North Sawler plots.

	1957		1958		1959		1960	
	R	B	R	B	R	B	R	B
Captan	33	67	30	70	44	56	14	86
Captan Perthane	20	80	59	41	34	66	3	97
Glyodin	13	87	10	90	15	85	0	100
Glyodin Perthane	20	80	6	94	16	84	4	96
Ferbam	31	69	41	59	58	42	42	58
Ferbam Perthane	58	42	87	13	83	17	75	25
Dichlone	10	90	16	84	19	81	8	92
Dichlone Perthane	30	70	36	64	19	81	3	97
Sulphur	92	8	100	0	100	0	98	2
Sulphur Perthane	96	4	99	1	99	1	100	0
Unsprayed check	33	67	67	33	61	38	79	21

during the four years records were taken, is necessary. In the captan plot and in the captan-perthane plot *B. arborea* was the most numerous mite species. The complex of predators in the captan plot kept the population of mites at a lower density than in the captan-perthane plot. The predators in the latter plot were mostly *H. harti* and thus predation pressure was not as great particularly in the first two seasons of the experiment. The active periods of the species constituting the predator complex overlap providing predation during the entire season whereas *H. harti* is active for a much shorter period. The mites were controlled in both plots but in the captan-perthane one the buildup of *H. harti* and the fast decline of mites in 1959 with a resulting low population of *H. harti* in 1960 is more noticeable.

Mites were very low in the glyodin treated plots probably due to the direct effect of glyodin on the mites. The numbers of mites in plots treated with glyodin were similar to the numbers recorded in the unsprayed check plot which suggests that the other fungicides allowed mite increases by inhibiting some control agent. Perhaps the population in the glyodin plots was more normal. The poorer foliage in the unsprayed check may also have suppressed the mites. An increase in mites after fungicide treatments has been noted in other orchards. Despite the low number of mites on the glyodin plots, a relation between predators and mites similar to that in the other plots existed. There was the same suggestion of a cycle although at much lower population levels. The effect of perthane on the predator complex in this plot was similar to that in the captan-perthane treatment.

Ferbam treatments created a slightly different mite complex. Instead of the mites being mostly the brown species, in the plot treated with ferbam about 50 per cent were European red mite and on the ferbam-perthane plot they were nearly all red mite. The numbers of mites on trees treated with ferbam only were kept low by the predator complex but on the perthane side they increased sharply during 1958 and 1959 but were reduced by 1960. Here again, H. harti was the main predator and reduced this large population of mites to low numbers. The amplitude of the fluctuation in the plot was greater under this treatment than on the plot treated only with ferbam or on any of the plots discussed in the foregoing. A further reduction in mites probably occurred in 1961.

The relation between mites and predators on the dichlone and dichlone-perthane plots was almost identical with that recorded on the ferbam and ferbam-perthane plots. The big difference between the two sets of plots was in the mite complex. Brown mites were definitely more numerous than the European red mite species on the dichlone treated trees. It appears that on the dichlone-perthane treated plot the crash in mite numbers occurred in 1959, a year earlier than the other plots. This caused a reduction in predator numbers which resulted in some buildup of mites the following year, 1960. From the perthane plots on the ferbam and dichlone series it is suggested that the predator is capable of reducing both species of mites because similar relations existed when either species was dominant.

The interaction between _H. harti_ and a single species of mite host was shown more clearly on the sulphur and sulphur-perthane treatments than on any of the other plots. In these plots the European red mite was the only mite species present and _H. harti_ was the main predator. There were more species of other predators on the sulphur alone treatment but even in the presence of these _H. harti_ was the most numerous. In this simplified situation it appears that _H. harti_ is capable of overtaking and causing a crash in red mite numbers within a three year period. Both mite and predator numbers were very low in 1957 and a buildup in numbers occurred in 1958 and early 1959. When the predators hatched in 1959 they reduced the mites to such low numbers there was not sufficient food to sustain the predators until oviposition time. This is reflected in the extremely low numbers of _H. harti_ and mites found in 1960.

In other plots, where a complex of mites existed, the brown mite, due to its distribution, was probably not as vulnerable to attack as was the European red mite. This resulted in a carryover of brown mite which is the more numerous species shown on most of the 1960 graphs.

The unsprayed check maintained a relatively uniform low population of phytophagous mites and predators probably because there was no influence from spray chemicals and probably the foliage was not as attractive to mites. The numbers were lower than the other non-insecticide plots with the exception of the glyodin treated plot. This contributes to the belief that most fungicides in some subtle manner allow some increase in mite numbers.

Some general observations can be made by way of summary of the above experiments. Numbers of _H. harti_ can increase in the presence of sufficient food to control mixed populations of brown and European red mites and also populations of the latter species alone. The resulting predator-prey cycle where this predator alone is involved takes from three to four years from one low point to the next. The amplitude of such a cycle is much greater than a predator-prey relationship where the predator complex is composed of several species. In the plots treated with a fungicide alone, the complex of predators was composed mainly of the following species:

H. harti, Deraeocoris fasciolus, Anthocoris musculus (Say), Typhlodromus spp. and small numbers of many other species. This complex had a much greater regulating effect on mite populations than when H. harti was the sole predator. This was true even when numbers of H. harti were as great as the total numbers of individuals in all the species in the predator complex. Predation was continued for longer periods when more than one species was involved because, in most cases, active stages of the various species do not exist at the same time. The data (Figure 7) show that increases in numbers of mites precede increases in the numbers of predators. There is some evidence of density-dependence between H. harti and mites but because of the time required to respond to change in mite density this does not prevent considerable fluctuations in mite numbers.

2. CODLING MOTH AND BUD MOTH EGGS

The effect of DDT, perthane, and sulphur on populations of H. harti has been discussed together with the amount of predation occurring on phytophagous mites in plots treated with these chemicals. Tests were conducted to show that codling moth, Carpocapsa pomonella (L.), and eye-spotted bud moth, Spilonata ocellana (D. & S.) eggs were prey for this predator and to show that the amount of predation was related to the numbers of predators present. The DDT, perthane, and sulphur treated trees described in Section VI - 1, provided three levels of predator populations. Adults of the codling moth and bud moth were contained in sleeve cages on individual limbs, on trees in each plot. Ten to 15 moths were included in each cage. After a number of eggs had been deposited (2-3 days) the cages were removed and put on another limb. Egg counts were made on each leaf in each position when the cages were removed, and ten days later. The number of eggs that were preyed upon during the ten day period was then determined.

Predation on the Lepidoptera eggs followed the same pattern as did the predation on the phytophagous mite population. More eggs were destroyed in the plots where predators were more numerous. The per cent predation that occurred during 1956 under the different treatments is summarized as follows:

	DDT	Perthane	Sulphur
Codling moth eggs	6.6	36.3	70.9
Bud moth eggs	3.9	20.1	33.1

Where predators were scarce, as in the DDT treated plot, there was very little predation, but in the perthane plot, where _H_. _harti_ was the only predacious species present, considerably more predation occurred. Where a complex of predators existed, such as in the sulphur plot, predation was even greater. In the sulphur plot _H_. _harti_ was the main predator but other species were present in sufficient numbers to cause the additional predation. In this demonstration the concentration of eggs on isolated limbs would tend to keep individual predators present and feeding once they had found the prey. In a normal situation the prey eggs would be sparsely scattered throughout the tree and the predator would only encounter them by chance. In these cases too the numbers of eggs preyed upon would be closely correlated with the number of predators in the trees.

During the 1957 season similar cages with codling moths were placed on some trees in the North Sawler orchard. Eggs were deposited on trees in the plots treated with the following chemicals: sulphur, sulphur-perthane, dichlone-perthane, DDT treatment the previous year (1956), and DDT (1957). The total numbers of _H_. _harti_ collected in these plots by tapping during the season, the number of eggs preyed on (expressed as per cent) and the actual number of eggs destroyed per 3 limbs were:

	Numbers *H. harti*	Per cent of eggs preyed on	Number of eggs preyed per 3 limbs
Sulphur Perthane	39	30.7	177
Dichlone Perthane	34	29.2	107
Sulphur	29	28.1	41
DDT (1956)	29	26.3	79
DDT (1957)	4	2.75	3

The first four plots supported a similar population of predators which was reflected by similar percentages of the total available eggs destroyed. The effect of the 1956 treatment of DDT superimposed on the regular sulphur treated plot had been lost which resulted in this plot being virtually the same as the sulphur plot. In the trees treated with DDT in 1957 the predators were destroyed, and had not built up again at this time, which resulted in very little predation on the codling moth eggs.

Probably the predation of lepidopterous eggs would be greater under the attacks of a complex of predator species. In these tests where *H. harti* was almost the only predator present the number of destroyed eggs did not exceed 30 per cent. More individuals would probably cause more destruction but in most commercial orchards numbers of *H. harti* higher than is reported here do not occur.

C. INFLUENCE OF SPRAY CHEMICALS

Orchard pest control programs that allow beneficial species to work at a maximum must have pesticides that are selective in their action. This requires knowledge of the effect of the pesticides on the beneficial species as well as on their toxicities to the pests. In the course of determining the toxicities of control chemicals to predators and parasites considerable data have been accumulated on the predator H. harti. This has been included in published papers by A. W. MacPhee and the writer the most recent of which was in 1961 (MacPhee and Sanford 1961).

The data on the direct effect of chemicals on this species was obtained from small plots in commercial orchards. Each result has been summarized from replicates on two to four tree plots in several orchards, and in most cases in different years. This means that no determination of effect has been made on the basis of one test alone. Counts on this species in most tests were made visually, searching clusters for nymphs from the ground. Most counts were based on 100 clusters. At least two counts, several days apart, were made for each test. The summarized results for all materials and dosages tested on this species to date are given in Table 14.

One extremely useful characteristic of H. harti is its apparent tolerance of normal dosages of many wide spectrum spray chemicals. It is perhaps the most chemically resistant mirid predator species in Nova Scotia orchards and although there may be a drastic reduction in numbers, enough usually survive to provide a nucleus from which the species can attain substantial numbers. The effect of some selected examples of wide spectrum chemicals on a number of predator species including Miridae and other groups and the effect of the chemicals on _H. harti_ in relation to the other species is demonstrated by data in Table 15. _H. harti_ is partially resistant to DDT 2 lb., Diazinon 0.5 lb., and malathion 0.25 lb. The effect of perthane and sulphur on _H. harti_ has been discussed in another section together with the usefulness of these chemicals in manipulating predator populations. The selective innocuous effect of these chemicals on _H. harti_ numbers compared to other predator species is readily seen from Table 15. Perthane in particular is detrimental to most other predators while sulphur is detrimental in varying degrees. The effect of perthane on predators has been discussed more fully in a previous paper (Sanford and Lord 1962).

Table 14. Direct effect of orchard pesticides on *H. harti*.

Material	Formulation	Dosage per 100 gallons water	Effectiveness
Aramite		2 lb.	0*
Bacillus thuringiensis Berliner preparation[1]		4 lb.	0
Bordeaux		3 lb. copper sulphate + 10 lb. lime	0
Calcium arsenate		3 lb.	0
Captan		2 lb.	0
Chlorocide[2]		1.5 lb.	0
Demeton	26.2% emul. conc.	1 pt.	+
DDT	50% w.p.	2 lb.	+
DDT		0.5 lb.	+
DDT		0.25 lb.	0
Diazinon[3]	25% w.p.	2.0 lb.	++
Diazinon		0.5 lb.	+
Diazinon		0.25 lb.	+
Diazinon		0.125 lb.	+
Diazinon		0.062 lb.	+
Dichlone		2 lb.	0
Dichlone		0.5 lb.	0
Dimethoate[4]	43.6% E.C.	0.5 pt.	++
Dodine		0.75 lb.	0
Erad[5]		0.5 pt.	0

(cont'd)

Table 14. (cont'd)

Material	Formulation	Dosage per 100 gallons water	Effectiveness
Eradex[6]	50% w.p.	0.5 lb.	+
Ethion	25% w.p.	1 lb.	++
Fixed nicotine		3 lb.	0
Genite[7]	50% emul.	1.5 pt.	0
Glyodin		1.5 qt.	0
Guthion[8]	25% w.p.	1 lb.	++
Guthion		0.5 lb.	++
Guthion		0.125 lb.	0
Kelthane[9]	25% w.p.	2 lb.	+
Kelthane		1 lb.	0
Kepone[10]	50% w.p.	2 lb.	0
Lead arsenate		4 lb.	0
Malathion	25% w.p.	2 lb.	++
Malathion		1 lb.	++
Malathion		0.5 lb.	+
Malathion		0.25 lb.	+
Malathion		0.125 lb.	+
Menazon[11]	4 lb./gal.	0.5 pt.	+
Menazon		0.25 pt.	+
Menazon	70% w.p.	0.25 lb.	+o
Menazon		0.125 lb.	0

(cont'd)

Table 14. (cont'd)

Material	Formulation	Dosage per 100 gallons water	Effectiveness
Meta-systox-R[12]	2 lb./gal.	0.5 pt.	++
Nicotine sulphate	40%	1 pt.	0
Ovex	50% w.p.	0.5 lb.	0
Parathion	15% w.p.	0.75 lb.	++
Parathion		0.38 lb.	++
Perthane[13]	25% w.p.	3 lb.	0
Phosphamidon[14]	4.8 lb./gal.	1 pt.	++
Pyrethrum	1%	3 lb.	+o
Rhothane[15]	50% w.p.	2 lb.	+
Ryania	100%	5 lb.	0
Ryania	50%	6 lb.	0
Sevin[16]	50% w.p.	2 lb.	+
Sevin		1 lb.	+
Sulphur	Wettable	8 lb.	0
Summer oil		1 gal.	0
Synthetic cryolite			0
Tedion[17]	50% w.p.	0.5 lb.	+o
Trithion[18]	25% w.p.	1 lb.	+
Trithion		0.25 lb.	+
Zineb[19]	50% w.p.	2 lb.	0

(cont'd)

Table 14. (cont'd)

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* No effect, 0; reduction of numbers, +; practical elimination, ++; possible reduction, evidence inconclusive, +o.

1 Wettable powder preparations of B. thuringiensis Berliner spores (Rohm and Haas Co.) (75 x 10⁹ spores per gram).

2 p-chlorobenzyl p-chlorophenyl sulphide (Boots Pure Drug Co.).

3 O,O-Di ethyl O-(2-isopropyl-4-methyl-6-pyrimidinyl phosphorothioate (J. R. Geigy A. G.).

4 O,O-Dimethyl s-(N methylcarbamoylmethyl) phosphorodithioate) (Amer. Cyanamid Co.).

5 10% phenylmercuric acetate (Green Cross Products).

6 2,3-quinoxalinedithiol cyclic trithiocarbonate (Chemagro Corp.).

7 2,4-Dichlorophenyl benzene sulfonate (Allied Chem. Corp.).

8 O,O-Dimethyl S-(4-oxo-benzotriazino-3-methyl) phosphorodithioate (Chemagro Corp.).

9 1,1-bis -p-chlorophenyl)-2,2,2-trichloroethanol (Rohm and Haas Co.).

10 Decachloro octahydro-1,3,4-metheno-2H-cyclobuta (cd) pentalen-2-one (Allied Chem. Corp.).

11 O,O-dimethyl S- (4,6/diamino-1,3,5-triazin-2-yl) methyl phosphorothiolothionate (Plant Protection Ltd.).

12 O,O-dimethyl S-2-(ethylsulfinyl) ethyl phosphorothioate (Chemagro Corp.).

13 1,1-bis (p-ethylphenyl)-2,2-dichloroethane (Rohm and Haas Co.).

(cont'd)

Table 14. (cont'd)

14	dimethyl 2-chloro-2-diethylcarbamoyl-1-methyl vinyl phosphate (California Chemical Co.).
15	2,2-bis (p-chlorophenyl)-1,1-dichloroethane (Rohm and Haas Co.).
16	1-naphthyl N-methylcarbamate (Union Carbide Chemicals Co.).
17	2,4,4^1,5-tetrachlorodiphenyl sulfone (Niagara Chemical Co.).
18	O,O-diethyl S-p-chlorophenylthio methyl phosphorodithioate (Stauffer Chem. Co.).
19	Zinc ethylene-1, 2-bisdithiocarbamate (Rohm and Haas Co.).

Table 15. Effects of spray chemicals on predator and parasite populations in Nova Scotia orchards.

Predator(s) and parasite(s)	DDT (50% w.p.) 2 lb.	Diazinon (25% w.p.) 0.5 lb.	Malathion (25% w.p.) 0.25 lb.	Perthane (25% w.p.) 0.75 lb.	Trithion (25% w.p.) 1 lb.	Wettable sulphur 8 lb.
Acarina						
<u>Anystis</u> <u>agilis</u> Banks	++	o	-	++	+	+
<u>Mediolata</u> <u>novae-scotiae</u> Nes.	o	o	-	o	-	++
<u>Phytoseius</u> <u>macropilis</u> Banks	-	-	-	-	-	++
<u>Typhlodromus</u> <u>finlandicus</u> (Oudms.)	-	++	-	+	-	+
<u>Typhlodromus</u> <u>rhenanus</u> (Oudms.)	++	++	-	+	-	+o
<u>Typhlodromus</u> <u>pyri</u> Scheuten	+	+	-	+	-	+
Miridae						
<u>Atractotomus</u> <u>mali</u> (Meyer)	++	-	++	++	+	o

(cont'd)

Table 15. (cont'd)

Predator(s) and parasite(s)	DDT (50% w.p.) 2 lb.	Diazinon (25% w.p.) 0.5 lb.	Malathion (25% w.p.) 0.25 lb.	Perthane (25% w.p.) 0.75 lb.	Trithion (25% w.p.) 1 lb.	Wettable sulphur 8 lb.
Campylomma verbasci (Meyer)	+o	++	-	+	-	+
Deraeocoris fasciolus Knight	++	+o	++	++	+	o
Deraeocoris nebulosus (Uhl.)	-	-	++	-	++	-
Diaphnidia spp.	++	-	++	-	++	o
Hyaliodes harti Knight	+	+	+	o	+	o
Phytocoris spp.	-	-	-	-	o	-
Pilophorus perplexus D. & S.	++	-	-	-	-	++
Plagiognathus obscurus Uhl.	++	++	++	+	-	+o
Psallus sp.	-	-	-	-	+	-

(cont'd)

Table 15. (cont'd)

Predator(s) and parasite(s)	DDT (50% w.p.) 2 lb.	Diazinon (25% w.p.) 0.5 lb.	Malathion (25% w.p.) 0.25 lb.	Perthane (25% w.p.) 0.75 lb.	Trithion (25% w.p. 1 lb.	Wett-able sulphur 8 lb.
Anthocoridae						
Anthocoris musculus (Say)	+	++	+o	++	+o	o
Thysanoptera						
Haplothrips faurei Hood	++	++	+	++	++	+
Leptothrips mali (Fitch)	++	-	-	++	-	+
Parasitic hymenoptera						
Aphytis mytilaspidis (LeB.)	++	-	-	-	-	++

Legend: No effect, o; reduction of numbers, +; practical elimination, ++; possible reduction, evidence inconclusive, +o.

VII. SUMMARY

The characteristics of each stage and the life history of the predacious mirid Hyaliodes harti Knight have been determined by laboratory and field studies. Some ecological aspects of this insect were also investigated, including its distribution, food hosts, plant hosts, relation to other species in its environment, value as a predator, and the toxic effect of spray chemicals on it.

The eggs of H. harti can be readily distinguished from those of other apple inhabiting mirids. The characters used to distinguish and separate eggs of each species in situ include the size, shape and color of the visible egg cap, the type and age of the wood containing the egg, and the position of the egg on the wood. The eggs also were separated on the basis of size after they were dissected from the wood and measured.

Measurements of head capsules of nymphs were distributed by frequency into five distinct groupings indicating five nymphal instars. Morphological characters used to distinguish each stage include size, color markings, and mesothorax and wing pad development. The adult female is slightly larger than the male and in most cases can be readily distinguished by a large white mark on the scutellum. This is much smaller on the male.

There is one generation of H. harti per year in Nova

Scotia. It overwinters as an egg on the host tree, hatching about the middle of June. The nymphal stages are active until the end of July. The first adults appear during the third week of July and occur throughout most of August. Oviposition occurs about mid-August, females depositing up to 30 eggs each.

The distribution of this species is determined by the available food and the characteristics of the host plant. During the active stages the nymphs are found in proximity to available prey. They move from low to higher densities of prey. At oviposition time adults fly to trees in which prey is abundant which results in the eggs being deposited where food will be available for the young nymphs the following year. New growth is also essential for oviposition. Continuous losses of nymphs from the trees occur throughout the season.

H. harti preys mainly on the red mite, _Panonychus ulmi_ (Koch) and other species of phytophagous mites but is also an effective predator on lepidopterous eggs and small larvae. It is capable of destroying various stages of a number of species provided they occur when _H. harti_ is active. Its predation value is limited because there is only one generation each year but this is compensated somewhat by an active period of about eight weeks.

Treatments with perthane and sulphur destroyed most species of predators with the exception of H. harti. P. ulmi numbers were not affected. Using these materials almost pure populations of H. harti and P. ulmi were obtained. In this predator-prey relationship this predator was able to increase in numbers sufficiently to destroy populations of the mites in three to four years. When numbers of other predacious species were present the total predation was much greater with a smaller amplitude in the cyclic oscillations.

H. harti is comparatively resistant to many spray chemicals. Perthane and sulphur are the notable ones but lower dosages of most others are non-toxic to some degree. This information has been useful when preparing control programs that are destructive to the pests and comparatively harmless to the predators.

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