THE BIOLOGY OF THE BALSAM WOOLLY APHID, *CHERMES PICEAE* RATZ., IN OREGON AND WASHINGTON AND THE IDENTIFICATION AND EVALUATION OF ITS NATIVE PREDATORS

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

June 1960

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Date thesis is presented May 11, 1960

Typed by Helen Sewell

ACKNOWLEDGMENTS

Acknowledgments should first be made to the Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service, and the Department of Entomology, Oregon State College. The cooperative agreement between these two organizations made this study possible. The writer is also indebted to the following people for their help and guidance in the planning of the study and the preparation of this thesis:

To Dr. Julius A. Rudinsky, Associate Professor of Entomology, who helped outline the project, carefully reviewed the thesis, and offered many helpful suggestions.

To Messrs. Robert L. Furniss and Kenneth H. Wright, U. S. Forest Service, for their cooperation, suggestions as to methods, and constructive criticism on the development of the entire project.

To Mr. Paul E. Buffam, U. S. Forest Service, whose careful field work was invaluable in compiling much of the material in this study.

To Mr. Wallace C. Guy, U. S. Forest Service, for his guidance in photographic techniques and for help in processing the prints for this thesis.

To his wife, Gwendolyn L. Mitchell, who performed not only the usual tasks of proof-reading and offering encouragement, but who was also often called upon to do such menial tasks as taking notes and helping rear insects.

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INTRODUCTION

The balsam woolly aphid, Chermes piceae Ratz., (Hemiptera: Chermidae)[1] is an European import that is notorious in the western hemisphere for its effects on trees in the genus Abies. Currently it is the most destructive forest pest in the Pacific Northwest. The most frequently infested hosts in Oregon and Washington are subalpine fir, Abies lasiocarpa (Hook.) Nutt. and Pacific silver fir, A. amabilis (Dougl.) Forbes. At lower elevations the insect also infests grand fir, A. grandis (Dougl.) Lind. Besides native trees, the balsam woolly aphid has also been observed infesting several exotic species of Abies.

Purpose of Study

At the present time there are no known quick remedies to halt a balsam woolly aphid outbreak. Organic phosphates, such as malathion, are fairly effective in controlling infestations on ornamentals, but are not feasible on large scale projects in the forest. Logging heavily infested areas may exert some degree of control, but its greatest value lies in salvaging dead and dying timber. Because no adequate control measures are available, the Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service, entered into a cooperative agree-

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1/ The generic name Chermes is used by Miss Louise Russell, U. S. National Museum. In Canada, Adelges is the preferred generic term. Dreyfusia is the generic name used in Europe.

ment with Oregon State College to explore the possibilities of biological control. The writer was selected to do much of the work on this problem.

Objectives and Scope of Study

Long-term objectives of the cooperative study were: (1) to determine the habits of *C. piceae*, (2) to assess the effectiveness of biotic factors, and (3) to develop a biological control program. Achievement of the main objectives was approached from two different directions: (1) By the study of the biology and behavior of the balsam woolly aphid, and (2) by a study of the native and introduced predators.

So as to proceed in an orderly manner, the over-all problem was broken down into its various components, and to each facet secondary objectives were assigned. Different components were studied each year until their objectives were met.

Several investigations were undertaken within the framework of the cooperative agreement and some are still in progress. The objectives of the studies whose results are reported in this thesis were:

1. To determine the biology of the balsam woolly aphid in the Pacific Northwest and to find if there is an observable difference in behavior of aphid populations on various host species and in different areas;
2. To obtain and identify as many of the native predators as possible that prey on *C. piceae* populations in the Pacific Northwest and to evaluate their importance in controlling aphid populations.

These studies were made while working with the Experiment Station during the years 1957, 1958, and 1959. The identification and evaluation of native predators received the most intense study and will occupy the majority of this paper.

Background Information on the Balsam Woolly Aphid

The first introduction of C. piceae in North America was believed to have occurred around 1900 in southeastern Canada (3, p. 9). There, and subsequently in New England, it became a serious pest on balsam fir, A. balsamea (L.) Mill.. In 1928, the insect was found on the west coast in San Francisco, California (1, p. 78). Serious damage to grand fir in Oregon's Willamette Valley around 1930 announced the insect's first appearance in the Pacific Northwest.[2/] The current oubreak was discovered in southwestern Washington in 1954. Further investigations the same year revealed an infestation in both silver and subalpine fir covering 276,160 acres. The following years revealed a continual increase in the size of the infestation, both in Oregon and Washington. In 1957, the area of infestation reached an all-time high of nearly 600,000 acres. Since then the outbreak area has decreased somewhat with some localities showing considerable improvement, while others have grown progressively worse.

C. piceae differs from most chermids in that it has abandoned the typical pentamorphic life cycle in which there is an alternation between

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2/ Unpublished files of the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

primary and secondary hosts. In North America, the insect has been found to be of one form--completely parthenogenetic and feeding solely on trees in the genus Abies. The winged progrediens form present in southeastern Canada has not been found in the Pacific Northwest.

The balsam woolly aphid, corresponding to the pentamorphic sistens form, has three nymphal instars. The adult is purple to black, wingless, and almost spherical. It is almost invariably covered with a wool-like secretion and is usually associated with a clutch of amber-colored eggs. Maximum adult size seldom exceeds 1 mm., and the newly hatched crawler may be as small as 0.35 mm. With the exception of the first instar, all stages are almost identical with the adult and live out their entire lives anchored to one spot on the bark surface. The first instar has two distinct forms. The first form is a long-legged, amber-colored crawler stage which seeks out the feeding location. The second is a black, flattened, resting stage which is usually referred to as the neosistens stage.

Once the crawler has selected the feeding location, the insect inserts its long, thread-like mouthparts into the cortical tissue and starts feeding on sap nutrients. At the same time the insect also pumps saliva into the tree. This saliva is believed to contain a toxic material, which adversely affects the living cells of the tree.

An attack by the balsam woolly aphid may take one of two forms: (1) It may occur in the crown area; or (2) it may occur on the main stem. The symptoms of attack and nature of damage are strikingly different in the two types of infestation. Crown infestations kill or inhibit the buds, thus preventing new growth. As the old needles slowly drop, the crown gradually becomes more and more ragged and thin, until the tree finally dies of starvation. This process may take years. The stem attack is usually more serious. Here the insect indirectly affects the tracheids and quickly reduces the flow of transpiration water between the roots and crown. Such an infestation may kill a tree in one or two years. Crown distortion is also associated with this type of infestation, but frequently does not become conspicuous because the trees die so quickly.

BIOLOGY OF THE BALSAM WOOLLY APHID

There have been several studies on various aspects of *C. piceae* biology. In Europe, investigations were made by Marchal (15), Karafait and Franz (12), Pschorn-Walcher and Zwölfer (19), and Varty (22). In southeastern Canada, intensive studies on balsam woolly aphid biology were made by Balch (3). The following section presents biological information on the balsam woolly aphid as found in the Pacific Northwest.

Methods and Procedures of Study

One European silver fir, *Abies alba* Miller, and several native silver, subalpine, and grand firs with heavy stem infestations were tagged as permanent sample or collection trees. An attempt was made to locate these trees in areas that would represent a fair cross-section of the region's infestation zone. Table 1 presents the general locations of the trees, the species represented, and the approximate elevations of the study areas. In 1957, collections and observations were made at least every two weeks in each area except Benton-Lane Park. Benton-Lane was not visited until 1958. In 1958 and 1959, travel to the more distant places, such as Toutle River and Wind River, Washington, was curtailed, although the other bi-weekly observations were continued.

Information was obtained during the visitations in three ways: (1) By general observations; (2) by taking infested bark samples back to the laboratory for study; and (3) by making aphid population counts on one-inch square, permanent sampling plots. From the derived data, it was hoped to determine (a) the number of balsam woolly aphid generations per season, (b) what stages are present at different times of the year, (c) some indication of reproduction rate and potential, and (d) any other pertinent information on the balsam woolly aphid such as dispersal and mortality factors.

Table 1.--Elevation, location, and tree species studied at predator collection areas.

Location	Tree Species	Elevation
Toutle and Green River Drainages, Wash.	*A. amabilis*	2500-3500
Wind River Arboretum (Near Carson, Wash.)	*A. alba* and *A. lasiocarpa*	1000
Black Rock, Oreg. (Upper Warnick Creek Drainage)	*A. amabilis*	2800
Corvallis, Oreg.	*A. grandis*	230
Benton-Lane Park (Near Monroe, Oreg.)	*A. grandis*	350
Willamette Pass, Oreg.	*A. lasiocarpa*	4000

Seasonal History

Every investigation on the seasonal history of the balsam woolly aphid has shown the insect as having more than one generation per year. Karafiat reported three generations in Central Europe (13, p. 67). Varty noted two and sometimes a partial third generation in England (22, p. 30-31). Balch found only two generations in southeastern Canada (3, p. 17-23). Cooperative studies in Oregon and Washington by the writer representing the U. S. Forest Service, Dr. J. A. Rudinsky for Oregon State

College, and Mr. N. E. Johnson for Weyerhaeuser Company have revealed aphid populations having two, three and four generations per year. This section reports the results of those investigations.

Rudinsky's work was done at Corvallis, Oregon and Johnson's was in Washington's Green River drainage. Their study methods have been reported (11) (21). Investigations at Wind River, Washington, and Black Rock and Willamette Pass, Oregon, were carried out by the writer. Also, in 1958 and 1959, the writer took over Rudinsky's work at Corvallis.

Two Generation Cycle - In general, the life cycle in the higher elevations starts with the overwintering form of the first generation (hiemosistens) breaking diapause in early spring. This resumption of spring activity is characterized by a swelling of the first instar (neosistens) and a conspicuous glob of colorless "honeydew" at the anal end of the insect. The sistentes then proceed through three moults and give rise to a second generation (aestivosistens). The second generation repeats the pattern and throughout the fall and early winter produces the overwintering form of the first generation. The upper chart in figure 1 presents a graphical picture of aphid populations having two generations per year.

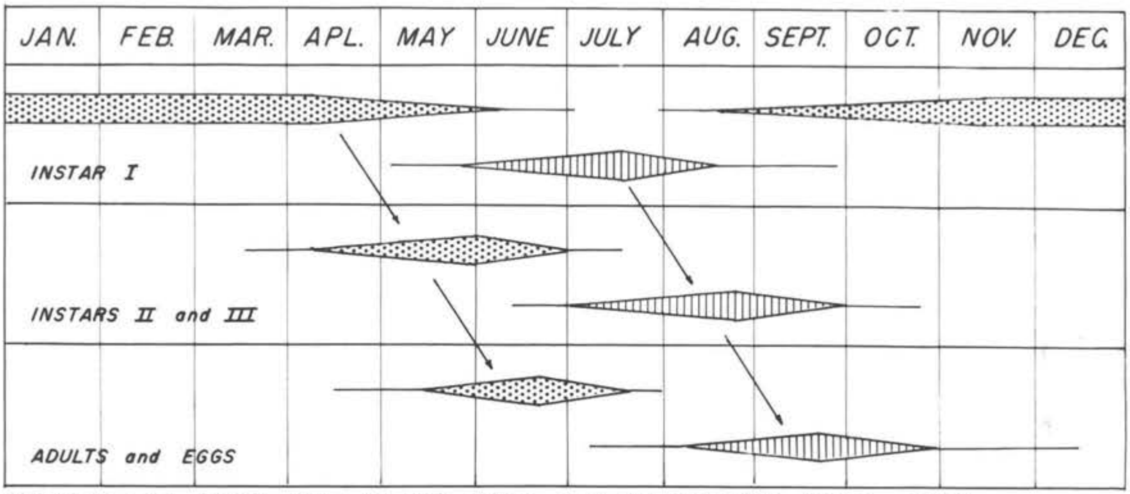
Resumption of spring acitivity may begin anytime from the first part of March to early May, depending upon the particular area and the weather. Spring temperature is doubtless the deciding factor. It was found, for example, that neosistentes collected in late December could be forced to break diapause after being subjected to room temperature for only five days. During the warm spring of 1957, populations broke diapause about four weeks earlier than they did the next two years. Compounding this variation even further, no two areas are exactly the same, in all respects, even though they may both have the same number of aphid generations per year.

The two generation diagram in figure 1 for Green River, Black Rock, and Willamette Pass assumes a normal year in an average area. It describes most accurately the seasonal history of the balsam woolly aphid population at Willamette Pass. The Green River population starts about two weeks earlier, and Black Rock is about two weeks later. This discrepancy is carried throughout the first generation and partly into the second generation. Once the warm summer weather arrives, the slower starting populations develop at a somewhat faster rate. The result is that the second generation peaks at about the same time in all areas.

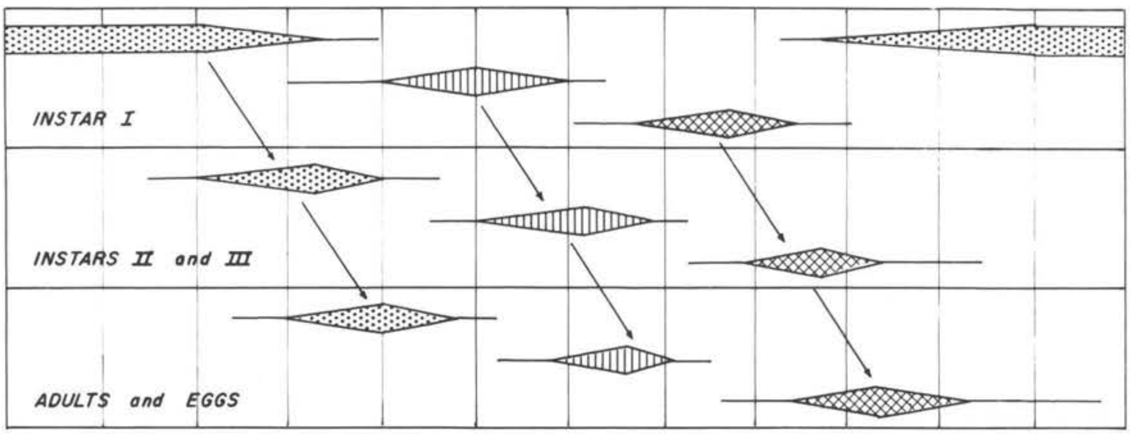
Even stand position of the host tree and aphid position on individual trees affect aphid development rate. It was found at Green River, for instance, that insects on one tree located along a cutting line developed a full month ahead of those insects located 40 feet away within the stand. At Corvallis, it was observed that there was about one weeks difference in the development rate between insects on the exposed and shaded side of the same stand-edge tree. Twenty feet away, within the stand, the difference was about two weeks. On trees within the forest, aphids settled around the stem's lower two or three feet were invariably one to two weeks behind the population living higher on the tree.

Because of the variation in rates of aphid development, there is considerable overlap in generations. From the time that the first generation adults start laying eggs, until late December, all life stages are present in some degree. The first generation is generally the slowest to develop.

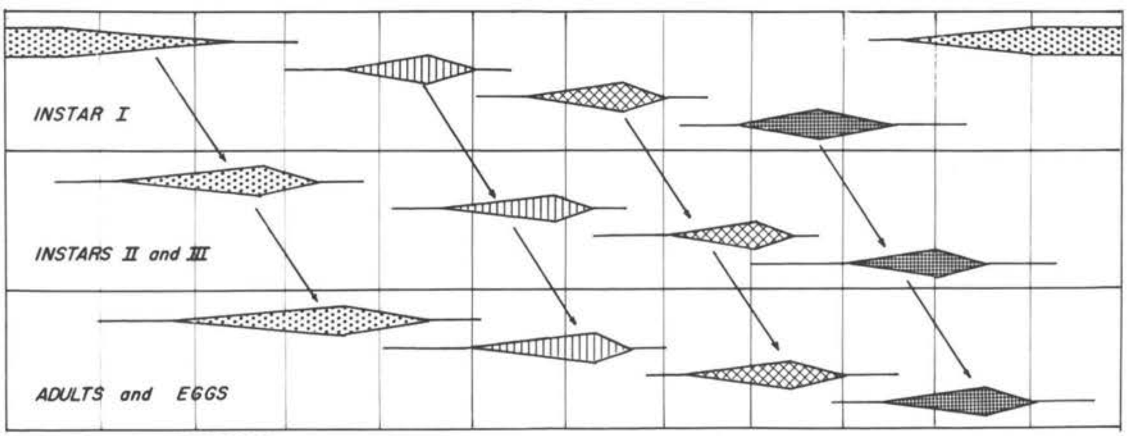
Figure 1. Seasonal occurrence of the balsam woolly aphid at five areas in Oregon and Washington: two generations per year at Green River, Washington and Black Rock and Willamette Pass, Oregon; three generations at Wind River, Washington; four generations at Corvallis, Oregon.



GREEN RIVER, WASH. AND BLACK ROCK AND WILLAMETTE PASS, OREG.



WIND RIVER, WASHINGTON



CORVALLIS, OREGON

KEY: [dotted], 1st generation; [vertical lines], 2cd generation; [cross-hatched], 3rd generation; [fine dark cross-hatching], 4th generation.

Duration of the second stadium is from two to three weeks, and the third stadium is another two or three weeks. Adults appearing in mid-June and early July usually have an oviposition period of about two weeks. Those developing earlier, when temperatures are low, may take four to six weeks to complete their oviposition.

Motile nymphs first appear around early June, but usually do not reach their peak numbers until the end of the month or early July. The peak crawler population indicates that the collapse of the first generation adult population is imminent. Within two or three weeks, about the only stage present will be the resting first instar. If the spring transition from cold to warm weather is abrupt, most of the aphid population will start development at about the same time. Similarly, the end of the generation will be uniform. When this happens, as it did in 1959, there is a very sharp and distinguishable break between the first and second generation. Then, for the next two or three weeks after the collapse of the adult population, the balsam woolly aphid population will be composed of mostly first instars in the resting stage. When the transition from winter to spring temperatures is gradual, the quiet period is almost obliterated. Separation of the two generations then becomes very difficult. This happened in 1957.

Second generation activity begins with second and third instars almost exploding into abundance in late August and early September. The adult population reaches its peak in late September. Oviposition begins almost immediately with the appearance of the first adults and is finally halted around the end of October. Egg hatch starts shortly after the appearance of the first adult and continues up until late November--at least a full month after oviposition has halted. Apparently the temperature required for incubation is slightly lower than that required for oviposition and instar development. This is not too surprising as eggs were observed hatching in a refrigerator after being kept there for a month at 45° F. Temperatures around 40° F. are too low for incubation, and prolonged temperatures just below the freezing level will kill the embryo.

Live second and third instars are usually present on the trees until the end of December, although they are quite rare after the end of October. At Willamette Pass, live adults and eggs were fairly common up to the last observations in late December. This condition also existed on a few protected trees at Black Rock, although there, heavy fall rains usually cleaned the infested boles of every life stage except the neosistens. On rare occasions, especially noticeable during the mild 1957-1958 winter, a few first generation first instars will moult in early fall and over-winter as second instars.

Three Generation Cycle - Warmer spring temperatures at Wind River Arboretum permit more rapid development than conditions at higher elevations. At least three generations are completed by fall. The middle chart in figure 1 presents the occurrence of life stages throughout the year.

Essentially, the progress of the population at Wind River is the same as at the higher elevations. The main difference is the earlier resumption of spring acitivity and the more rapid instar development. Breaking of diapause starts around early March. By the first of April, second and third instars are abundant. Also, a few adults are usually present, but do not reach a peak until early May. Because of a typical slow transition to warm spring temperatures, there is very little break between the first and second generation.

Intermediate stages of the second generation first appear in significant numbers around the first of June, and the adult population reaches its peak in mid-July. For some reason the collapse of the second generation is very fast and quite uniform throughout the population. Consequently, there is a distinct break between the second and third generation. After a two or three week lull in which most of the population is in the first instar resting stage, there is a rapid burst of development, and adults again become abundant around early October.

In 1957, it appeared that the warm, late fall might have permitted another complete or partial generation. If there was, it was not detected. Investigations in 1958 and 1959 showed no sign of development beyond the third generation.

<u>Four Generation Cycle</u> - The seasonal history of the balsam woolly aphid at Corvallis differs from Wind River in that a portion of the population goes on to a fourth generation. Figure 1 presents a graphic picture of the four generations as found at Corvallis, Oregon.

The Corvallis *C. piceae* population, and all other populations observed in the Willamette Valley, start seasonal development earlier than at any other area observed in the region. Second and third instars appear around mid-January. By February 1 adults and eggs are usually present, although egg hatch is usually delayed until about April 1. As at Wind River, the gradual warming in the spring prevents an abrupt break between the first and second generation, but by some compensating factor allows a sharp distinction between the second and third.

Most progeny of the third generation, especially those hatching in late September, settle down and do not resume activity until after January 1. However, a significant number of the earlier hatching insects break diapause in September and October and proceed through a fourth generation. This generation is not too apparent since it overlaps with the third and is usually small.

Fecundity of the Balsam Woolly Aphid

Fecundity assessment of the balsam woolly aphid was obtained by counting the number of hatched and unhatched eggs in well-developed, isolated clutches. Counts were made for both first and second generation adults that developed in the shade. The resultant egg counts from the first generation showed a maximum of 84, a minimum of 30, and an average of 61 eggs per clutch. For the second generation, the maximum was 67, the minimum 35, and the average 52.

During the investigations, observations indicated that aphids living on open-grown or stand-edge trees produced more eggs than those living in the shade. Detailed egg counts on seven, first generation egg clutches showed the suspicion to be true. Counts revealed a maximum of 110 eggs per clutch, a minimum of 51, and an average of 92.

Miscellaneous egg counts of unhatched eggs were made several times throughout the three years of study. Once the eggs begin to hatch, the size of the clutch remains more or less static. Oviposition is apparently just about equal to incubation in the middle of the season. The largest clutches of unhatched eggs occur in the spring when incubation is apparently slower than oviposition. Just the reverse happens in the fall. The largest number of unhatched eggs found in mid-summer was 28. Generally the number ranged from 10 to 15 eggs per clutch.

Rough counts in 1957 seemed to indicate that the species of the host influenced the insect's fecundity. More detailed checks in 1958 and 1959 failed to prove this point. Observations also suggested that balsam woolly aphid populations having the greatest density produced adults with the largest fecundity. No single population was followed long enough to prove this suspicion. However, European work by Kloft on Abies alba showed that balsam woolly aphid recundity does rise with population density (14, p. 440). The reason is that the aphids cause a physiological change in the bark which results in an increased protein content. The increased protein provides better nourishment for the aphid. The insect then responds with an increased number of eggs--about twice as many as an adult in an endemic population.

Dispersal

Several four-inch square glass plates covered with petroleum jelly were placed in various infestations throughout the region. One purpose of the slides was to determine the pattern and rate of balsam woolly aphid dispersal. Slides located at Black Rock and Willamette Pass revealed that practically all air dispersal took place in the crawler stage. Out of 271 aphids counted on 15 slides, only 10 were in the egg stage. Considering the difficulty experienced in trying to remove crawlers from infested material by hand, it is apparent that dispersion of crawlers through the air is the normal means of dissemination.

At Willamette Pass, three slides were lined out in a westerly direction from a moderately heavy bole-infested subalpine fir. One was placed three feet from the base of the tree, the second 18 feet away, and the third 40 feet away. After a two week period of prevailing westerly winds, the first plate revealed 15 aphids, the second 4 aphids, and the third none. An easterly wind prevailed the next two weeks, during which time the number of crawlers on the infested tree increased. A check at the end of the period showed the first slide to have 90 aphids on it. The second plate revealed 18 aphids and the third 7 aphids.

Slides set in clearings up to 80 feet away from the nearest surrounding infested trees, almost always had three to four crawlers per week. However, slides placed at the base of bole infested trees showed that the majority of the chermids leaving the host fell within a few feet of the base of the tree. On stand edges and ridge tops, crawlers dropping directly from the bole could be an important factor in long range dispersion, although their significance is probably negligible when the infested trees are within rather extensive stands. Dispersion in this manner is suspected of being especially effective in the late summer and early fall when localized convection storms are a common feature in the mountainous areas.

Balsam Woolly Aphid Survival and Physical Mortality Factors

There appears to be no truly accurate way of determining all the causes of mortality between the different C. piceae stages. Nevertheless, even though the exact reasons for mortality cannot be pinpointed, good numerical estimates of accumulative losses can be obtained by analyzing the plot data taken at Willamette Pass and Black Rock. These estimates of losses are best obtained between the spring adult population and its resting first instar progeny and then between the summer neosistens population and the fall adults.

Losses between first generation adults and second generation neosistentes are probably caused by two factors: (1) Predation on eggs and crawlers; and (2) dispersing crawlers leaving the tree. Observations show that very few eggs fail to hatch during late spring and early summer. Based on the average egg count of 61 eggs per adult in the first generation, and assuming no dispersal and no predation, the peak neosistens population on the study tree at Willamette Pass in 1959 should have been 1830 aphids per square inch. At Black Rock, a heavier adult population should have produced 3904 neosistentes per square inch. Actually, the resting population at both areas was less than 100 neosistentes per square inch. This represents more than 94 percent population loss at Willamette Pass and about 97 percent at Black Rock. How much of this loss is due to predation and how much is due to dispersion is difficult to determine.

Predator studies at Willamette Pass and Black Rock, which will be discussed later, showed no significant predation effects. Nevertheless, predators were present, and they were eating something. No doubt they reduced the dispersing population. Figures are not presently available to estimate the amount of reduction by dispersal, although in situations where predator populations are small, as they are in Oregon and Washington, this reduction is probably very slight.

The next question is how much mortality is sustained by the dispersing population? This is another question which cannot be answered. The loss is probably tremendous. Dispersal studies showed that the great majority of dispersing aphids fell very close to the base of the tree. Some must crawl back to the tree, although the large majority probably perish after much futile wandering. Air-borne crawlers doubtless meet a similar fate. Certainly the odds are great for landing in an undesirable location.

In 1959, survival between the summer neosistens population and the resulting second generation adult population was variable. At Willamette Pass, the loss was 27 percent while at Black Rock it was only 2 percent. The reason for the large difference between the two areas cannot be explained. Predator populations were quite uniform on both trees during that period. Probably variation in host condition was the major reason for the difference. The upper part of the Willamette Pass tree was obviously in weak condition, and the population on the upper stem was showing a definite decline.

Occasionally adverse weather will seriously affect C. piceae populations. In 1959, a damp, cool fall in high-elevation areas slowed development of the second generation and appears to have reduced the density of the over-wintering population. Most of the second generation reached the stage of abundant egg hatch about the same time fall rainstorms and freezing temperatures began. The result was that many eggs were washed from the trees, and egg-incubation and oviposition were slowed or stopped completely. This was especially apparent at Willamette Pass. An examination of the aphid population on December 18 revealed that practically no egg hatching had occurred since November 18, even though sizable egg clutches were still abundant. The viable appearance of the eggs suggested that they might still hatch; however, attempts to hatch them in the laboratory failed.

Another check on the overwintering generation was a population count on a tree where the aphid infestation was protected from rain by a walk-in type cage covered with plastic screen. The cage apparently produced a "greenhouse effect" which allowed the second generation to develop about three weeks earlier than populations on exposed trees. It was found that the adults on the caged tree had produced an average of 2.7 settled first instars per adult, as compared to an average of 1.2 on an exposed tree. This fact is given more significance when it is noted that the spring generation on the same exposed tree produced an average of 3.0 settled first instars per adult.

IDENTIFICATION OF ARTHROPODS ASSOCIATED WITH CHERMES PICEAE

Recent introductions of foreign predators into the Pacific Northwest have necessitated a knowledge of the native predator complex affecting C. piceae. This section discusses the methods and procedures used in collecting and rearing the associated organisms and summarizes what species were found and when they were present. To facilitate future identifications, a field key to the immature stages is also included. All forms discussed are either known predators of the balsam woolly aphid or are suspected as being possible predators. Parasites were not found associated with C. piceae.

This is not the first attempt to catalog the predators naturally associated with chermids, although the only other North American study was one by Brown and Clark in eastern Canada (4). Investigations in Europe were: Wilson's study of the predators attacking Pineus species in the British Isles (24), Pschorn-Walcher's and Zwölfer's work on Chermes spp. in Central Europe (17), and another study by Pschorn-Walcher and Zwolfer in Sweden (18). One other Central European study on predators attacking C. piceae was made by Schremmer (20).

Methods and Procedures of Study

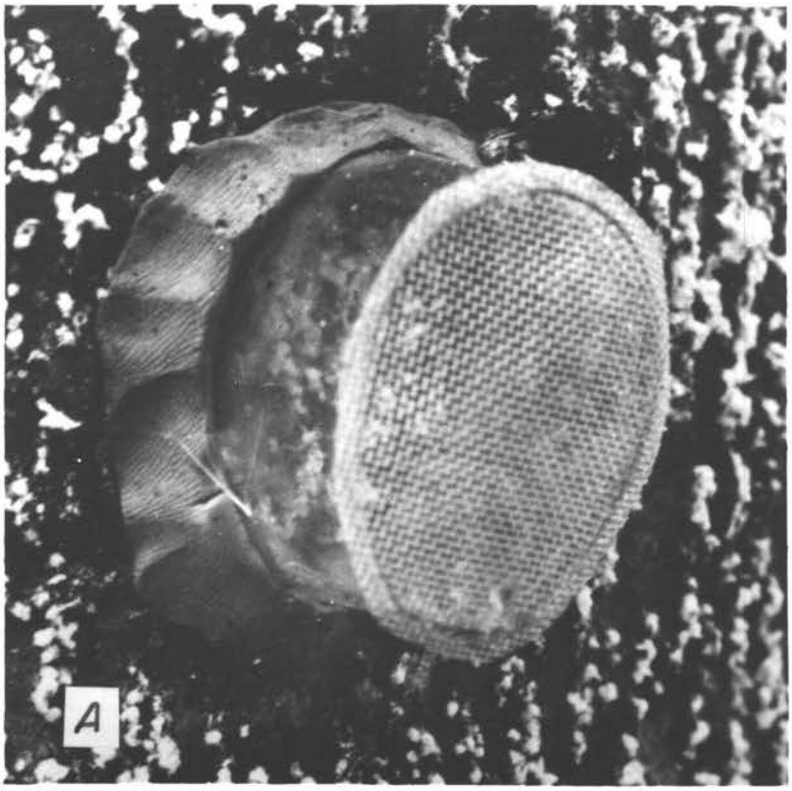
Rearings to obtain the adult forms of the predators were undertaken both in the field and in the laboratory. In the field, small plastic cages with screen tops were used to isolate individual predators (Figure 2A). Cages were attached to the tree by embedding them in a ring of modeling clay pressed onto the bark. These cages proved useful in rearing neuropterans, but not so successful for syrphids which pupate in the soil. However, one advantage of caging syrphids was that young larvae could be carried to maturity. Also, caging in the field was useful in determining if an insect was merely an associate of C. piceae or definitely a predator. Once it was determined that a particular species was a predator and pupated in the soil, it proved easier to collect them as they fell from the tree.

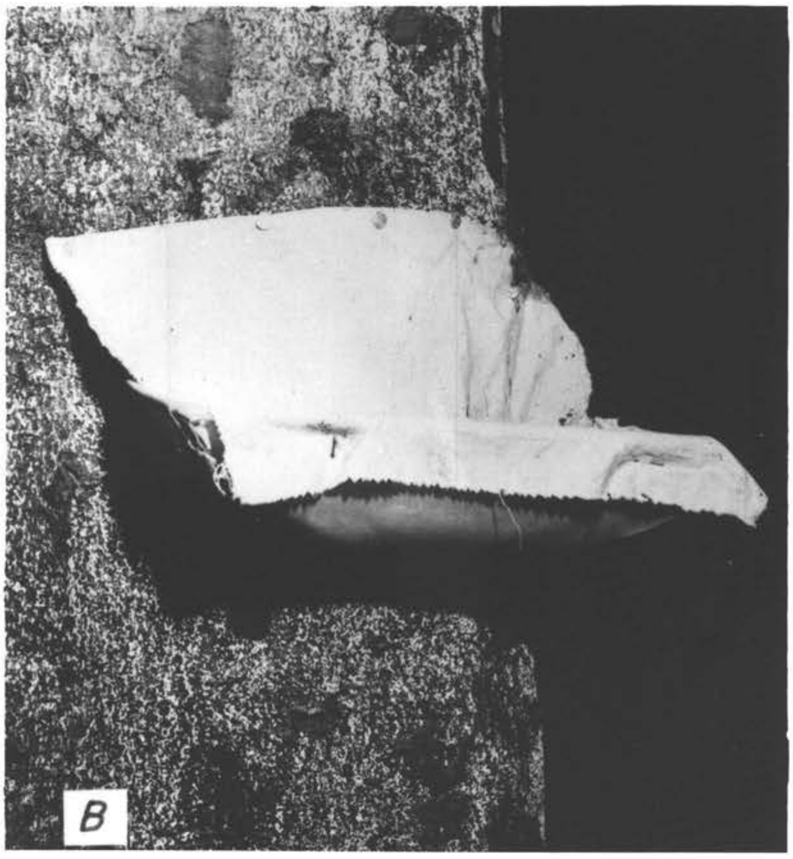
Small trays made of plastic screen rimmed with eight-gauge wire were devised to catch the larvae leaving the tree to puapte (Figure 2B). This method of capturing the falling larvae was used quite successfully with one syrphid. It was also helpful in locating small itonidid larvae. Three species of syrphids were found, however, that would neither pupate when caged on the tree nor drop into the trays. In this case, puparia could be obtained only by hand picking mature larvae and rearing them in wet sand.

Large collections of almost all species were best obtained by chopping down infested trees and bringing short log bolts into the laboratory. Predators could then be collected as they pupated on the log or under the log on the floor. To associate adults with pupae and parasites with hosts, it was necessary to rear each insect individually.

Early in the investigation some difficulty was experienced in laboratory rearings, especially with dipterans. Conditions too damp or too dry arrested development and often killed the adults or produced malformed specimens. Extreme moisture favored the development of fungi. Rearing in gel capsules over damp sand finally proved to be the most satisfactory method for small flies. Large species were best reared on damp sand in 4-inch shell vials. To discourage fungi, the soil was

Figure 2. Equipment for confining, rearing and capturing predators in the field: A, Plastic cage for confining and rearing larvae; B, Cloth-covered, screened tray for capturing falling larvae.





covered with sterilized gauze and the vials loosely plugged with surgical cotton.

One field problem encountered was that of detecting very small predator species and then determining whether or not the species or stage was predaceous on C. piceae. Adapting a binocular microscope to fit an elevator-type camera tripod solved this problem in part (Figure 21). This apparatus allows the observer to minutely cover about 90 square inches of bark surface without moving the tripod. More important, both hands are free to handle vials, probes, etc. Both microscope and tripod are light and are easily carried by one man. Chief disadvantages are: (1) Much time is required to cover a relatively small bark area, and (2) the apparatus can be operated only from the ground. The latter shortcoming was overcome by removing the microscope's rack and pinion and replacing it with a metal "dog". The microscope was then suspended by an adjustable strap attached to a limb or a nail driven into the tree. This adaption allowed considerable maneuverability. The one disadvantage was that the microscope was difficult to focus, and one hand was needed to hold it steady.

Known and Possible Predators Collected

Three years of study have revealed 25 species of arthropods associated with the balsam woolly aphid in the Pacific Northwest. This section lists those species according to whether they are known predators of the balsam woolly aphid or whether they are merely associated and may possibly be predaceous. Syrphids were identified by the late Professor C. L. Fluke of the University of Wisconsin and by Dr. H. S. Telford of

Washington State University. All other insects and mites were determined by the various experts in the U. S. National Museum.

Known Predators

CLASS INSECTA:

Diptera: Syrphidae - Cnemodon rita Curran
Diptera: Syrphidae - Syrphus vitripennis Mg.
Diptera: Syrphidae - Syrphus opinator O. S.
Diptera: Syrphidae - Metasyrphus lapponicus Zett.
Diptera: Syrphidae - Metasyrphus attenuatus Hine
Diptera: Chamaemyiidae - Leucopis sp. near atrifacies Ald.
Diptera: Chamaemyiidae - Leucopis sp. near americana Mall.
Diptera: Chamaemyiidae - Leucopis sp.
Diptera: Itonididae - Lestodiplosis sp.
Diptera: Itonididae - Undetermined species
Neuroptera: Hemerobiidae - Hemerobius neadelphus Gurney
Neuroptera: Chrysopidae - Chrysopa quadrimaculata Burm.
Neuroptera: Chrysopidae - Chrysopa sp.
Coleoptera: Coccinellidae - Mulsantina picta (Rand)

CLASS ARACHNIDA: ORDER ACARINA

Trombidiformes: Anystidae - Anystis sp.
Trombidiformes: Tromidiidae - Allothrombium sp.

Possible Predators

CLASS INSECTA

Diptera: Syrphidae - Metasyrphus amalopsis (O.S.)
Neuroptera: Hemerobiidae - Hemerobius conjunctus var. conjunctus Fitch
Neuroptera: Raphidiidae - Agulla sp. near adnixa (Hagen)
Coleoptera: Coccinellidae - Cycloneda polita Csy.
Coleoptera: Unknown family

CLASS ARACHNIDA: ORDER ACARINA

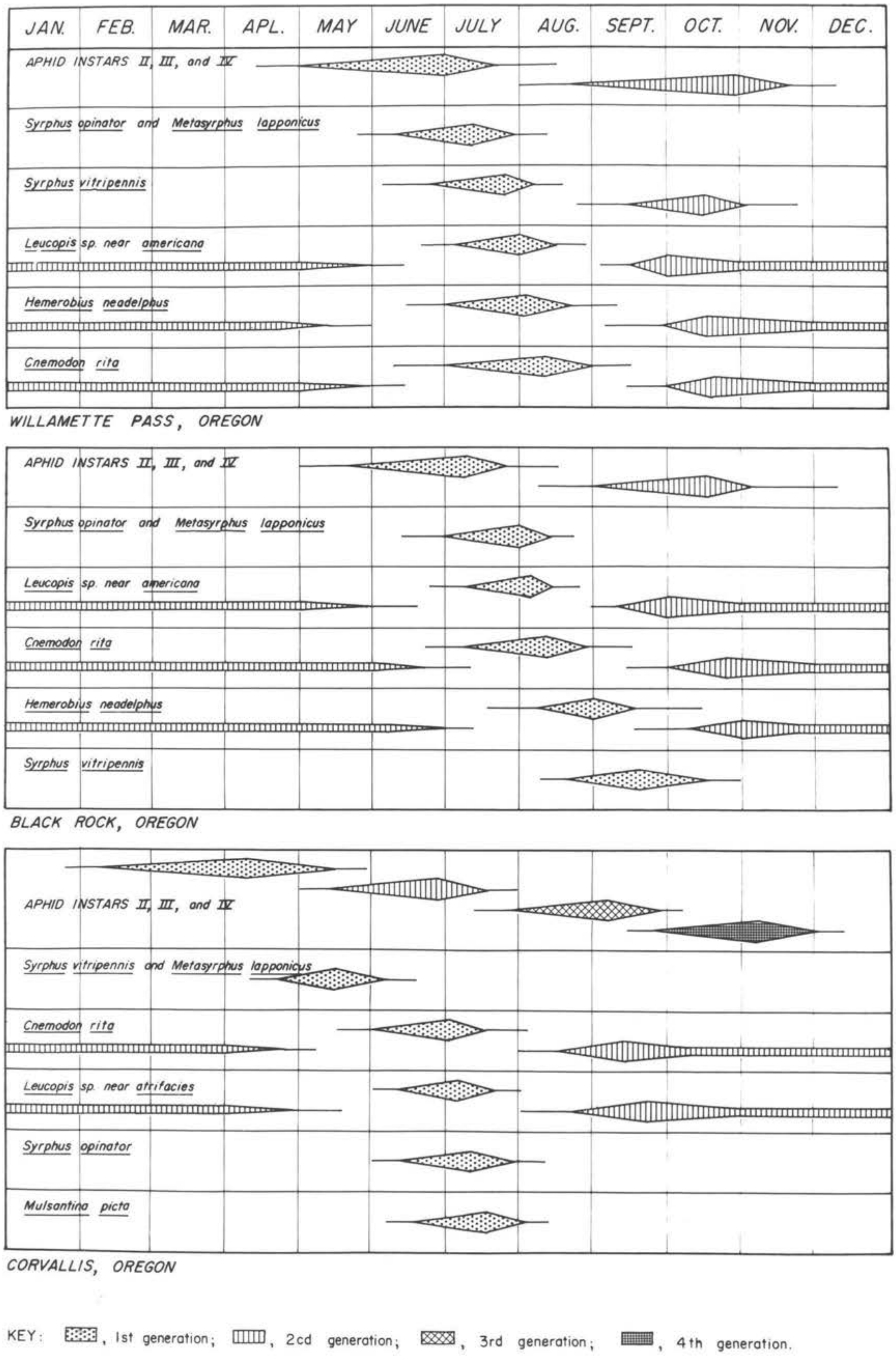
Trombidiformes: Bdellidae - Biscirus uncinatus (Krm.)
Trombidiformes: Anystidae - Anystis agilis (Banks)
Trombidiformes: Tydeidae - Tydeus sp.
Mesostigmata: Phytoseiidae - Typhlodromus bakeri (Garman)

Summary of Predator Occurrence

As their prey, balsam woolly aphid predators vary in time of occurrence from year to year. However, timing of predators in relation to their prey is usually fairly constant. Figure 3 presents 1959 egg and larval sequence of the most common predators at three areas in Oregon. Also included in the chart is the 1959 occurrence of C. piceae stages usually attacked by the predators. At Willamette Pass, predator species occurred at about the same time as in 1958, but 1959 Black Rock populations were about two weeks late. The 1959 picture at Corvallis was confusing. Syrphus vitripennis and Metasyrphus lapponicus occurred at about the same time as in 1958, but Syrphus opinator and Mulsantina picta were about a month late.

One thing that figure 3 does not show is predator density. Generally, the different predator species will vary considerably in density from year to year and from place to place within the same year. For instance, S. opinator occurred in very large numbers in 1958 at Corvallis, but was difficult to find in 1959. Conversely, S. opinator was extremely abundant in 1959 at Willamette Pass, but quite scarce in 1958. A constant feature of predator density through 1958 and 1959 was the proportion of spring and early summer predator numbers as compared to fall populations. In all cases but one, the spring densities were far larger than those in

Figure 3. Summary of predator occurrence at three places in Oregon in 1959 as compared to their prey population.


JAN.
FEB.
MAR.
APL.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
APHID INSTARS II, III, and IV
Syrphus opinator and Metasyrphus lapponicus
Syrphus vitripennis
Leucopis sp. near americana
Hemerobius neadelphus
Cnemodon rita
WILLAMETTE PASS, OREGON
APHID INSTARS II, III, and IV
Syrphus opinator and Metasyrphus lapponicus
Leucopis sp. near americana
Cnemodon rita
Hemerobius neadelphus
Syrphus vitripennis
BLACK ROCK, OREGON
APHID INSTARS II, III, and IV
Syrphus vitripennis and Metasyrphus lapponicus
Cnemodon rita
Leucopis sp. near atrifacies
Syrphus opinator
Mulsantina picta
CORVALLIS, OREGON
KEY: , 1st generation; , 2cd generation; , 3rd generation; , 4th generation.

the fall. On the basis of total season predator population, 75 percent of the predators occurred before the start of the last aphid generation.

Confusing questions about predator occurrence which have received no answer are: (1) Why do S. opinator and M. lapponicus have only one generation when they are generally reported as multivoltine species (5)? (2) Why does S. vitripennis have two generations at Willamette Pass, one spring generation at Corvallis, and one fall generation at Black Rock? and (3) why does Hemerobius neadelphus occur so much later at the low elevation of Corvallis than it does at Willamette Pass? In some cases it appears that answers to these questions would be achieved by more diligent searching for extremely small predator populations. At other times the problem seems more basic--predators switching hosts as more desirable prey appears and disappears.

Field Key to Insect Larvae Associated with Chermes piceae

The following key is based on mature larvae and is designed to be used with a 10X hand lens. Mites are not included. Mites can be best separated by using family characteristics described in a textbook by Baker and Wharton (2). Attempts were made to avoid color characteristics as main separation features in the key, although in one instance, between Syrphus opinator and Metasyrphus lapponicus, it could not be avoided. The writer has found no other way of distinguishing the two insects in the field. Although color is generally undesirable as a primary separation character, it often is the most conspicuous feature of a larva and is therefore useful in field determination. For this reason, color is frequently used as a secondary separation character, especially in those instances where color has proved fairly constant.

Not all insects found associated with the balsam woolly aphid are included in the key. A few species were left out because either the larval stage is not known or because only a few specimens were collected. In the case of Metasyrphus attenuata, only two larvae were collected and all were placed in rearing. One insect is included in the key which is not a native predator. Aphidoletes thompsoni is an imported European predator. It was included because it shows good promise of becoming established in the Pacific Northwest and because of its similarity with the two native itonidids.

1. Larvae without legs..2

- Larvae with legs..12

2. Posterior respiratory processes absent; larvae pinkish to light orange; not exceeding 4 mm. in length (Figures 15A, B, and C)..3

- Posterior respiratory processes present, either fused into one median projection or separated into two lateral projections; larvae not pinkish or orange; length 2.5-15.0 mm...............5

3. Ventral surface with 9 distinct pairs of pseudopods; body hairs conspicuous (Figure 15A).....................Lestodiplosis sp.

- Ventral surface without pseudopods; body hairs not conspicuous...4

4. Larva with distinct pair of sclerotized, curved, anal horns; body broadest in posterior half (Figure 15B)....Unknown Itonidid

- Larva without anal horns, cauda produced into squared, fleshy projections; body broadest in middle portion or frontal half (Figure 15C)............................Aphidoletes thompsoni

5. Posterior respiratory processes separated into two lateral protrusions (Figures 14A, B, and C)...........................6

- Posterior respiratory processes fused into one median protrusion.8

6. Larva conspicuously covered with spines; posterior respiratory processes only slightly longer than wide and not subspherical (Figure 14C)...........Leucopis sp. near atrifacies

- Larvae without conspicuous spines; posterior respiratory processes either distinctly longer than wide or subspherical....7

7. Posterior respiratory processes subspherical; larva yellow in color (Figure 14B)................................Leucopis sp.

- Posterior respirator processes distinctly longer than wide; larva light grey in color (Figure 14A).......................... ....Leucopis sp. near americana

8. Larvae with prominent, fleshy pseudopods on ventral surface; posterior respiratory process closely appressed to body and situated in triangular shaped pocket (Figures 10 and 12)........9

- Larva with ventral surface smooth; posterior respiratory process distinctly elevated.....................................10

9. Larva mostly pale green with light brown, chevron-shaped patterns dorsally (Figures 9B and 10B)..........Syrphus opinator

- Larva mostly brown with dark brown to black, chevron-shaped patterns dorsally (Figures 11B and 12A)....Metasyrphus lapponicus

10. Body margin with large number of conspicuous spine-like projections, cerci-like projections especially prominent (Figure 21A)..............................Metasyrphus amalopsis

- Body margin without spine-like projections.......................11

11. Larva with fleshy, caudal protuberances, one on each side of respiratory process; body color uniform dirty yellow to olive green (Figures 4C and 5B).................Cnemodon rita

- Larva without caudal protuberances; body multi-colored, especially in fat bodies in dorsal vessel region (Figures 7B and 8C).........................Syrphus vitripennis

12. Mouthparts sickle-like, quite apparent from above...............13

- Mouthparts chisel-like, only barely visible from above..........15

13. Body smooth, without tubercles or conspicuous long hairs; lacking trumpet shaped empodium between tarsal claws (Figures 16B and 17B)........................*Hemerobius neadelphus*

- Body roughened with lateral bubercles and having conspicuous long hairs; trumpet-shaped empodium present....................14

14. Dorsal surface of head with four diagonal black lines and one small, central V-shaped mark; body covered with trash gathered from aphid wax masses (Figures 19A and B)..*Chrysopa quadrimaculata*

- Dorsal surface of head with three black areas which delineate a white Y-shaped design; body not covered with trash (Figure 18A)...*Chrysopa* sp.

15. Prothorax longer than the meso- and metathorax combined; color uniformly black..................................*Agulla* sp.

- Prothorax smaller than the meso- and metathorax combined; color black with white margins and white mid-dorsal line (Figure 20A)..................................*Mulsantina picta*

DESCRIPTIONS AND HABITS OF KNOWN PREDATORS

This section presents descriptions and biological information on the native predators found attacking the balsam woolly aphid in the Pacific Northwest. Descriptions feature the immature forms. Adults are seldom encountered with the aphid.

Larval drawings were made by microprojection of specimens cleared in lacto-phenol[3/] and mounted in Hoyer's solution. So as to reduce needless written description, great care was taken to make the drawings as accurate as possible.

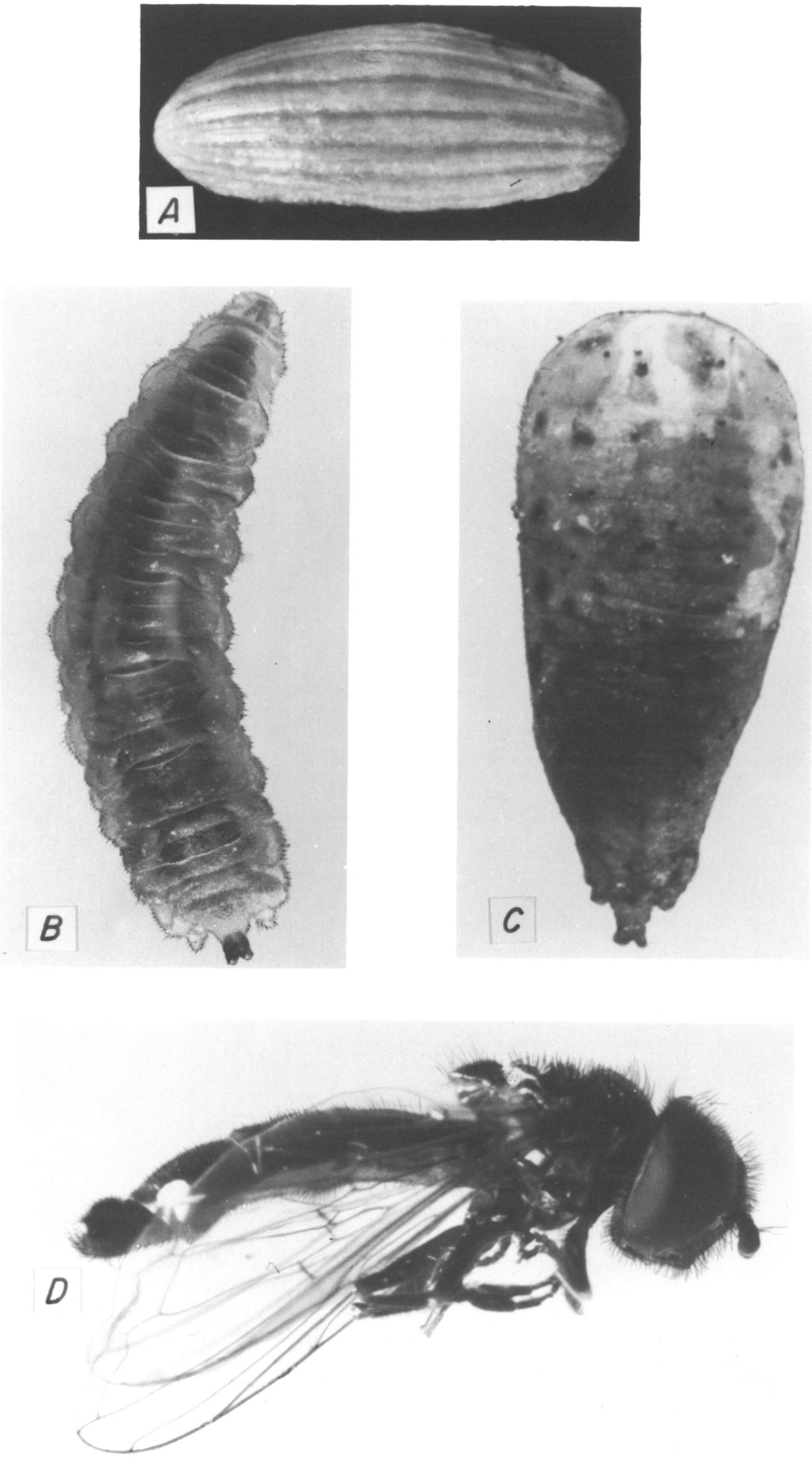
All photographs but one were taken by the writer with either a standard 4 x 5 clinical camera or a 35 mm. Exacta. Desired magnifications with the Exacta were obtained by utilizing, (a) a Bausch and Lomb binocular dissecting microscope, (b) a Carl Zeis monocular compound microscope, or (c) a bellows scope with extension tubes.

Cnemodon rita (Diptera: Syrphidae)

This is the region's most abundant and possibly most important predator of *C. piceae*. It ranges throughout the entire infested zone. Larvae were seen on almost every aphid-infested tree, regardless of how light the prey density or how isolated the tree. Appearance of the four insect stages are shown in Figure 4.

3/ Formula: Lactic acid, 50 c.c.; carbolic acid, 25 c.c. (add to volume); distilled water, 25 c.c.

Figure 4. The native syrphid predator <u>Cnemodon</u> <u>rita</u> Curran: A, egg (92X); B, third instar larva (13X); C, puparium (24X); D, male adult (18X).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Descriptions of Immature Stages - This section describes the egg, three larval instars, and puparium of C. rita. The adult is described in the literature by Curran (6, p. 366).

Egg: (Figure 4A). Length 0.75 to 0.90 mm.; width, 0.25 to 0.30 mm. White, elongate-ovoid, and slightly dorsoventrally flattened. Dorsal surface with several conspicuous longitudinal ridges; ventral surface smooth.

First Instar Larva: (Figure 5A). Length, 0.75 to 1.40 mm.; width, 0.22 to 0.47 mm. Mean length of mouth-hooks, 0.19 mm. Translucent white when first hatched, becoming dirty white after feeding. Segmentation obscure; integument smooth. Segmental spines two-segmented; distal segment much longer than proximal segment; as long as second instar spines; arranged in nine conspicuous trasverse rows, as all syrphids; first row belonging to first thoracic segment, the second row to the third thoracic segment, and the rest to the first seven abdominal segments; the eighth abdominal segment with one pair of lateral spines. Small pair of fleshy, caudal protuberances present on each side of respiratory process. Larva metapneustic, a character shared by all first instar syrphids; spiracles situated on two widely divergent, respiratory processes (Figure 5D).

Second Instar Larva: (Figure 5B). Length, 2.86 to 4.40 mm.; width, 0.80 to 1.28 mm. Mean length of mouth-hooks, 0.31 mm. Color varies from dirty white to light yellow-green; dark midgut visible through the integument. Segmental spines two segmented; 0.027 to 0.032 mm. long. Integument finely granulate, most visible on base of spiracular process. Caudal protuberances more apparent than on first instar.

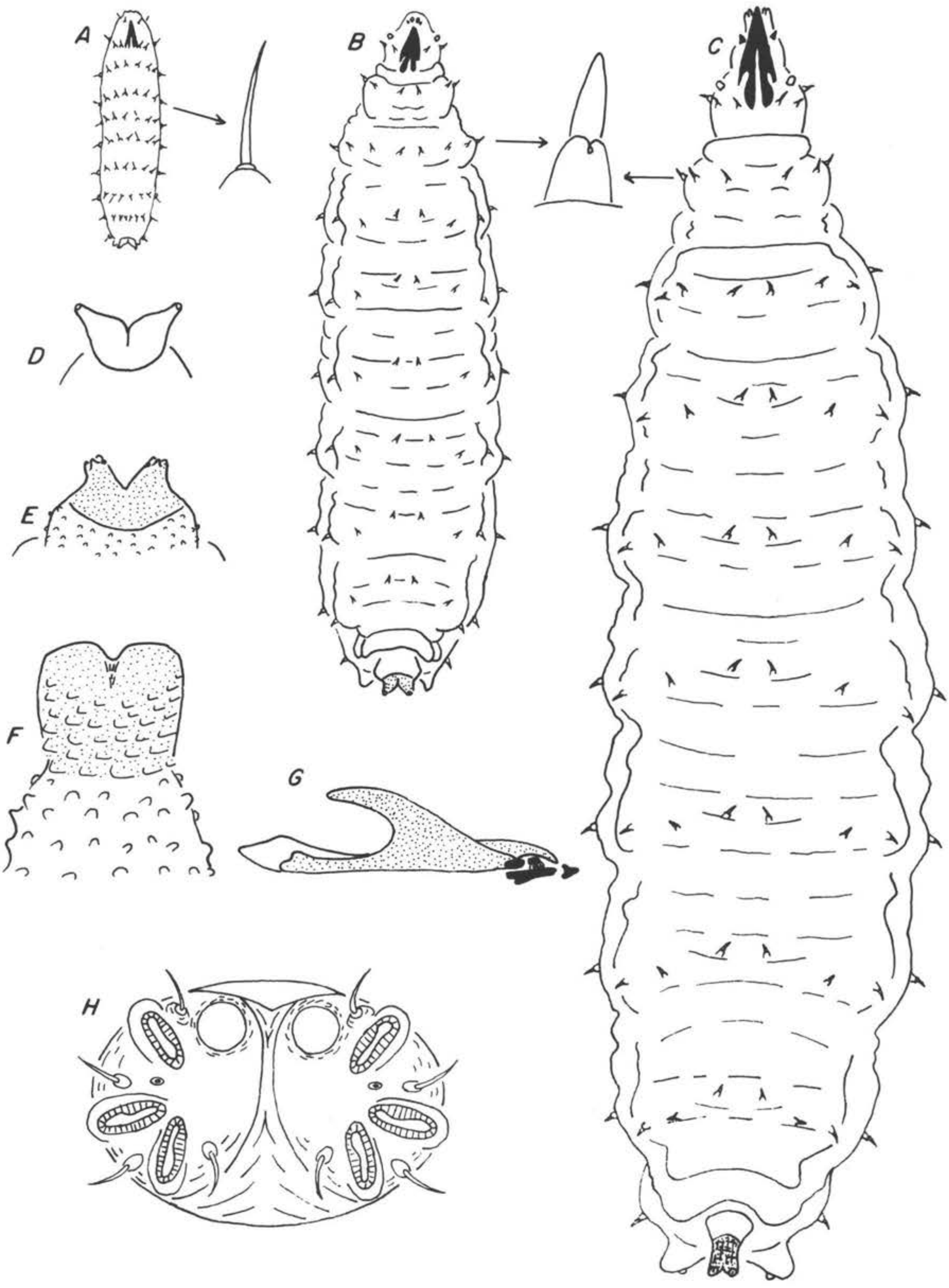
Larva amphipneustic, with usual caudal spiracles and another pair of spiracles on first thoracic segment; caudal respiratory processes slightly divergent but fused on a common base (Figure 5E).

Third Instar Larva: (Figures 4B and 5C). Length, 4.0 to 8.8 mm. Mean length of mouth-hooks, 0.55 mm. Color yellow-green when feeding and cryptic, olive-drab in prepupal stage; dark midgut usually visible through integument. Segmental spines two segmented; 0.06 to 0.09 mm. long; arrangement as in first and second instars. Integument covered with small, fleshy bumps; most evident on base of respiratory process. Caudal protuberances quite apparent. Larva amphipneustic, as all second and third instar syrphids; posterior respiratory processes almost completely fused (Figure 5F); spiracular plate with three slit-like openings, four long setae, and a circular spiracular scar; width of spiracular plates, 0.21 to 0.23 mm.

Puparium: (Figure 4C). Length, 3.7 to 4.5 mm.; width, 1.6 to 1.9 mm. Light brown to grey with randomly located darkened areas. Operculum lines of weakness distinct.

<u>Life History and Behavior</u> - <u>C</u>. <u>rita</u> has two generations per year. Time of occurrence is presented in figure 3. Ovipositing females were observed at Corvallis from May 15 to May 30. Although adults were not seen later than May 30, the appearance of unhatched eggs on aphid-infested trees suggests that the oviposition period may last as long as 30 days. This compares favorably to the flight time recorded for the closely related European species, <u>Cnemodon</u> <u>dreyfusiae</u> Del. and P.-W. (7, p. 271). Eggs are laid singly on the bark surface, in crevices, and tucked in balsam woolly aphid egg masses. The incubation period at

Figure 5. Larval drawings of the native predator <u>Cnemodon</u> <u>rita</u> Curran: A, first instar larva (28X); B, second instar larva (28X); C, third instar larva (28X); D, first instar respiratory process (120X); E, second instar respiratory process (64X); F, third instar respiratory process (100X); G, third instar mouth-hook (100X); H, third instar spiracular plate (255X).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H

room temperature is from three to four days.

Egg deposition occurs as frequently on the shaded side of the tree as it does on the exposed side. However, early spring oviposition was noted only on stand-edge trees. Most oviposition was observed on warm days when the temperature was about 70° F., although one female was observed laying eggs while it was raining.

Duration of the first larval stage was found to be four to five days at room temperature. Length of the second stadium is not known, although laboratory rearings show it to be at least four days. The feeding period of the third instar is from eight to ten days. The larva then takes about 15 days to form a puparium after feeding has ceased. Apparently this is a diapause stage. The adult emerges about 10 days after the puparium is formed.

Field observations suggest the total life period from the first oviposition period to the second is about 60 days. By subtracting the 29 days that the insect is in larval diapause, and in pupal, and egg stages, it is calculated that the first generation larva spends about 30 days actively feeding in the field.

Pupation occurs both in the soil and on the tree. The soil is the most common location, although many remain on the tree if there are abundant hiding places such as lichens or bark fissures. C. rita drops directly from the tree when it pupates in the soil. This habit allows the use of a tray for easy collection.

Winter is passed in either the mature larval or pupal stage. The site may be on the tree or in the soil. Those spending the winter on the tree, usually are deeply imbedded in lichen growth.

Natural Enemies - The following hymenopterous parasites have been reared from *C. rita*:

Chalcidoidea: Endrytidae - *Syrophophagus smithi* Kam.

Chalcidoidea: Pteromalidae - *Pachyneuron allograptae* Ashm.

Ichneumonidae: *Syrphoctonus* sp.

Ichneumonidae: *Phtorima* sp.

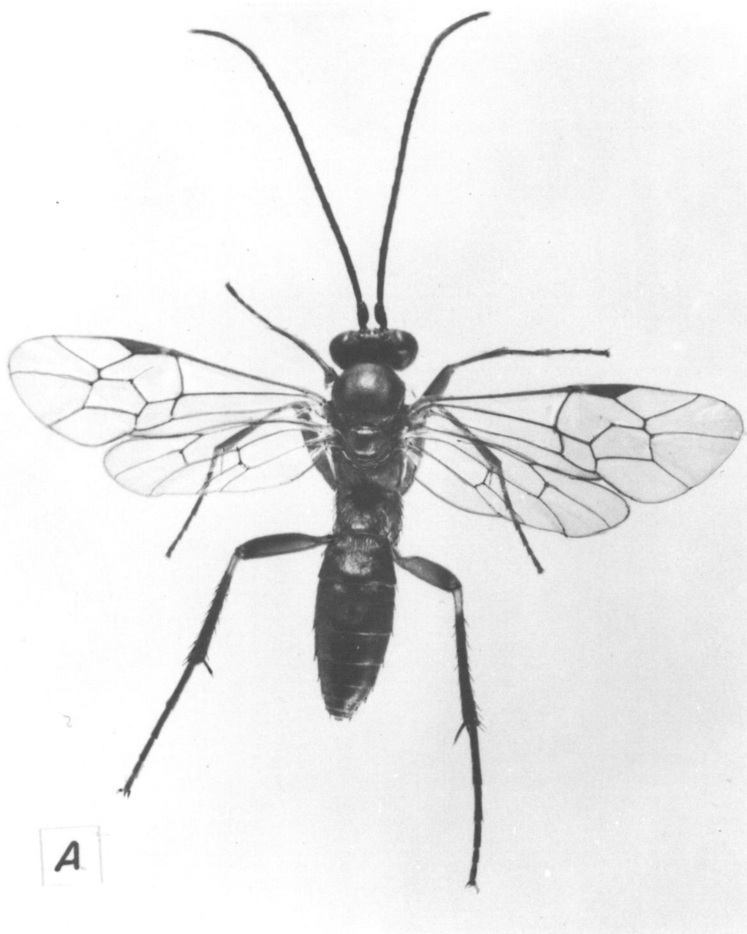
The chalcids, which are superparasites, account for the greatest amount of parasitism. Both species attack the pupal stage. The ichneumonids are larval parasites. *Syrphoctonus* sp. appears to be the more important of the two genera. At times, parasitism by this species is quite heavy. Dorsal and lateral views of *Syrphoctonus* sp. are shown in figure 6. Only one case of parasitism by *Phthorima* sp. has been found.

The amount of parasitism experienced by *C. rita* was quite variable. A few collections revealed aggregate parasitism as high as 90 percent, while other rearings showed very little parasitism. It appears that the greatest amount of parasitism occurs during the second generation when the syrphid population is smallest.

Two cases of predation on *C. rita* have been observed. One case was by an unknown ant and the other by a syrphid, *Metasyrphus amalopsis*. Predation by both of these insects is believed to be rare.

Discussion - Although *C. rita* larvae are found throughout most of the summer and at almost any prey density, the species is seldom very abundant on any one tree. Its value is further impaired because the predator does not appear until after the first balsam woolly aphid generation has already reached its peak; the insect then drops to extremely

Figure 6. The common syrphid parasite Syrphoctonus sp.: A, dorsal view (9X); B, lateral view (9X).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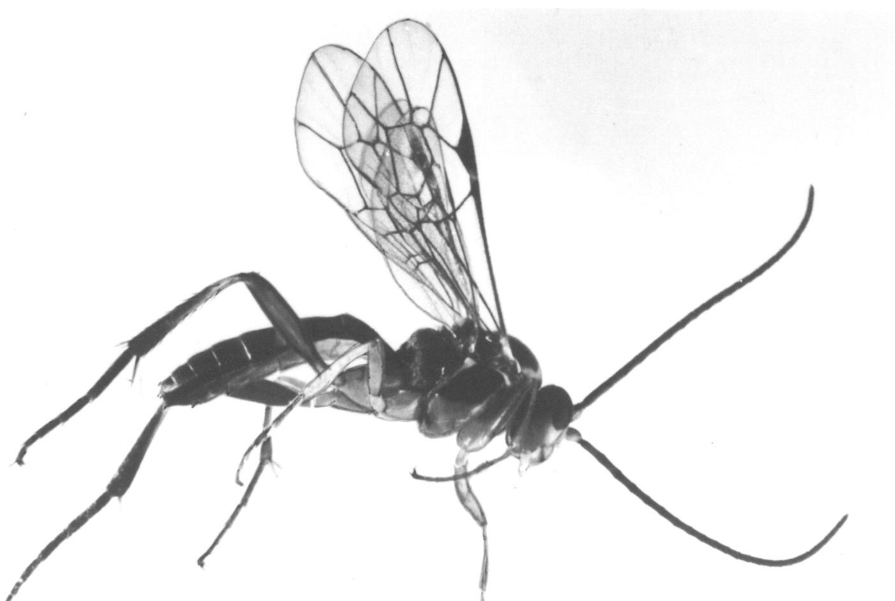

B

low levels when the second aphid generation is heaviest. A possible explanation for the light C. rita populations on C. piceae is that the predator has more than one host. The insect has been observed attacking an unknown species of Pineus at two different areas.

Syrphus vitripennis (Diptera: Syrphidae)

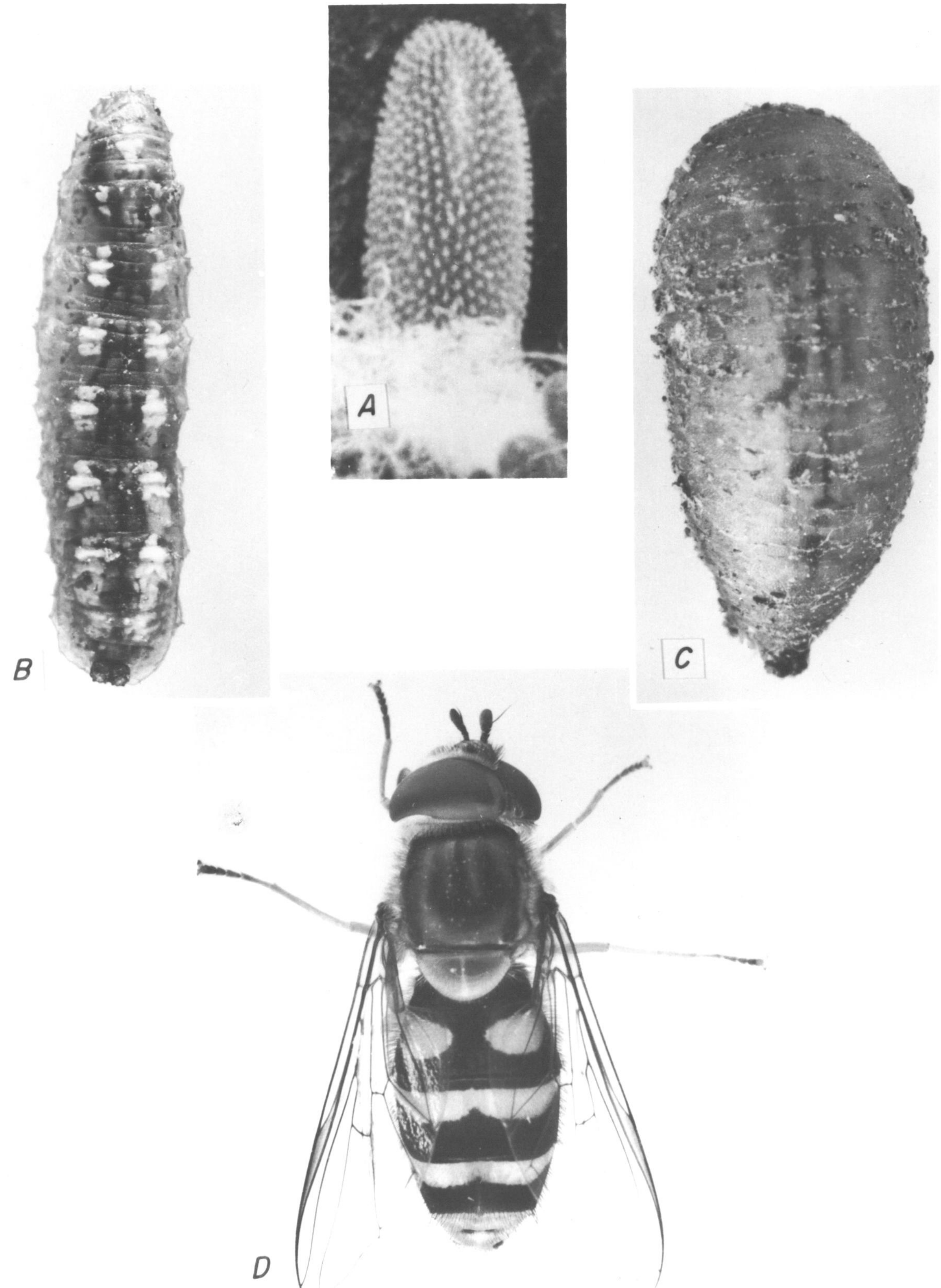
This is the region's second most abundant predator. It is apparently holarctic--being found in Europe as well as North America. As far as can be determined, this is the only known case of the insect preying upon the balsam woolly aphid. In the Pacific Northwest, the insect has been observed at every collecting point. However, it is usually associated with long established, heavy aphid populations. The species' four insect stages are illustrated in figure 7.

Descriptions of Immature Stages - This section describes the egg, three larval instars, and puparium of S. vitripennis. The adult is best described by Fluke (8, p. 70).

Egg: (Figure 7A). Length, 1.12 to 1.27 mm.; width 0.49 to 0.52 mm. Yellowish-white when first laid, later developing a greenish cast. Subcylindrical; slightly smaller at micropylar end. Entire surface conspicuously covered with numerous peg-like projections.

First Instar Larva: (Figure 8A). Length, 1.35 to 2.26 mm.; width, 0.36 to 0.50 mm. Mean length of mouth-hooks, 0.27 mm. Uniform pale green. Segmentation obscure; integument much longer than proximal portion; about as long as spines in instars two and three, 0.04 to 0.06 mm. Metapneustic; spiracular plates widely separate and only slightly sclerotized.

Figure 7. The native syrphid predator <u>Syrphus vitripennis</u> Mg: A, egg (46X); B, third instar larva (10X); C, puparium (16X); D, male adult (8X).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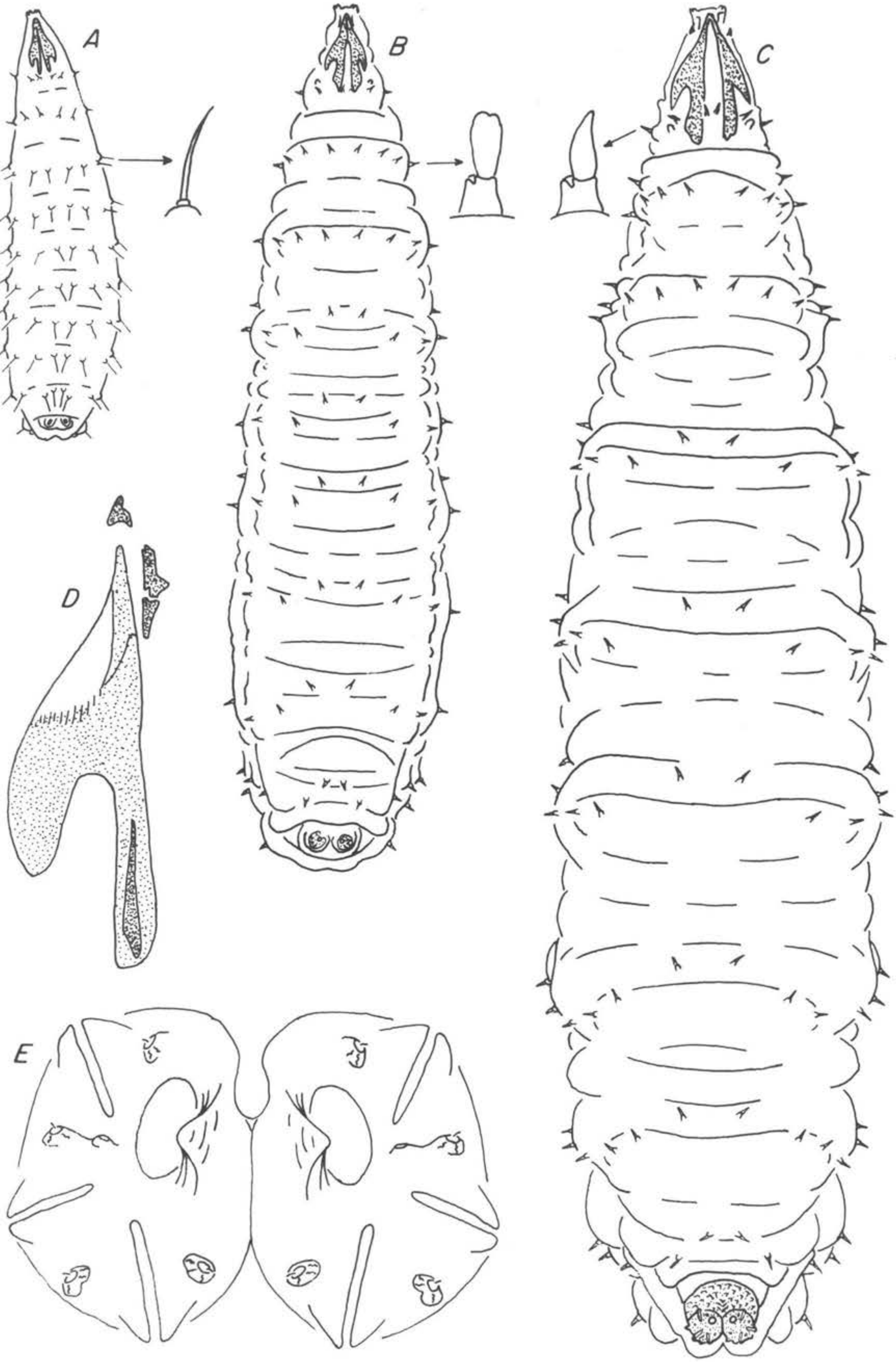
Second Instar Larva: (Figure 8B). Length 2.95 to 5.50 mm.; width, 0.80 to 1.40 mm. Mean length of mouth-hooks, 0.54 mm. Pale sea-green or pale yellow in pleural areas with wide orange and black mid-dorsal line extending from cephalic region to posterior respiratory process. Integument faintly granulate. Segmental spines two segmented, the proximal and distal half subequal; distal portion very blunt. Spiracular plates slightly raised, sclerotized, and distinctly separate, but closer together than in first instar.

Third Instar Larva: (Figures 7B and 8C). Length 6.4 to 10.5 mm.; width, 1.4 to 3.0 mm. Mean length of mouth-hooks, 0.92 mm. Color similar to second instar, becoming light brown in pleural areas just prior to pupation; occasionally the colors in the mid-dorsal area become obliterated and the larva assumes a uniform pale brown or light green. Integument distinctly, but finely granulate. Segmental spines two segmented, with distal and proximal segments subequal; distal portion coming to distinct point. Respiratory processes completely fused into one heavily sclerotized protrusion; spiracular plate characterized by three slit-like spiracular openings, one subelliptical spiracular scar, and four small setae situated on conspicuous raised areas; mean width, 0.58 mm. (Figure 8E).

Puparium: (Figure 7C). Length, 5.2 to 6.2 mm.; width, 2.7 to 3.1 mm. Uniform light brown; granulate. Larval design showing through integument for a short period after pupation; adult abdominal design outwardly visible a few days before emergence.

Life History and Habits - S. vitripennis has two generations per year at the higher elevations, although occasionally the first generation

Figure 8. Larval drawings of the native predator Syrphus vitripennis Mg.: A, first instar larva (31X); B, second instar larva (31X); C, third instar larva (31X); D, third instar mouth-hooks (75X); E, Spiracular plate of third instar larva (138X).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E

will be absent. This happened in 1959 at Black Rock. Generally, the fall generation is the larger of the two. Balsam woolly aphid infestations in the lowland areas experience only a spring generation. The exact reason for only one generation is not known. Possibly the soil gets too dry in the summer to allow a second emergence. Normally the predator pupates in the soil, although under dry conditions the larvae go into aestivation and will not develop further. It was found in the laboratory that the soil must be quite moist before pupation will occur.

The oviposition period at Willamette Pass was observed to last at least 15 days. Eggs were laid singly and conspicuously on the bark surface of the infested trees. The duration of the larval stages is not known. All stages feed from outside the wax masses and prey on all aphid stages except the neosistentes. Puparia were formed in the laboratory 10 to 17 days after being placed in damp soil. Adults emerged about 10 days later.

Parasite information was not obtained because of early difficulty in obtaining puparia. After this problem was solved, predators became difficult to find. A total of only 10 adults were reared.

Discussion - Synchronization with the host for maximum effectiveness is good with *S. vitripennis*. The insect's chief drawback is that it generally occurs in small numbers. Another fault is its erratic distribution between trees. Sometimes *S. vitripennis* may be extremely abundant on one tree, while on an adjacent tree with a similar prey density of the insect may be very scarce.

Syrphus opinator (Diptera: Syrphidae)

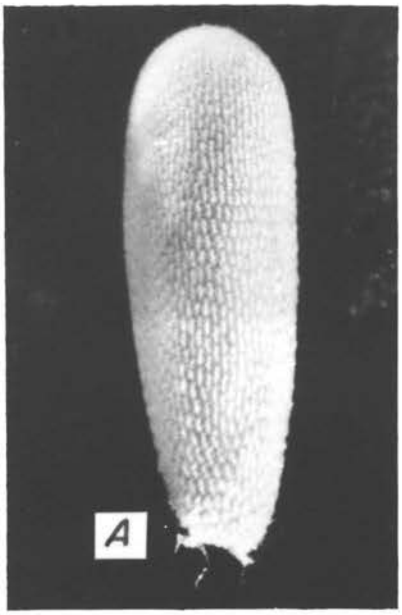
S. opinator ranges throughout the entire balsam woolly aphid infestation zone. The population density achieved is variable. On occasions the insect is quite plentiful and appears to reduce the aphid populations. At other times it is extremely scarce. The immature stages are very similar to two other syrphids preying on the balsam woolly aphid: Metasyrphus lapponicus and M. attenuatus. Owing to early difficulties in rearing, there was some confusion between the species, especially between S. opinator and M. lapponicus. This confusion was not resolved until 1959. Heiss' larval descriptions of the two genera proved generally inadequate for separating the species (10, p. 42). S. opinator larvae seem to be more related to the genus Metasyrphus than they do to the genus Syrphus. Figure 9 presents the four insect stages of S. opinator.

Descriptions of Immature Stages - This section describes the egg, three larval instars, and puparium of S. opinator. The adult is best described by Fluke (8, p. 78).

Egg: (Figure 9A). Length, 1.12 to 1.36 mm.; width, 0.38 to 0.39 mm. White; subcylindrical; narrowest at micropylar end. Surface with conspicuous longitudinal reticulations.

First Instar Larva: Length, 1.90 to 3.08 mm.; width, 0.40 to 0.65 mm. Mean length of mouth-hooks, 0.27 mm. White when first hatched, becoming greyish-white to green after feeding. Integument smooth. Segmental spines 0.10 to 0.14 mm. long; two segmented, the distal portion being much longer than the basal segment. Ventral surface with

Figure 9. The native syrphid predator Syrphus opinator O. S.: A, hatched egg (58X); B, third instar larva (10X); C, puparium (13X); D, male adult (10X).



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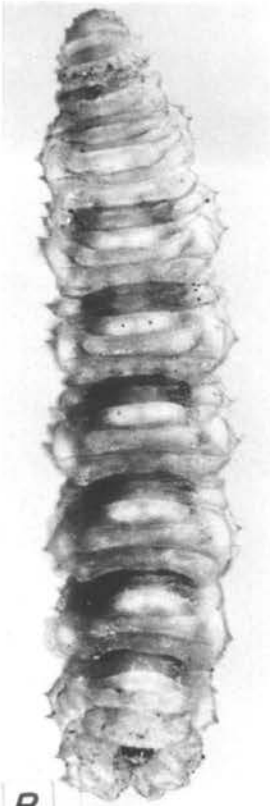


B

C

D

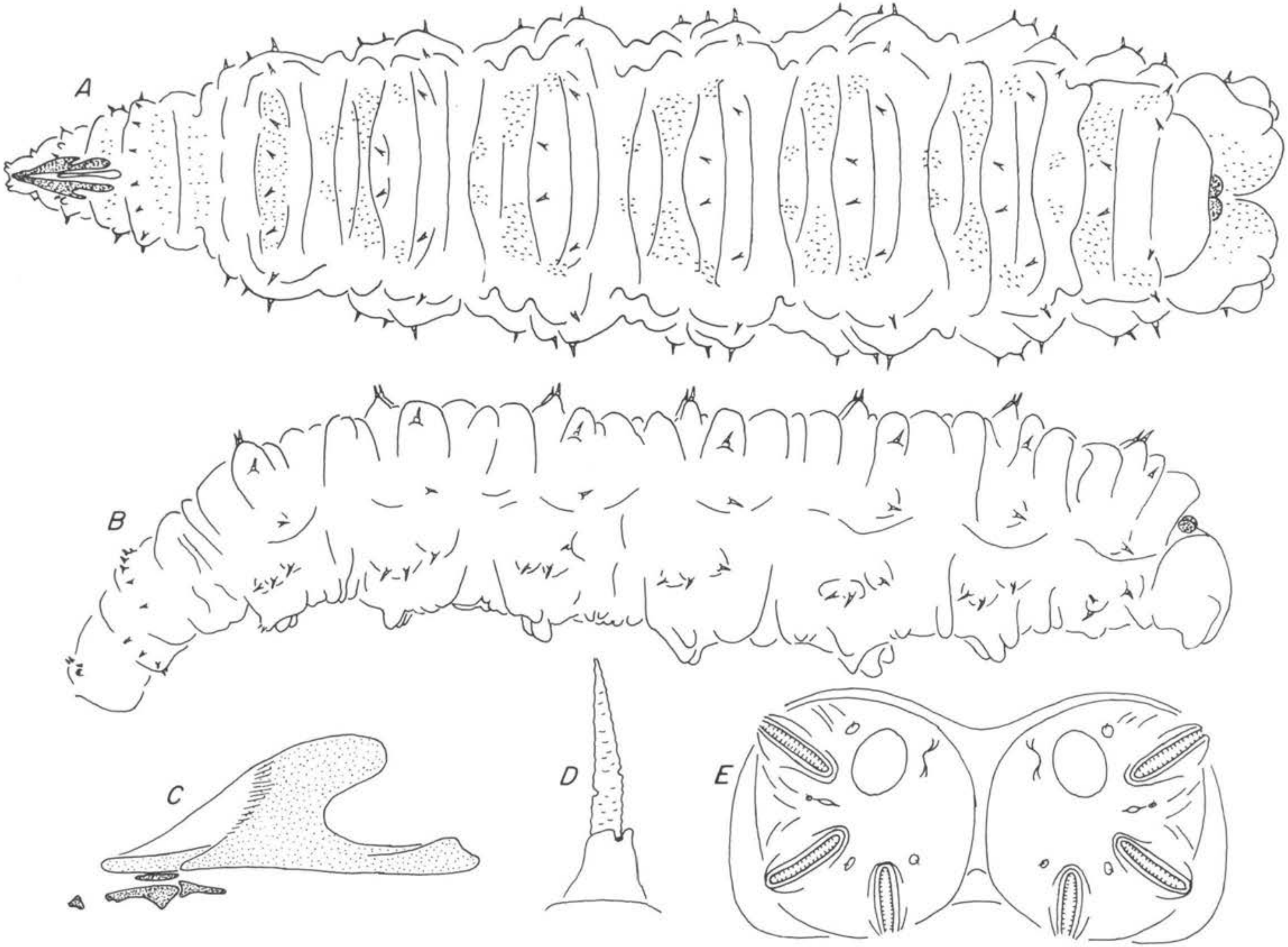
seven pairs of fleshy pseudopod projections; each projection with three lobes. Spiracular plates well separated and only slightly sclerotized.

Second Instar Larva: Length, 3.0 to 7.0 mm.; width, 0.71 to 1.15 mm. Mean length of mouth-hooks, 0.52 mm. Green in pleural region, becoming increasingly paler cephalad; head region yellowish-cream; dorsally the green is broken by six light brown to dark green chevron-shaped patterns. Integument densely covered with microscopic spinules; a few spinules dark in dorsal chevron area, the rest beige. Segmental spines two segmented; distal segment about 2-1/2 times the length of basal portion. Ventral pseudopods as first instar. Spiracular plates completely separated but closer than in first instar; plates distinctly sclerotized.

Third Instar Larva: (Figures 9B and 10). Length, 7.2 to 13.1 mm.; width, 1.3 to 2.9 mm. Mean length of mouth-hooks, 0.77 mm. Color same as second instar except dorsal areas sometimes become light brown just prior to pupation. Spinules similar to second instar except shorter. Segmental spines as second instar except distal portion wrinkled and crenate. Ventral portion with pseudopods as first and second instars. Posterior respiratory processes completely fused; spiracular plate 0.35 to 0.43 mm. wide; usual three spiracular openings and elliptical scar; spiracular openings frequently surrounded by blackened areas.

Puparium: (Figure 9C). Length 5.9 to 6.9 mm.; width, 2.3 to 3.0 mm. Light brown. Surface exhibiting spinule pattern of the third instar larva. Operculum lines of weakness distinct. Adult abdominal color pattern outwardly visible a few days prior to emergence.

Figure 10. Larval drawing of the third instar Syrphus opinator O. S.: A, dorsal view (19X); B, lateral view (19X); C, mouth-hooks (75X); D, segmental spine (200X); E, spiracular plate (170X).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Life History and Behavior - *S. opinator* has only one generation per year on *C. piceae*. The eggs are laid conspicuously on the bark surface of infested trees. Oviposition time is usually around mid-March at Corvallis and about May 1 at Willamette Pass. Duration of the feeding larval period is from 20 to 30 days in the laboratory and about 50 to 60 days in the field. The insect is a very active feeder and preys on all stages of the balsam woolly aphid except the resting first instar.

Puparia are easily obtained in the laboratory, but adults do not readily emerge unless conditions are moist. Puparia placed in a humid environment at room temperature will produce adults in about 10 days. Under dry conditions at the same temperature, emergence will be delayed as long as one or two months. In nature, pupation occurs in the soil, although a few specimens were observed to form puparia on the tree. Those that pupate in the soil do not drop directly from the tree to the ground, but rather migrate down the stem and away from the tree. For this reason, the tray could not be utilized for collecting *S. opinator*. Laboratory observations showed the migratory period as lasting from 12 to 36 hours.

Caged adults feeding on honey, sugar, powdered milk, and water lived for 18 to 24 days--females surviving a few days longer than the males. Attempts to propagate this species by caging males and females with infested log bolts failed. It appears that mating was not achieved.

Natural Enemies - The following hymenopterous parasites have been reared from *S. opinator*:

Chalcidoidea: Pteromalidae - Pachyneuron allograptae Ashm.

Ichneumonidae: Diplazon orbitalis Cress

Ichneumonidae: Syrphoctonus spp. (Two species)

The first two species were reared from insects that pupated on the tree. The chalcids were collected from several puparia, while the ichneumonid, D. orbitalis, is represented by only one specimen. The two unknown species of Syrphoctonus are the most important parasites. Both attack the larval stage.

The amount of parasitism suffered by a S. opinator population is quite variable. Parasitism at Corvallis in 1958 was about 15 percent. In 1959 at Willamette Pass, parasitism before the July 16 collection was less than five percent. Thereafter, parasitism by the two Syrphoctonus species was more than 90 percent.

It was noted on several occasions at Wind River Arboretum, that ants frequently remove S. opinator eggs from the bark of the infested trees. The importance of this depredation is not known.

Discussion - When abundant, S. opinator is very effective in reducing the prey population. Its chief drawback is that it does not exert its greatest effect until the first aphid generation has reached or passed its peak. By then a large number of eggs have already hatched and sistentes constituting the next generation have already settled.

It appears that there is a linear relationship between the predator population and its host density. Counts at Corvallis in 1958 on the relation of predator number to prey density revealed the following:

Number of prey per square inch	Number of S. opinator per 100 square inches
42.0	5.72
21.0	1.93
7.4	0.21

One confusing feature about S. opinator is that there is only one generation per year on balsam woolly aphid. Adults are known to emerge shortly after pupating in the soil. Collections by the writer and a check of specimens in the insect collection at Oregon State College have revealed that adults are in flight well into October. The answer seems to lie within one of two alternatives: (1) Either S. opinator hibernates as an adult; or (2) it changes hosts. The latter alternative seems more probable. The writer has observed the predator feeding on an unknown species of Cinara and Campbell and Davidson have recorded S. opinator as preying on seven different aphid species which are pests of farm crops (22, p. 61).

Metasyrphus lapponicus (Diptera: Syrphidae)

M. lapponicus is a holarctic species that has been observed attacking C. piceae in southeastern Canada (3, p. 40), and Sweden (18, p. 798). In Oregon, M. lapponicus adults have been reared from every collection locality. It has not yet been reared from Washington collections, although larvae appearing to be M. lapponicus have been observed. The species often occurs in association with Syrphus opinator and S. vitripennis. Generally, however, its population is smaller than either of the two Syrphus species. Three stages of M. lapponicus are shown in figure 11.

Descriptions of Immature Stages - This section describes the egg, three larval instars, and puparium of M. lapponicus. Little attention is given the egg or first two larval instars, since they are very similar to the same stages of S. opinator. The adult is described by Fluke (8, p. 14).

Egg: Length, 1.05 to 1.29 mm.; width, 0.38 to 0.41 mm. Shape and surface configuration indistinguishable from S. opinator.

First Instar Larva: (Figure 12A). Length, 1.90 to 3.30 mm.; width, 0.32 to 0.67 mm. Mean length of mouth-hooks, 0.28 mm. Almost identical to S. opinator in all other respects.

Second Instar Larva: (Figure 12B). Length, 4.74 to 7.20 mm.; width, 1.15 to 1.67 mm. Mean length of mouth-hooks, 0.50 mm. Indistinguishable from S. opinator in all respects except color. Color dark to light brown in pleural areas, becoming increasingly paler cephalad; dorsally the brown is broken by six black, chevron-shaped patterns.

Third Instar Larva: (Figures 11A and 12C). Length, 8.27 to 12.21 mm.; width, 1.8 to 3.44 mm. Mean length of mouth-hooks, 0.93 mm. Form similar to S. opinator. Color as second instar. Integument with characteristic designs formed by black, closely set spinules; remaining integument covered with translucent, beige spinules. Segmental spines as S. opinator except not crenate. Width of spiracular plate 0.41 to 0.51 mm.; plate similar to S. opinator except being slightly larger, having more pronounced spiracular carinae, and presenting a spiracular scar which is oriented laterad rather than mesad.

Puparium: (Figure 11C). Length, 5.5 to 6.9 mm.; width, 2.3 to 3.0 mm. Dark orange-brown, with surface spinule patterns of the third

Figure 11. The native syrphid predator Metasyrphus lapponicus Zett.: A, third instar larva (12X); B, puparium (15X); C, male adult (11X).

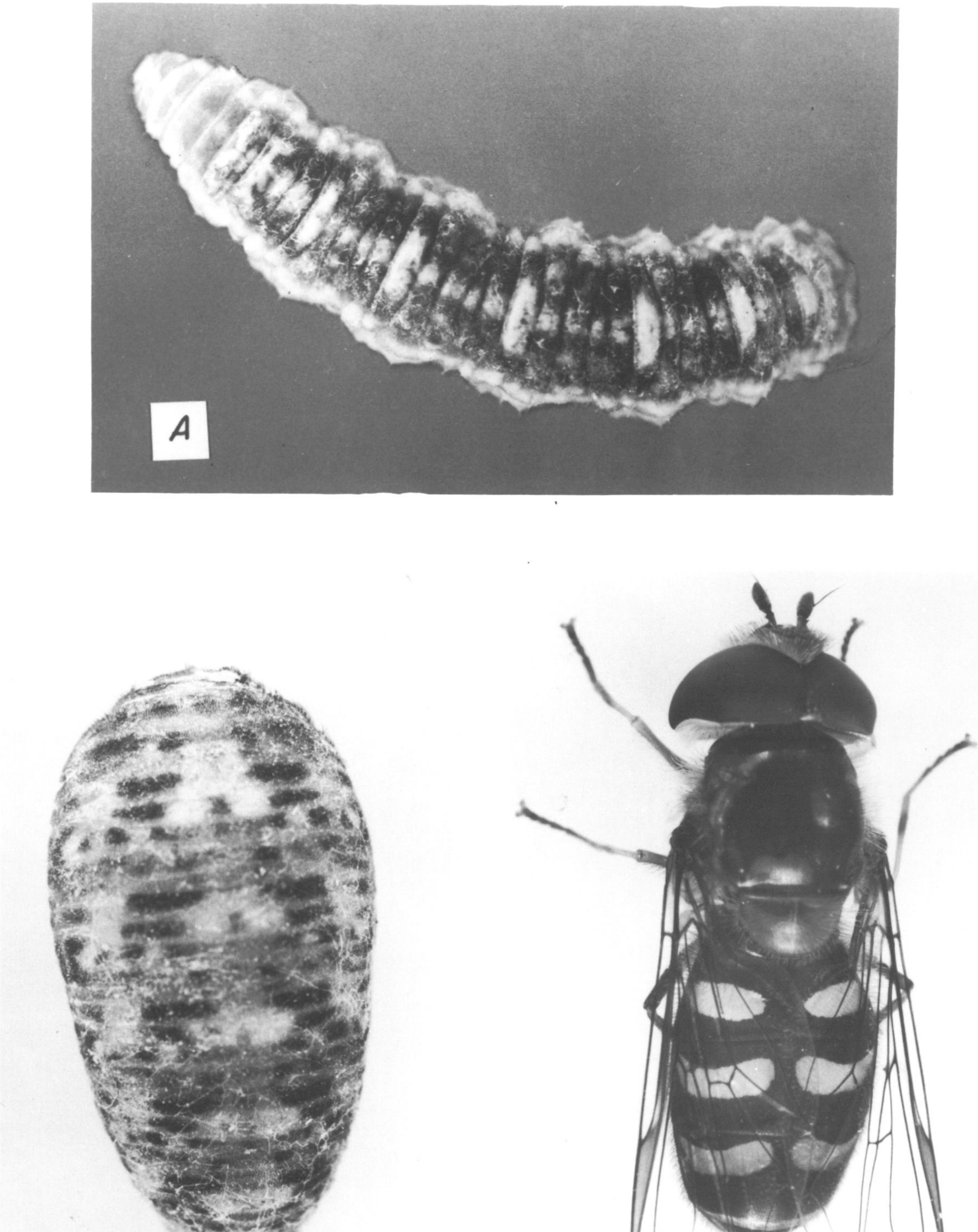
A
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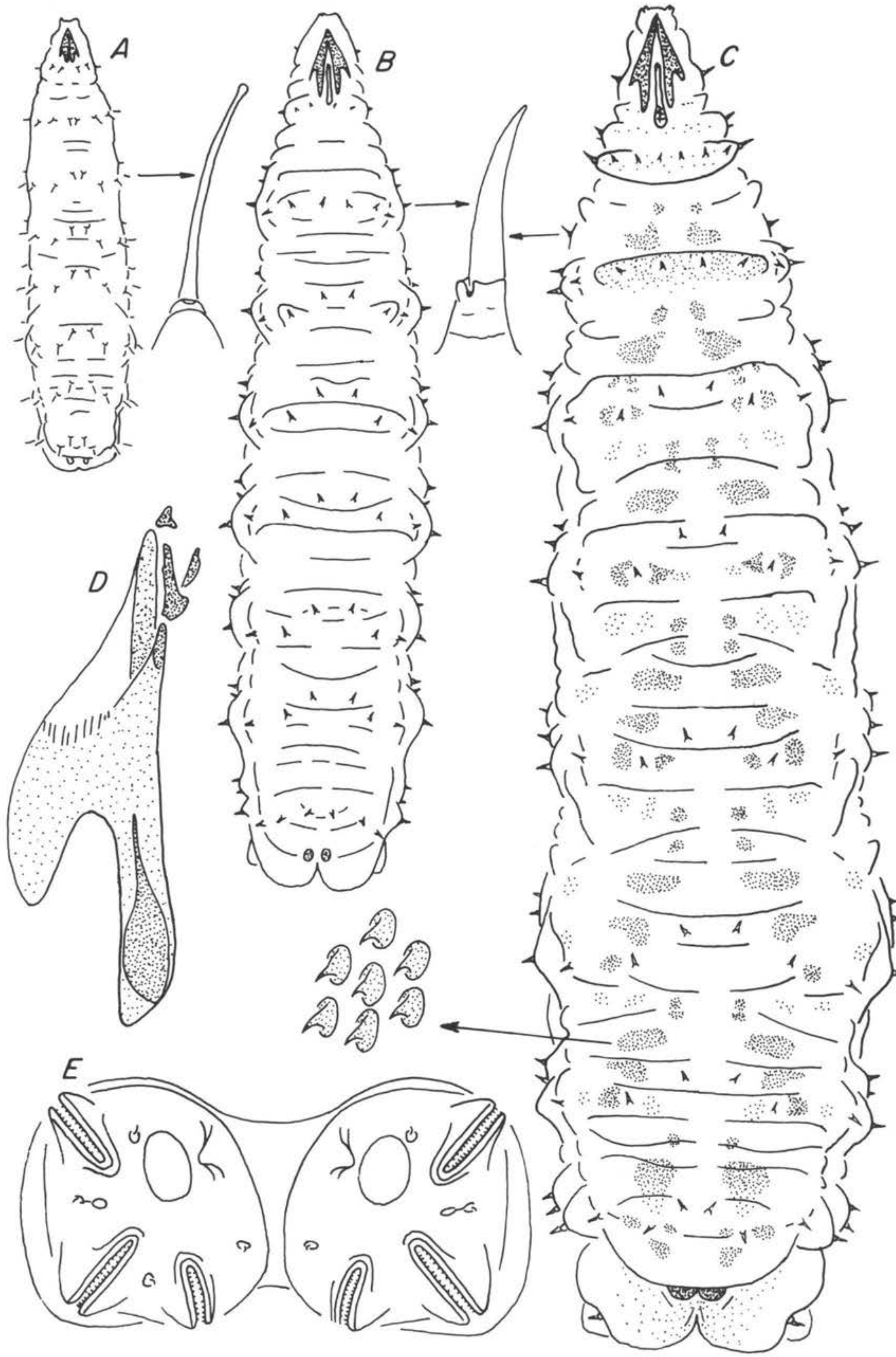
Figure 12. Larval drawings of the native predator _Metasyrphus lapponicus_ Zett.: A, first instar larva (22X); B, second instar larva (22X); C, third instar larva (22X); D, third instar mouth-hooks (86X); E, spiracular plate (170X).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E

instar larva distinct. Sutures of operculum evident.

Life History and Behavior - *M. lapponicus* has one distinct spring generation and may also have a small summer generation. Because only a few puparia of the summer form were obtained, and because all were parasitized, the presence of a second generation was never definitely established. Spring oviposition starts around May 1 at the high elevations and about mid-March in the Willamette Valley. Eggs are laid singly and conspicuously on the bark of the aphid-infested tree.

In 1959, an ovipositing adult was captured at Corvallis. It was then released in a cage with three species of *Chermes*: *C. piceae*, *C. cooleyi* Gill., and *C. tsugae* Ann. The female lived 25 days and deposited 41 eggs--most of them by the end of the third day. Of the 41 eggs, 35 were laid on *C. tsugae*, 2 on *C. cooleyi*, none on *C. piceae*, and 4 on the sides of the cage. Progeny were then reared in the laboratory on *C. tsugae*. A break-down of the resulting 40 day rearing period from egg to adult showed the following:

Egg stage	3 to 4 days
First larval stadium	5 to 6 days
Second larval stadium	8 to 9 days
Third larval stadium (one larva) ...	14 days
Pupal stage	9 days

In the field, the same development took from 60 to 70 days.

This insect also has a one or two day migratory period before pupation. Normally it pupates in the soil, although it is not unusual for *M. lapponicus* to remain on the tree. As *S. opinator*, emergence is delayed considerably in a dry environment.

Except for Diplazon orbitalis, M. lapponicus has shown the same predator complex as S. opinator.

Discussion - Since M. lapponicus is usually a minor member of a larger predator complex, it is difficult to estimate the significance of its role in reducing balsam woolly aphid populations. Observations indicate that individually the larvae are quite efficient. The species' chief fault is its late arrival and its low numbers.

Metasyrphus attenuatus (Diptera: Syrphidae)

Very little is known about this species. Two third instar larvae were collected feeding on C. piceae at Corvallis on May 1, 1959. Both larvae were placed in rearing, and one adult was obtained.

Superficially, the larvae and puparia were indistinguishable from M. lapponicus. Therefore, this species may cause some difficulty in future field determinations. However, if M. attenuatus remains as rare on C. piceae as it appears at present, few problems will be encountered.

Leucopis sp. near atrifacies (Diptera: Chamaemyiidae)

This species is found only at the lower elevations. Populations are usually light, although larvae are more abundant than another Leucopis species found associated with C. piceae. Extremely heavy L. atrifacies populations have been observed preying on an unknown Pineus species at Corvallis. The four insect stages of L. atrifacies are presented in figure 13.

Descriptions of Immature Stages - This section describes the egg, third instar larva, and puparium of L. atrifacies. The first and second instars are not known.

Egg: (Figure 13A). Length, 0.45 to 0.48 mm.; width 0.17 to 0.18 mm. White; oblong-ovate; smallest at micropylar end. Surface with numerous undulating, branching, longitudinal striations.

Third Instar Larva: (Figures 13B and 14C). Length, 2.0 to 3.9 mm.; width, 0.62 to 1.08 mm. Mean length of mouth-hooks, 0.28 mm. Light grey to pale yellow; sub- cuneiform; segmentation moderately distinct. Integument densely covered with numerous, large, recurved spines; faintly arranged in rows. Larva amphipneustic; spiracles of first segment extended on three branched arms. Posterior respiratory processes 0.055 to 0.073 mm. long; 0.059 to 0.073 mm. wide at base; widely separated; densely spinose; darkly sclerotized; terminating with three branched spiracular arms.

Puparium: (Figure 13C). Length, 2.1 to 2.3 mm.; width, 0.69 to 0.76 mm. Light to dark brown; anterior portion flattened dorso-ventrally into a lip-like shelf. Spinose appearance of third instar maintained.

Life History and Behavior - *L. atrifacies* has two generations per year. Eggs are laid singly on the bark surface, in wax masses, and tucked under lichen growth. They are usually very difficult to find, even when populations are heavy. Mature larvae are equally difficult to detect. They feed completely within the wax masses. Detection is made even more difficult because the chermid wool clings tenaciously to the larva's spines.

Pupation takes place on the tree. Usually some secluded spot is selected. It may be under lichen, in bark fissures, or within a heavy mat of chermid wool. If the population is heavy and hiding places are

Figure 13. The native chamaemyiid predator <u>Leucopis</u> sp. near <u>atrifacies</u> Ald.: A, hatched egg (126X); B, third instar larva (36X); C, puparium (45X); D, female adult (43X).

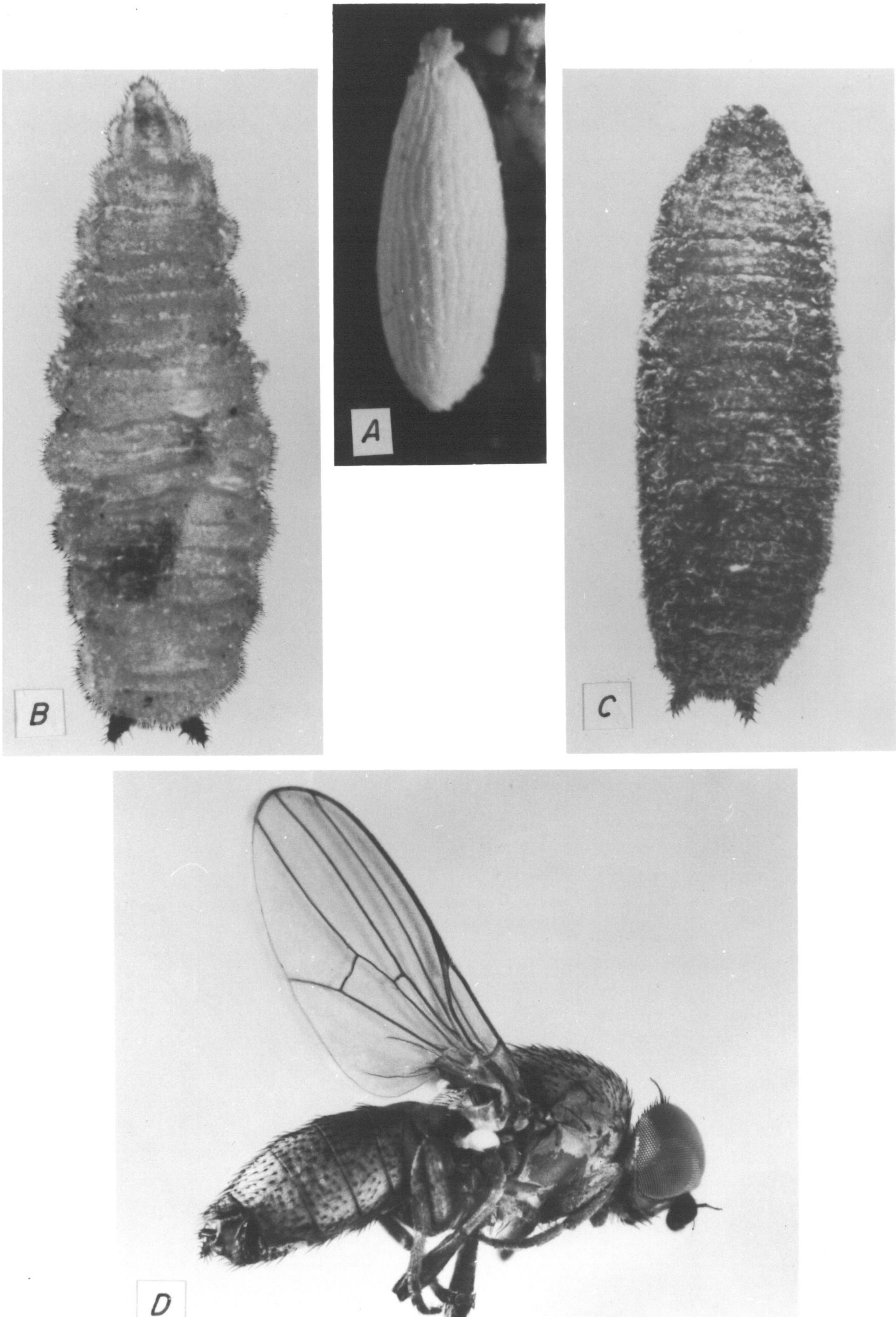
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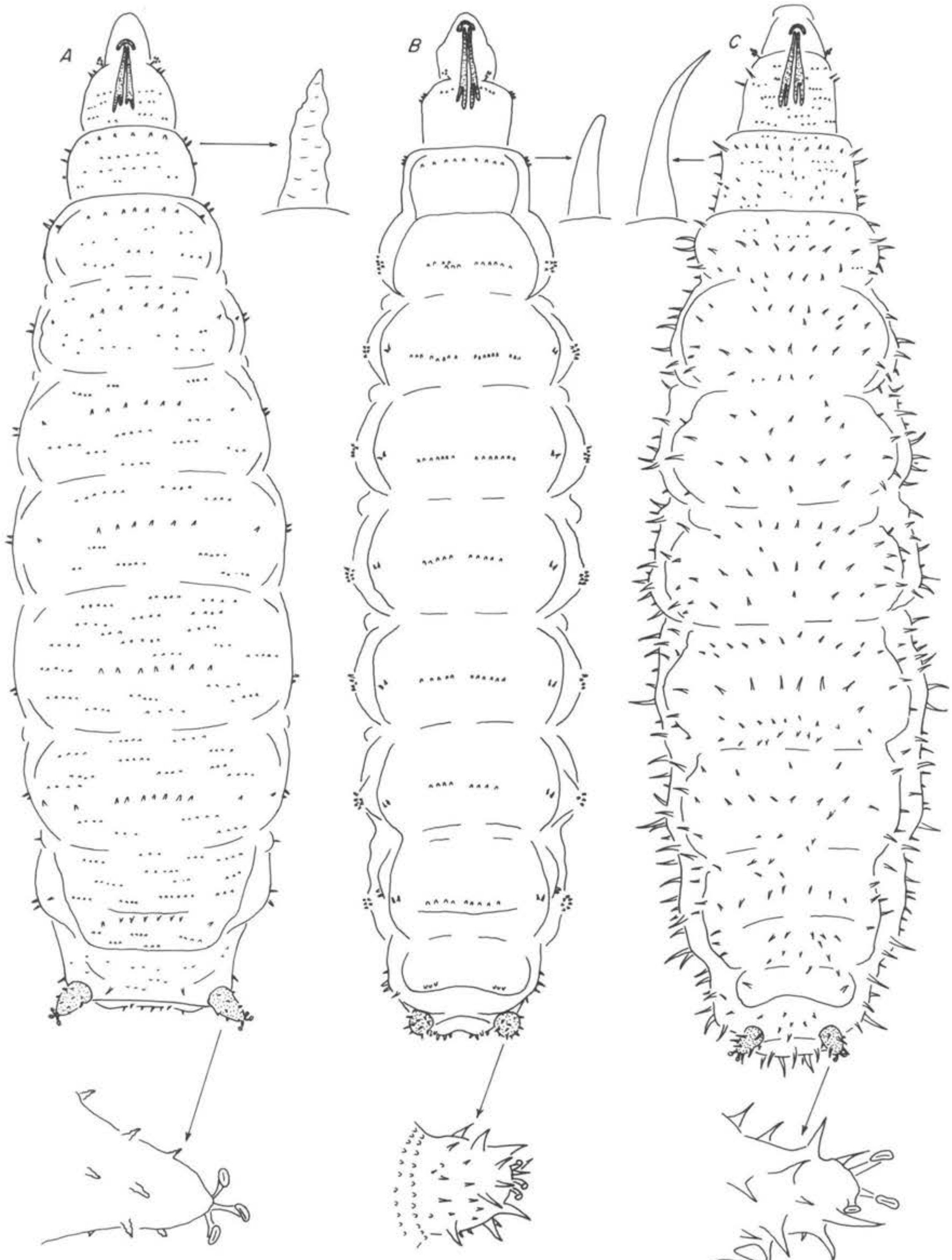
Figure 14. Larval drawings of three mature, native chamaemyiid predators in the genus *Leucopis*: A, *Leucopis* sp. near *americana* Mall. (45X); B, *Leucopis* sp. (64X); C, *Leucopis* sp. near *atrifacies* Ald. (53X).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scarce, the pupating larvae become quite gregarious. Sometimes 10 to 15 puparia are congregated under one small piece of lichen.

Winter is passed in either the larval or the pupal stage. Most of the overwintering population are puparia, although a significant number of insects remain in the larval stage. Apparently all three larval instars will overwinter on the tree. Puparia collected in the fall need an extended cold treatment at temperatures near freezing before adults can be reared. The cold period must be at least 30 days.

Two parasitic chalcids were reared from the puparia of this species --*Pachyneuron* sp. and *Lygocerus* sp. Aggregate parasitism by these two species was close to 25 percent.

Discussion - The control contribution by *L. atrifacies* appears to be negligible. The insect's chief drawback is low numbers. It is rare to find more than 10 larvae per five-foot section of balsam woolly aphid infested tree. As a contrast, as many as 17 larvae of the same species has been found on less than three square inches of *Pineus* sp. infested bark.

Leucopis sp. near *americana* (Diptera: Chamaemyiidae)

This species is found at all elevations in the Pacific Northwest. Populations are usually quite small; seldom being greater than five or six larvae per five-foot bole section. On rare occasions, however, populations are found to be rather large. Usually these large numbers occur on trees with long established *C. piceae* infestations and high aphid densities.

Descriptions of Immature Stages - This section describes only the third instar larva and the puparium. The egg and first two larval instars are not known.

Third Instar Larva: (Figure 14A). Length, 2.57 to 4.01 mm.; width, 0.64 to 1.38 mm. Mean length of mouth-hooks, 0.30 mm. Pale, light grey; distinctly cuneiform; segmentation slightly obscure. Integument smooth between numerous transverse rows of small intersegmental spines. Segmental spines distinctly sinuate; arranged in 8 transverse rows. Larva amphipneustic; anterior spiracles extended into four branched arms. Posterior respiratory processes 0.12 to 0.15 mm. long; 0.08 to 0.10 mm. wide at base; well separated; slightly spineose; well sclerotized; terminating in very conspicuous branched spiracles.

Puparium: Length, 2.4 to 2.8 mm.; width, 0.9 to 1.1 mm. Light to dark brown; subcuneiform; anterior end dorsoventrally flattened to form a lip-like shelf; posterior respiratory processes same as third instar larva.

Seasonal History and Behavior - The seasonal history behavior of *L. americana* is very similar to *L. atrifacies*. Both have two generations per year. *L. americana* feed within the chermid wax masses, but are easier to detect than *L. atrifacies* because of their larger size and absence of wool gathering spines. Pupation usually occurs on the bark, although a collection of several larvae and puparia in a tray at Black Rock suggests that at least some of the population pupate in the soil. Winter is passed in either the larval or pupal stage. A cold period is needed to break diapause in the fall-collected puparia.

L. americana is attacked by the same two parasitic chalcids reared from L. atrifacies.

Leucopsis sp. (Diptera: Chamaemyiidae)

This species was collected only once--on August 20, 1959 at the south boundary of the Yakima Indian Reservation near Goldendale, Washington. The species presented the heaviest predator population seen by the writer on balsam woolly aphid. Judging from the lack of abandoned puparia on the trees, it would appear that the species has but one generation per year in that locality. Larvae collected in August pupated on the stem and went into diapause. Diapause could be broken only by subjecting the puparia to an extended period of temperatures near freezing.

Mature larvae are conspicuously different from the other two Leucopis species found preying naturally on C. piceae. A drawing of this larvae is presented in figure 14B. Length of the mature larva ranges from 1.64 to 3.22 mm. and width from 0.64 to 0.90 mm. Mean length of mouth-hooks is 0.26 mm. Laval color is bright yellow, and segmentation is distinct. The integument is finely granulate. Segmental spines are well rounded distally. Dorsally, the spines are arranged in transverse rows; in the pleural areas, they are clustered in small groups on the outer margin of each segment. The anterior spiracles are branched into three arms. Posterior respiratory processes are well separated, heavily sclerotized, covered with spines, and almost spherical in form. The three spiracular arms are so short that they are almost lost in the mass of spines arising from the respiratory process.

The puparium ranges in length from 2.1 to 2.3 mm. Width varies from 0.69 to 0.76 mm. Its color is very light brown.

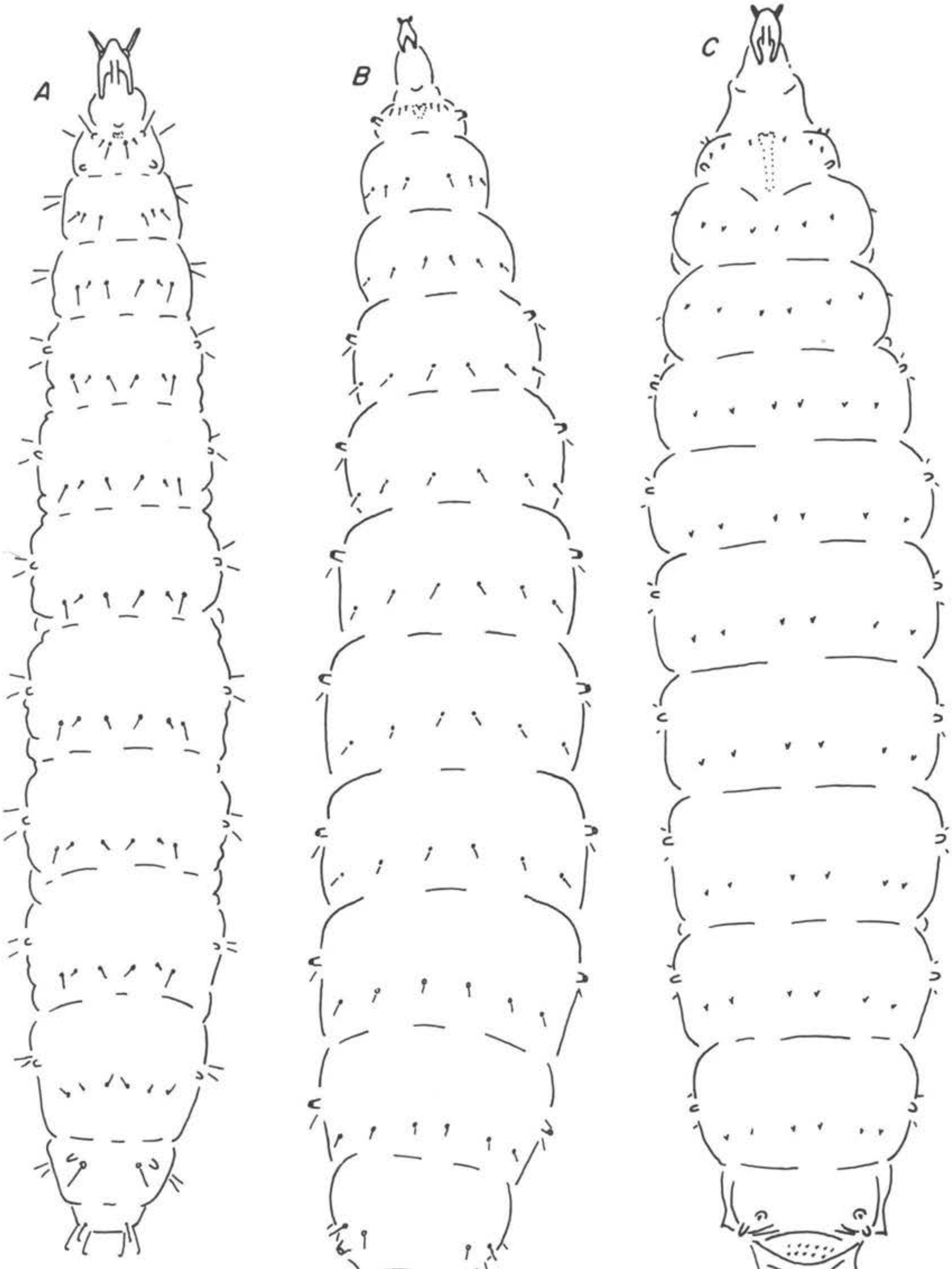
Lestodiplosis sp. (Diptera: Itonididae)

This insect has been found at almost every collection point in the balsam woolly aphid infestation area. It occurs in very small numbers and appears to be of little value in controlling *C. piceae*. Adults have never been reared, although the larvae are easily assigned to genus by the description given by Peterson (16, p. 264). A drawing of the immature larva is presented in figure 15A.

There appear to be two generations per year; the first complete generation appearing in mid-summer and the second in late fall. The second generation passes the winter in various stages of larval development. The small larvae feed completely within the aphid egg masses and are very difficult to detect. The pupa is not known. A very similar insect --perhaps the same species--attacking *Pineus* sp. at Corvallis, was found pupating in loosely spun cocoons under lichen on the tree.

The mature larva ranges from 1.92 to 2.55 mm. in length and from 0.35 to 0.44 mm. in width. It is dark pink in color and has a peculiar shagreened texture. The larva is very distinct in form and easily separated from the introduced *Aphidoletes thompsoni*. The most distinct features of the immature stages are nine transverse rows of fleshy pseudopods on the ventral surface. Each row has three lobes. Also conspicuous, are numerous long dorsal, lateral, and caudal setae.

Figure 15. Larval drawings of three mature itonidid predators associated with the balsam woolly aphid in the Pacific Northwest: A, the native Lestodiplosis sp. (72X); B, a native unknown species (56X); C, the introduced Aphidoletes thompsoni Mohn (75X).



Undetermined Itonididae (Diptera)

Few observations have been made on this predator. Larvae have been observed feeding on *C. piceae* in only three areas--Black Rock, Corvallis, and Toutle River. The insect makes its first appearance in late July and continues to be present until late September. Ten larvae represented the largest single collection. They were obtained from a tray attached to an aphid-infested Pacific silver fir at Black Rock. One adult female was reared from that collection, but unfortunately only males are used for identification. Figure 15B presents a drawing of the mature larva.

This species is a little larger than *A. thompsoni* and *Lestodiplosis* sp. Larvae range from 2.61 to 3.76 mm. in length and 0.54 to 0.82 mm. in width. The color is a pale pink. Two well sclerotized, recurved anal spines separate this species from the other two itonidids associated with the balsam woolly aphid. Also, the head capsule and spatula are formed somewhat differently.

The habits of this insect are similar to those of *Aphidoletes thompsoni*. Both feed entirely concealed by chermid wool, and are found only by disturbing them with a probe or removing their cover. Both pupate in the soil and make the same type of pupal chamber from silk and soil particles.

Hemerobius neadelphus (Neuroptera: Hemerobiidae)

This species is usually one of the more abundant insect predators attacking the balsam woolly aphid. At times, however, it is quite rare. The species ranges throughout the entire infested zone, although it is usually more abundant at the higher elevations. The four insect stages of H. neadelphus are presented in figure 16.

Descriptions of the Immature Stages - This section describes the egg, three larval instars, and pupa of H. neadelphus. A description of the adult is given by Gurney (9, p. 214).

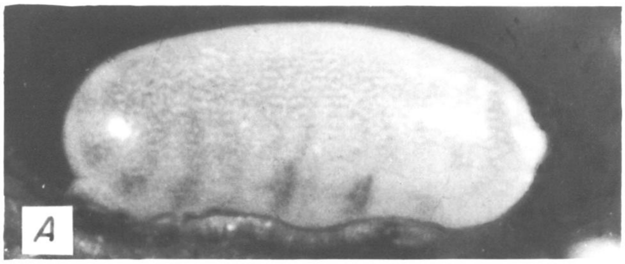
Egg: (Figure 16A). Length, 0.45 to 0.52 mm.; width, 0.19 to 0.22 mm. Beige when first laid, later becoming pinkish; abdominal segments of developing larva visible through chorion about one day prior to hatching. Barrel-shaped with conspicuous button on micropylar end. Surface with microscopic, short, longitudinal striations.

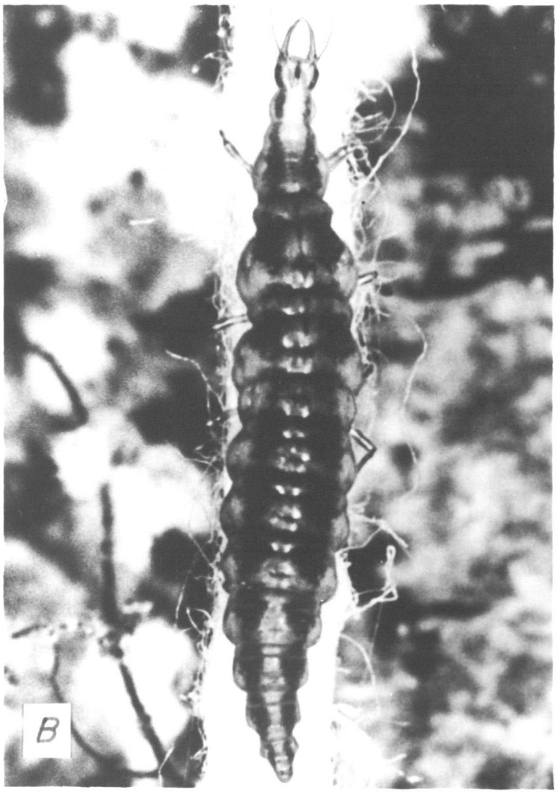
First Instar Larva: Length, 1.33 to 3.20 mm.; width, at third thoracic segment, 0.26 to 0.51 mm. Mean width of head capsule, 0.29 mm. Very similar to the second and third instar. One character (other than width of head capsule) which separates this stage from the second and third instars is the presence of a trumpet-shaped empodium (Figure 17F). Second and third instars have a much more abbreviated empodium (Figure 17E).

Second Instar Larva: Length, 3.02 to 4.96 mm.; width at third thoracic segment, 0.51 to 0.79 mm. Mean width of head capsule, 0.38 mm. Identical in all other respects to the third instar.

Third Instar Larva: (Figure 16B and 17A, B, C, D, and G). Length, 5.7 to 9.2 mm.; width at third thoracic segment, 0.82 to 1.54 mm. Mean width of head capsule, 0.49 mm. Beige with longitudinal brown bands on head and prothorax; meso- and metathorax and first five abdominal segments dark blue dorsally and beige in pleural areas; last five abdominal segments pink with two longitudinal red bands. Jaws composed of man-

Figure 16. The native hemerobiid predator <u>Hemerobius neadelphus</u> Gurney: A, egg (128X); B, third instar larva (12X); C, pupa (17X); D, adult (11X).





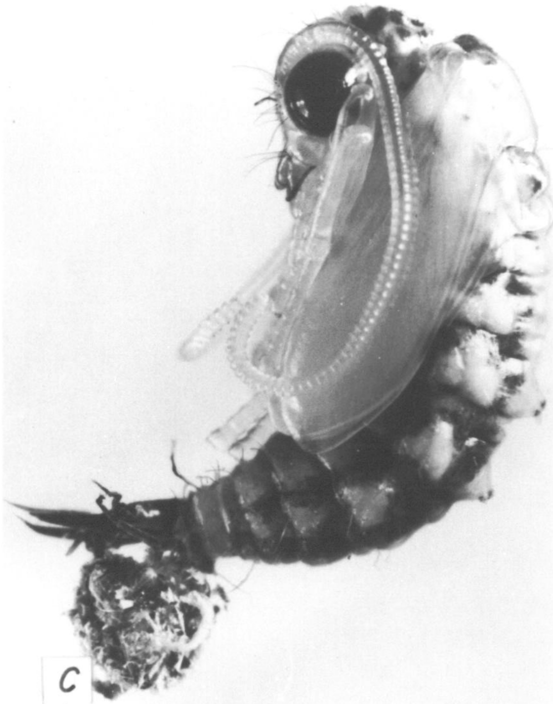


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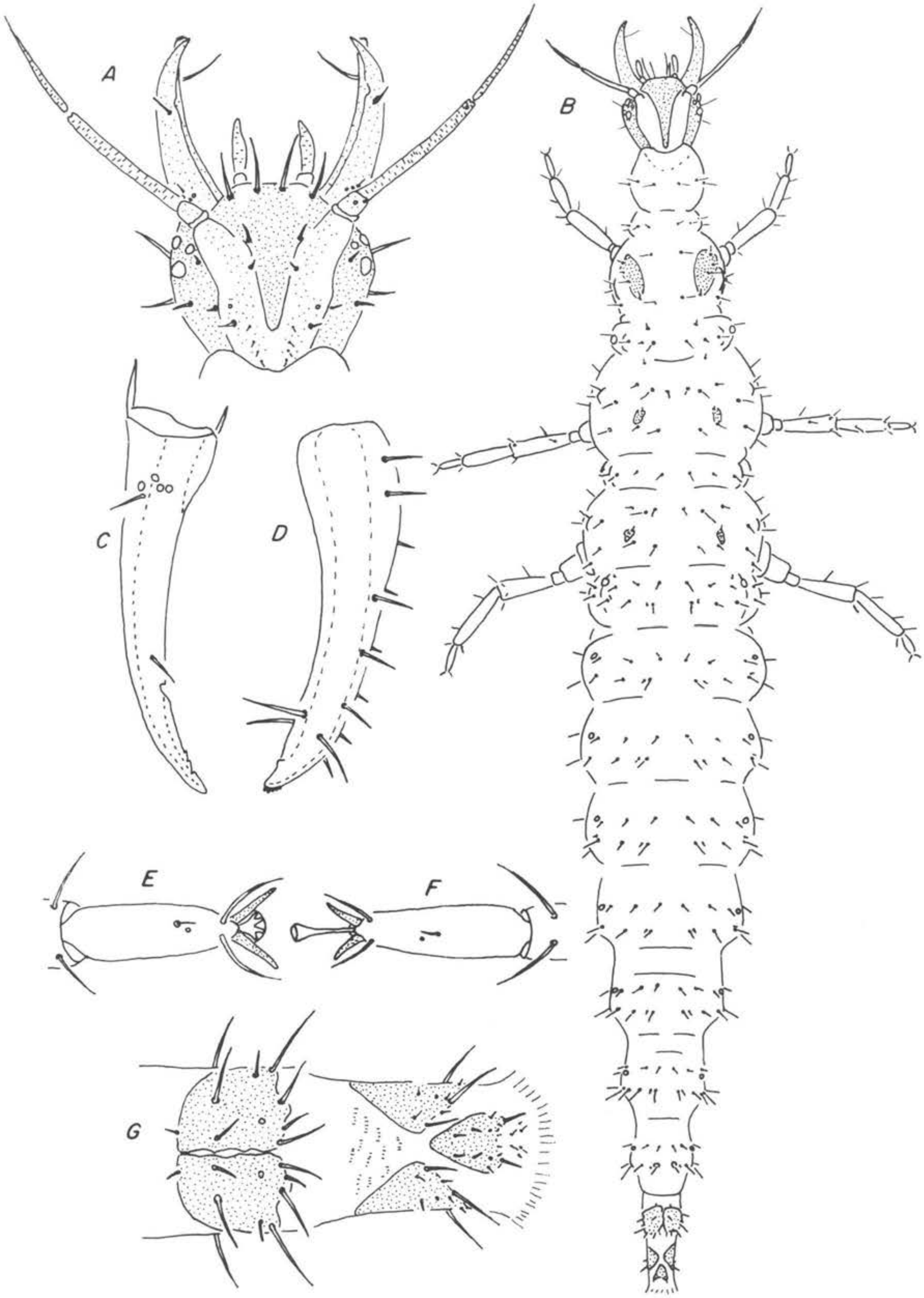
Figure 17. Larval drawings of the native hemerobiid predator *Hemerobius neadelphus* Gurney: A, head region of third instar larva (85X); B, third instar larva (24X); C, dorsal view of third instar right mandible (121X); D, ventral view of third instar right maxilla (124X); E, tarsus of third instar (186X); F, tarsus of first instar (274X); G, dorsal view of last two abdominal segments (103X).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dible and maxilla; mandible grooved ventrally, three or four barb-like serrations on inner margin near apex; maxilla grooved dorsally, blunt ended with sense organs. Labial palps 4-segmented. Antenna 4-segmented; distal segment short, bristle-like. Integument smooth except for sclerotized areas on pro-, meso-, and metathorax and on last two abdominal segments. Two or more rows of setae on each body segment. Nine spiracles; one on mesothorax and the rest on the first eight abdominal segments.

Pupa: (Figure 16C). Length, 4.0 to 4.7 mm. Enclosed in loosely spun cocoon. Brown and beige in color. Two conspicuous humps on dorsum of the second and third abdominal segments; each hump surmounted by four recurved spines, two bend caudad and two cephalad.

Life History and Behavior: H. neadelphus has at least two and possibly three generations per year at the higher elevations. For some reason there is only one late summer generation in the Willamette Valley. At Willamette Pass, oviposition starts around mid or late June. Eggs are laid singly directly on the bark of the aphid-infested tree or they are attached to lichen growing on the bark. There is a definite preference for attaching eggs to string-like lichen. As many as five eggs may be deposited on the same strand. Newly hatched larvae sometimes attack and destroy the other eggs.

All three larval stages feed from outside the wax mass and are easily detected. Larvae are extremely cannibalistic when confined together and are moderately so in their natural habitat. The duration of the three larval instars is about 20 days in the laboratory. The pupal period lasts about nine days. Pupation occurs in the soil or secluded in lichen growth and bark fissures on the tree. Overwintering may occur in either the larval or pupal stage; there is no diapause period.

Only one species of parasite, Anacharis punctatifrons Kieffer (Cynipoidea: Anacharidae), was reared from this neuropteron. It is a larval parasite which is seldom encountered in the rearings. Metasyrphus amalopsis readily attacks H. neadelphus. This syrphid appears to be the chief enemy of the hemerobiid.

Discussion - H. neadelphus does not appear to contribute much in the way of balsam woolly aphid population reduction. The insect spends most of its time running from one place to another. Another fault is that it does not attack new aphid infestations when the host population is low. The insect is found almost exclusively on those trees having heavy C. piceae populations. Still another fault of the hemerobiid is that it does not maintain a large population throughout the year. Initially, the predator numbers are rather large, but the population drops drastically after the end of the first generation. It was found in 1959 at Willamette Pass, that the first generation was more than 10 times the size of the second.

Chrysopa sp. (Neuroptera: Chrysopidae)

An occasional Chrysopa larva was found feeding on C. piceae at almost every collection point. Most of them were found in late summer. All appeared to be the same species, although it has not been proved. Because chrysopid eggs were never found, and because no more than one or two larvae were ever collected at a time, it is suspected that the insect's relationship with the balsam woolly aphid is accidental. The larva and adult are presented in figure 18.

Length of the larva varies from 8 to 11 mm. It is usually dark grey on the lateral margins and conspicuously red and pink along the dorsal midline. Lateral wart-like protuberances and conspicuous long hairs complete its distinguishing features.

Chrysopa quadrimaculata Burm. (Neuroptera: Chrysopidae)

Larvae of this species were observed only a few times and only at three areas--Corvallis and Benton-Lane Park, Oregon, and Goldendale, Washington. The insect is very interesting because of its habit of piling *C. piceae* wool, sistentes, and eggs on its back. In the early stage, it looks very much like a moving balsam woolly aphid wax mass. Evidently the insect has only one generation per year; the generation ending in late August. Pupae are easily obtained by caging the insect on the tree, but emergence will not occur unless the insect is cold-treated. A dorsal view of the larva with the wool removed and a ventral view with the wool in place is presented in figure 19.

The larva is about 4 mm. long and is colored a non-descript grey and black. The most distinctive features are the extremely long hairs and a hump-backed abdomen.

Mulsantina picta (Coleoptera: Coccinellidae)

This beetle is rarely seen attacking *C. piceae*. The only collections have been made in the Willamette Valley and at Wind River Arboretum. Balch also found this insect (i.e. *Cleis picta*) attacking *C. piceae* in New Brunswick (1, p. 40). The larva, pupa, and adult are presented in figure 20.

M. picta has one generation per year. Coccinellid eggs believed to belong to this species were seen on three occasions--twice on balsam woolly aphid infested trees and once in association with *Chermes cooleyi*. On all occasions the eggs were about 1 mm. long, dark red, clustered in groups of six, and standing on end. Oviposition was first noted in mid-May. Larvae were never common until around pupation time in early July. Pupation occurs on the bark, usually in a bark fissure or pitch pockets. The emerging adults do not remain associated with the chermid infestation.

Larvae are about 7 mm. long and are mostly black, with white margins and a white mid-dorsal line. Black areas are heavily sclerotized, rough textured, and quite spinose.

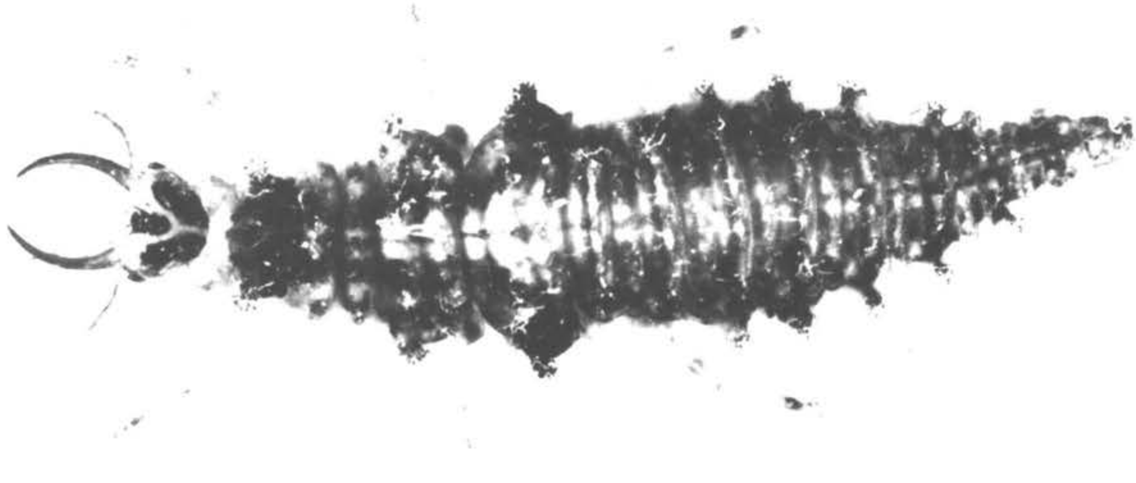
Pupae are mostly white to pink with conspicuous black areas on the dorsum. Length is around 5 mm.

Anystis sp. (Trombidiformes: Anystidae) and *Allothrombium* sp. (Trombidiformes: Trombididae)

Anystis sp. is usually present on almost every balsam woolly aphid infested tree at almost any time of the year. Although the mite seems to be everywhere, it is never too abundant on any one tree. Its principle hosts are probably other small mites. *Anystis* sp. is small, 0.39 to 0.51 mm. long, bright red, and extremely active.

Allothrombium sp. was observed by the writer only once--early May at Black Rock, Oregon. Mr. N. E. Johnson, entomologist for Weyerhaeuser Company, reports the mite to be more common in the Toutle and Green River

Figure 18. The native chrysopid predator <u>Chrysopa</u> sp.; A, mature larva (16X); B, adult (9X).



A

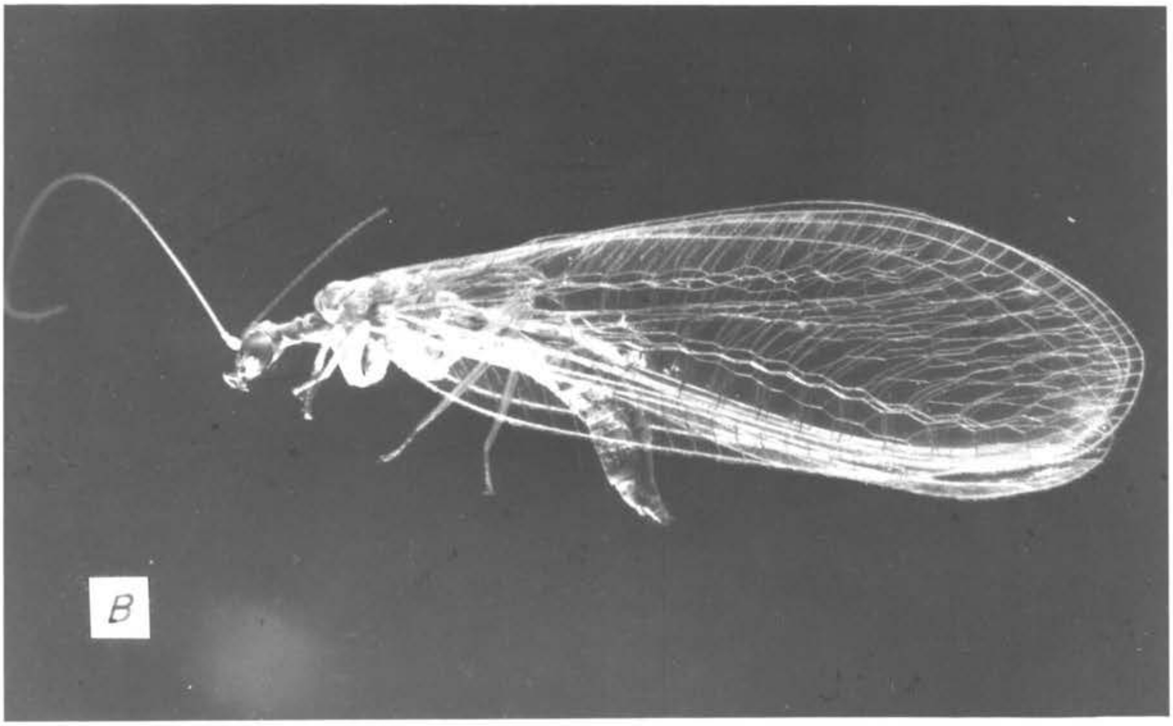
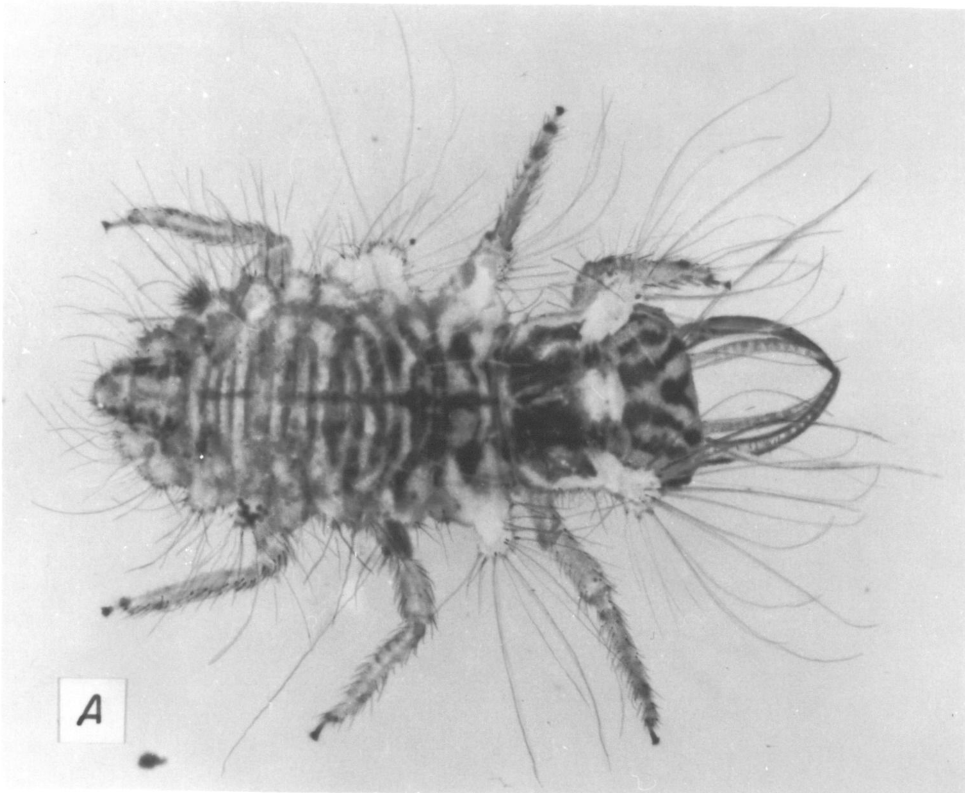


Figure 19. <u>Chrysopa quadrimaculata</u> Burm.--a native, trash carrying predator: A, dorsal view with trash removed (25X); B, ventral view with trash in place (25X)


A

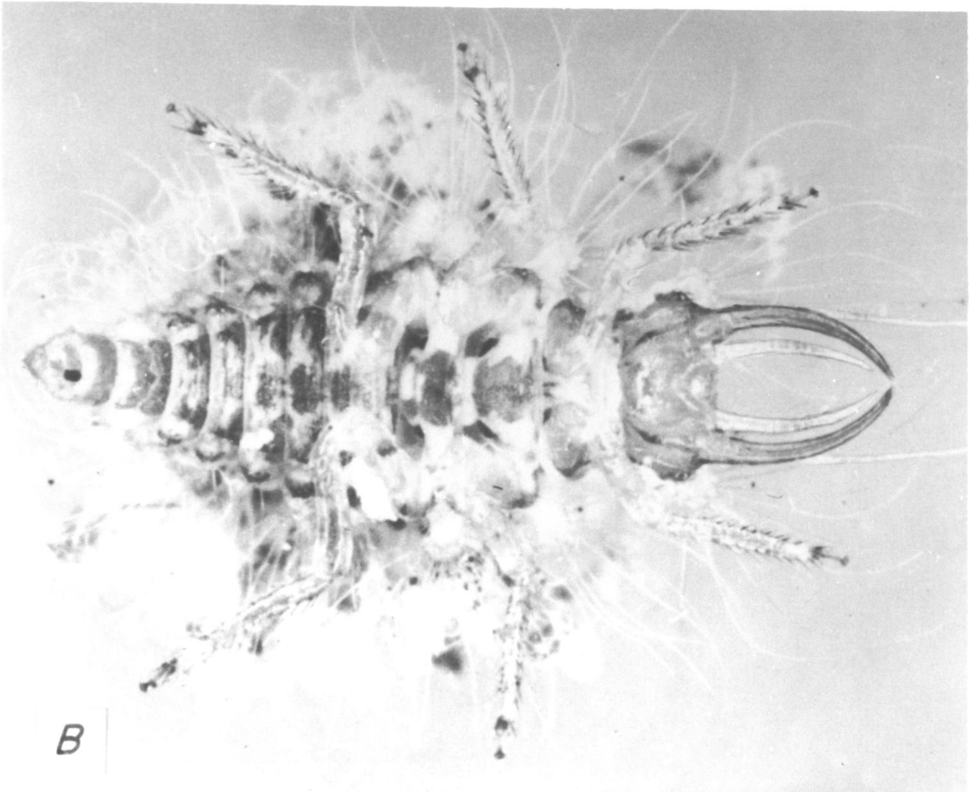
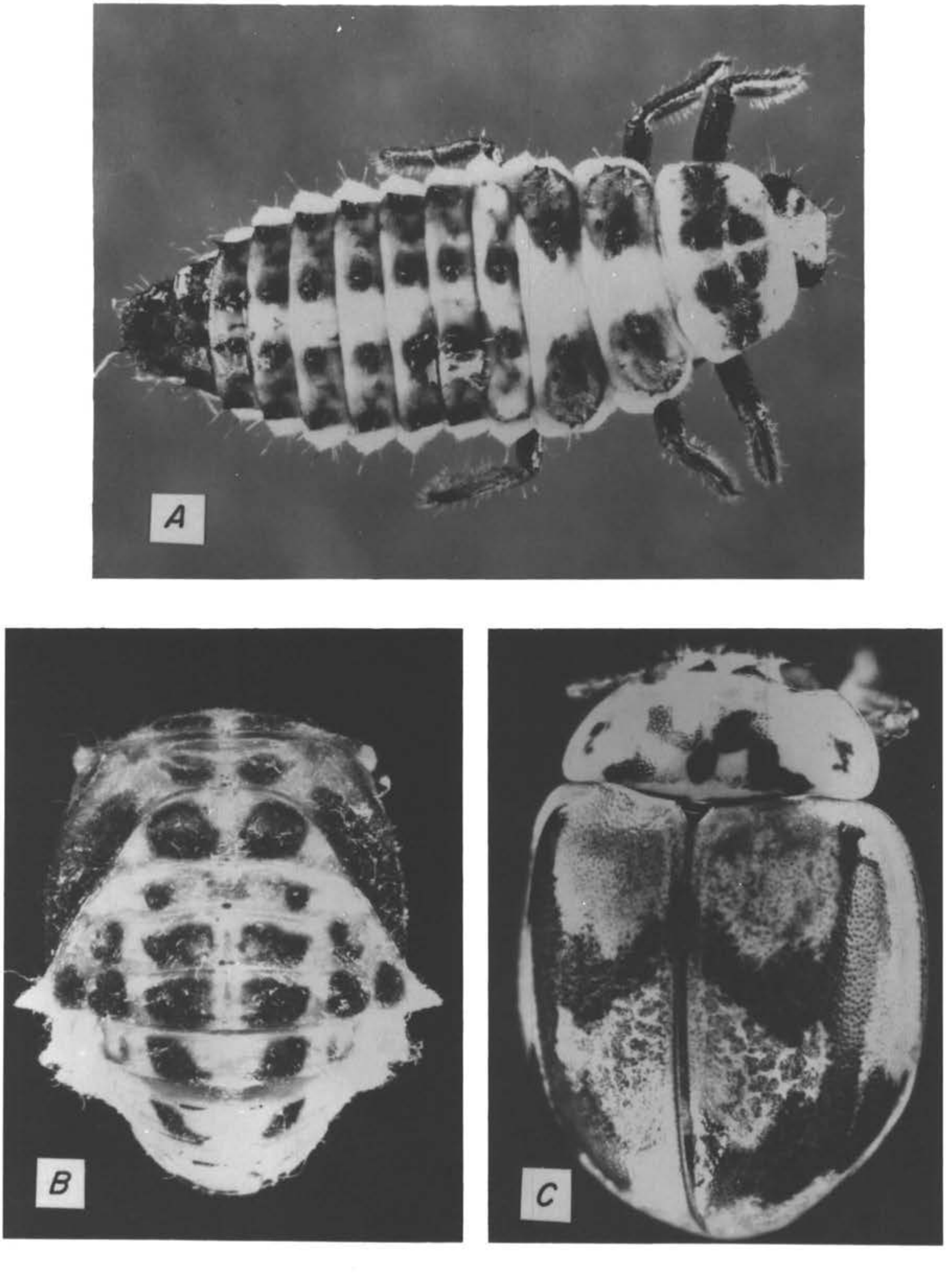

B

Figure 20. The native coccinellid predator Mulsantina picta (Rand.): A, mature larva (21X); B, pupa (15X); C, adult (25X)


A
B
C

drainages of Washington.[4] It was never observed completely devouring its prey. Usually it punctured the aphid with its chelicerae, sucked some fluid, and then moved to another aphid.

Allothrombium sp. is quite large--2.1 to 3.2 mm. long. It is bright red and covered with a velvety pile. Movement is extremely slow.

Discussion of Native Predator Complex

In North America, questions occasionally arise on the validity of calling the balsam woolly aphid an introduced pest. Several good reasons supporting the theory of introduction have been presented. Among the evidence presented is the paucity of predators attacking *C. piceae* in North America as compared to the rich faunal complex found associated with the balsam woolly aphid in Europe. It would be difficult to find better support for this argument than the results of the study just reported.

Every predator described as attacking the balsam woolly aphid in the Pacific Northwest has its counterpart in the European predator complex. Yet, in Europe, every one of those predators, except one *Leucopis* species, is considered of little importance in reducing *C. piceae* populations. They are general feeders known to attack a wide variety of homopterans. Similar to the predators in Oregon and Washington, they are ubiquitous but not abundant.

4/ Personal communication

The important predators in Europe, which are not found here, are specific to their host and achieve tremendous population densities when presented with an abundant host supply. In the Pacific Northwest, there is an almost unlimited host supply, but no predator able to grasp the advantage. Given the time, a good predator complex will probably evolve, but the development will take countless years, perhaps centuries.

It has long been a general opinion among some entomologists that host specificity, or at least host preference, is generally lacking among predators attacking homopterans. This is not strictly true. Just because a particular species can be reared on a great number of hosts, it does not mean that the predator is a general feeder. The ovipositing female selects the site. If the female randomly lays eggs on a large number of hosts and the progeny survive, the predator is a general feeder. Conversely, if the female oviposits on only one host, then the species is host specific, regardless of how many different hosts can be utilized for rearing.

A good example of host specificity and an effective predator complex is the one presented by the *Pineus* sp. infestation on Western white pine, *Pinus monticola* Dougl., at Corvallis. This *Pineus* species is almost identical to the balsam woolly aphid in all respects. Both live anchored to the stem, produce wool, have multiple generations, and reproduce parthenogenetically. Yet, examinations have shown the *Pineus* infestations as having at least five good predators. Each one of them achieves extremely large populations, and each is in perfect syncronization with the host. Only one of those predators *Leucopis* sp. near *atrifacies*, is found on *C. piceae*, even though in one case a balsam woolly aphid infestation is less than 100 feet away. Conversely, almost every predator found attacking the balsam woolly aphid is also found preying on *Pineus*; and in almost identical numbers.

The above discussion not only points out the significance of the balsam woolly aphid introduction theory, but also shows the futility of expecting insect control from the native predators feeding on *C. piceae*. If a well-established predator complex, such as the one on *Pineus*, will occasionally let its host population get out of control, what can be expected from predators which are merely casual feeders?

NOTES ON POSSIBLE PREDATORS OF *CHERMES PICEAE*

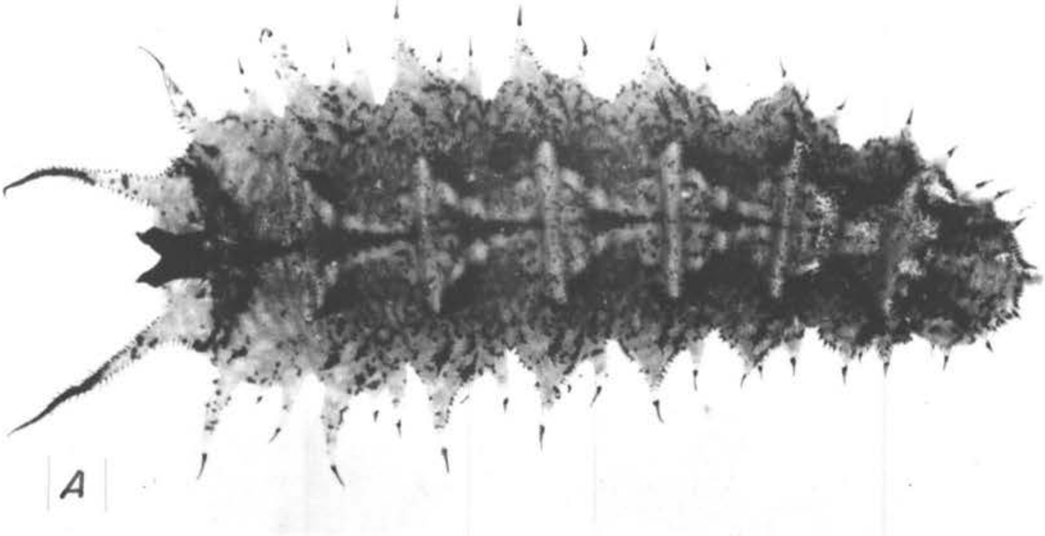
None of the arthropods to be discussed in this section have been observed feeding on the balsam woolly aphid. The possibility of their being predators is suggested by the fact that all were found in association with *C. piceae* and that all belong to groups known to be predaceous on insects. In general, the purpose of the section is to briefly expose the reader to what little information is known.

Insects Associated with the Balsam Woolly Aphid

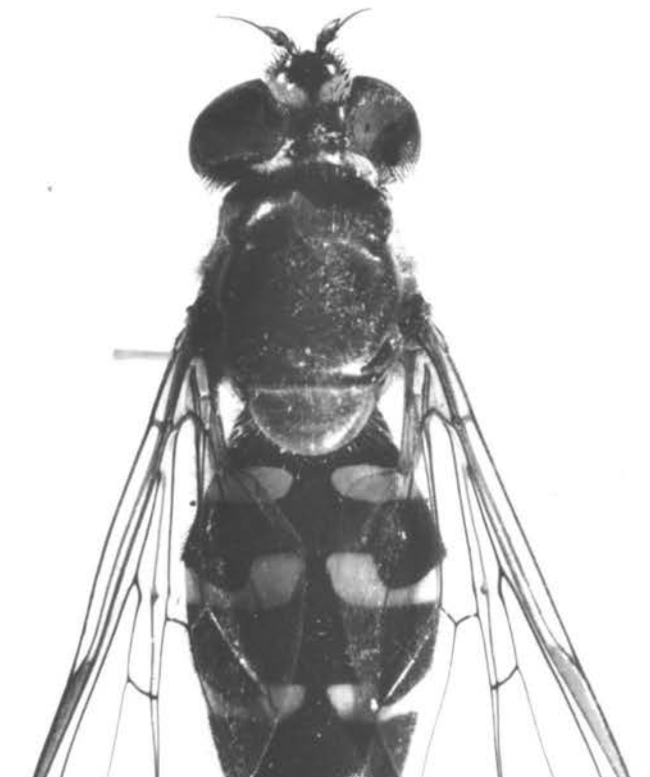
The first insect to be discussed is the syrphid *Metasyrphus amalopsis*. This insect is seldom encountered. Two mature larvae were collected from an aphid infested grand fir at Corvallis in January of 1957. Both formed puparia but only one adult was obtained. One mature larva was collected in August, 1957, at Willamette Pass. Several more were collected about the same time in 1958 and 1959 at Willamette Pass, Black Rock, and in Washington's Green and Toutle River drainages. The third instar larva and adult are presented in figure 21.

It is possible that *M. amalopsis* is primarily a feeder on other predators. Several times it was observed preying on *Hemerobius neadelphus*, and once it was seen attacking *Cnemodon rita*. The larvae are very quiescent and are always found adhering firmly to the bark. A characteristic of the larva is that when it is disturbed, it rears back to a "fright position" similar to many Lepidoptera. The mature larva is 8 to 11 mm. long and strikingly colored in various shades of pink, blue, green and black. Numerous long spines add to the unique appearance.

Figure 21. The syrphid Metasyrphus amalopsis O.S.--an associate of the balsam woolly aphid in the Pacific Northwest: A, instar larva (11X); B, adult (11X).



A



One specimen of Hemerobius conjunctus var. conjunctus was reared from a pupa found on the bark of a balsam woolly aphid infested tree in June, 1957, at Toutle River. The species were never collected again, and nothing further in known about it.

In 1957, one raphidiid adult, Agulla sp. near adnixa, was collected in association with C. piceae at Willamette Pass. In 1958 and 1959, several snakefly larvae were found in other areas as well as Willamette Pass. None were observed feeding naturally, nor could they be forced to feed on the balsam woolly aphid after starvation. Association of the larvae with the adult collected in 1957 was therefore never definitely established.

In 1958, two adult coccinellids, Cycloneda polita, were found associated with C. piceae. One was collected in May at Corvallis and the other in June at Wind River. Both appeared to be merely resting on the bark of infested trees, and neither was observed feeding. On June 17, 1959 at Benton-Lane Park, several C. polita were observed pupating on the bark around the base of an aphid-infested tree. Larvae were not seen; therefore, the predaceous habits were not established.

Mites Associated with the Balsam Woolly Aphid

The first mite to be mentioned is the bdellid Biscirus uncinatus. This mite was found associated with C. piceae in almost every area. Although the species has had ample opportunity to prey on the balsam woolly aphid, close observations has failed to detect it doing so. At Corvallis, it was once seen feeding on a phytophagous mite, Brevipalpus sp., which was abundant on grand fir.

The second mite, *Anystis agilis*, was observed in great abundance on two occasions at Black Rock. Both times they were seen on *C. piceae* infestations during a short period in late July. At neither time were they observed feeding.

The last two mites to be mentioned are *Tydeus* sp. and *Typhlodromus bakeri*. Both species were found at Black Rock in late December, 1957. They were not observed feeding, and no other collections have been made since that time.

EVALUATION OF NATIVE PREDATORS

In one of the previous sections, some qualitative estimates were made on the efficiency of individual predator species. This section presents the procedures and results of an attempt to quantitatively evaluate the combined effectiveness of all the predators. All information presented is based on work done in 1959.

A similar, more ambitious evaluation program was pursued in 1958 but was largely a failure. Although the results of the 1958 study were disappointing, the experience gained was valuable. It lead to more refined techniques and to a better understanding of the over-all evaluation problem.

Methods and Procedures of Evaluation

The method used for evaluation of predator effectiveness was a modification of a system designed by N. R. Brown and R. S. Clark at the Fredericton, New Brunswick, Forest Biology Laboratory.[5] On each of two study trees, a five-foot trunk section was marked off, beginning just above ground level, as a sampling area. The number, stage, and species of predators were recorded over the entire five-foot area. Prey populations were tallied on 10 one-inch square "sub-plots" within the area. These 10 plots were divided into two vertical rows of five each, located one

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5/ Method observed during a visit to Fredericton, N. B., in 1957.

foot apart on the north and south sides of the tree. A variation from the method used by Brown and Clark was to protect five of the one-inch plots from predation. This was done by the use of small screen cages covering every other plot. A tree that was used for sampling is shown in figure 23.

A metal, window-like template hung from two aluminum nails was used to delineate the one-inch square sampling units. Recording the population within these plots was aided by the use of a microscope attached to an elevator-type camera tripod (figure 22). Counts of the predator population were made with an ordinary reading glass. Records were taken every two weeks and kept on a standardized form.

From this sampling scheme, the predator population was calculated as to the number of larvae per 1000 square inches of bark surface and chermid populations were computed on the basis of "acceptable prey" (2nd, 3rd, and 4th instars) per square inch. The trend of the two populations were then followed by plotting them on graph paper. From these plottings, comparisons could be made between the protected and unprotected prey densities and the predator population.

Two trees representing two species in two areas were selected for sampling. Both trees had heavy balsam woolly aphid stem infestations. The tree species and areas represented were Pacific silver fir at Black Rock and subalpine fir at Willamette Pass. An important selection requirement was that the trees have aphid infestations extending close to the ground. An attempt was made to pick trees that would survive the summer.

For both areas, the differences between the aphid population exposed

Figure 22. Predator evaluation tree at Black Rock, Oregon, and the microscope arrangement that was designed for counting aphid populations.

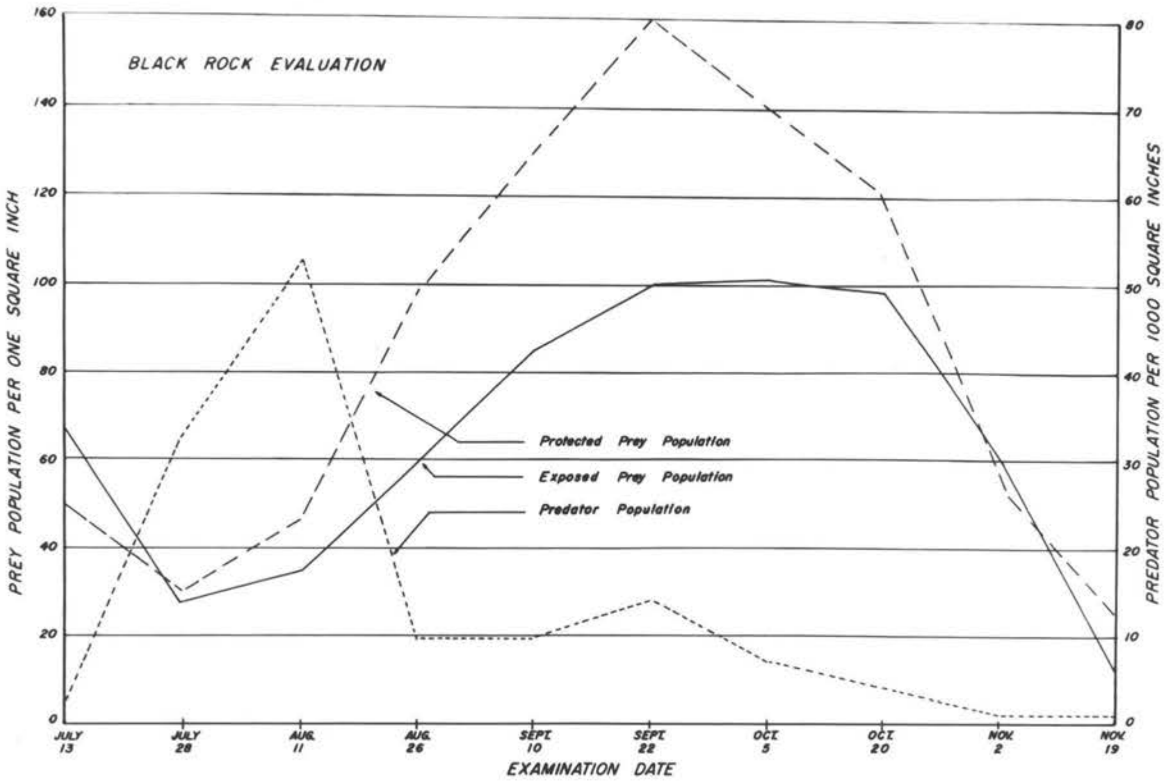
to predation and the aphid population protected from predation were subjected to statistical analysis. Two methods of analyzing were used. One test was a split plot analysis of variance on the accumulative difference between the two populations over the entire season. The second test was a simple T-test for each individual date.

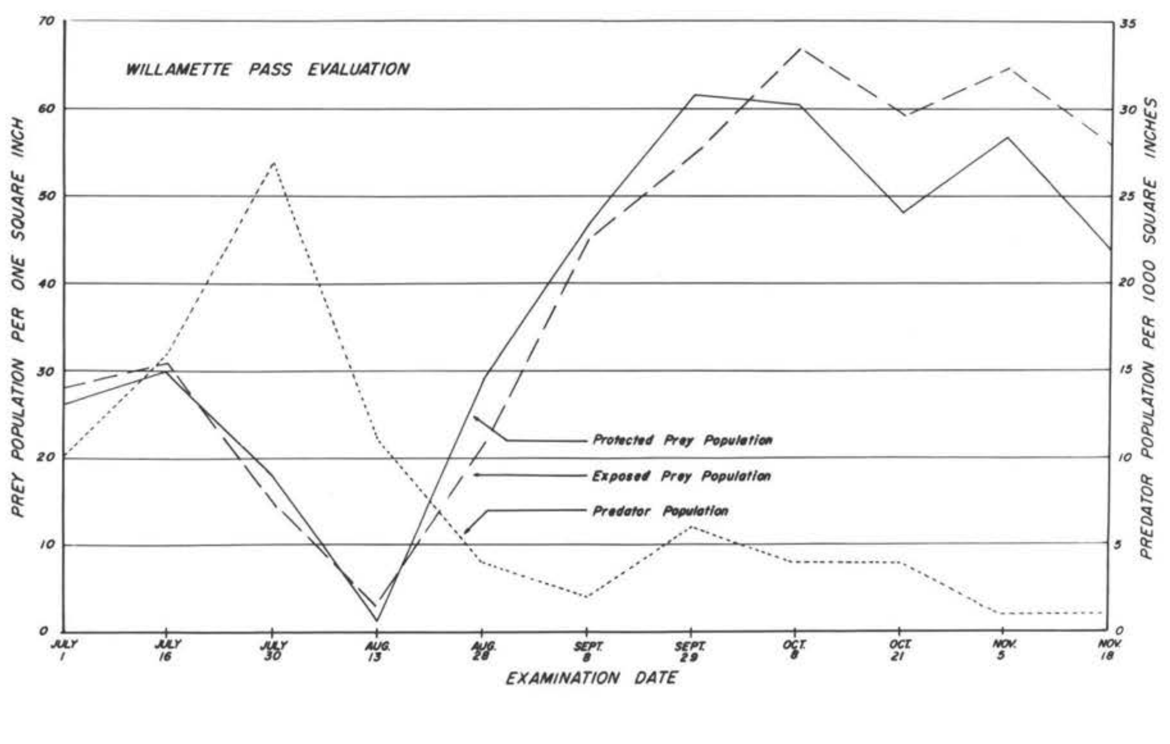
Results and Conclusions of Evaluation

Statistical analysis failed to show significant population reduction in either area as the result of predation. For the Willamette Pass data, this was expected, but the nonsignificance at Black Rock was rather surprising. At Black Rock, the difference between the exposed and protected prey populations was quite large. The mean population differences for both areas at different times of the year are shown in figure 23.

Examination of the raw data collected in 1959 revealed a fair amount of variation between plots. The reason for this variation is not known. Presumably some of it stemmed from observational error, although great care was taken to keep recording variation at a minimum. However, regardless of the source, the variation was not so great that it would have masked a truly notable host population reduction by predators. Even without statistical analysis, figure 23 shows that the effectiveness of the predator complex recorded in 1959 was far from adequate. At both Black Rock and Willamette Pass, the exposed prey population at the peak of the second generation was much greater than at the first generation peak. To be truly effective, the predators must reduce their prey density, or at least keep it static, over a considerable period of

Figure 23. Evaluation of native predator effectiveness in reducing balsam woolly aphid bark populations at two areas in Oregon. (Each point on the graph is an average of five population counts).


BLACK ROCK EVALUATION
PREY POPULATION PER ONE SQUARE INCH
PREDATOR POPULATION PER 1000 SQUARE INCHES
Protected Prey Population
Exposed Prey Population
Predator Population
0
20
40
60
80
100
120
140
160
10
30
50
70
JULY 13
JULY 28
AUG. 11
AUG. 26
SEPT. 10
SEPT. 22
OCT. 5
OCT. 20
NOV. 2
NOV. 19
EXAMINATION DATE


WILLAMETTE PASS EVALUATION
PREY POPULATION PER ONE SQUARE INCH
PREDATOR POPULATION PER 1000 SQUARE INCHES
Protected Prey Population
Exposed Prey Population
Predator Population
0
10
20
30
40
50
60
70
5
15
25
35
JULY 1
JULY 16
JULY 30
AUG. 13
AUG. 28
SEPT. 8
SEPT. 29
OCT. 8
OCT. 21
NOV. 5
NOV. 18
EXAMINATION DATE

time.

The conclusions drawn from the above discussion should not be that native predators offered no control benefits. There must have been some reduction in aphid population on the study trees, but it was probably so slight that it could not be detected by a mere five unprotected plots.

The native predators, being largely general feeders and not specific to C. piceae do not achieve populations large enough to uniformly cover the entire bark area. Therefore, it would not be improbable for an entire predator complex to miss five sample plots. Had the evaluation been made for an introduced predator that is specific to C. piceae, one might logically assume equal predation throughout every square inch of aphid population. In such case, five plots might be more than sufficient to assess the effects of predation on host population.

In conclusion, it must be stated that the data presented in this section are admittedly limited. Ideally, native predator evaluations should be continued for several more years in many different areas. This is especially true since numerical information is still not available on the exact amount of predation offered by native predators. But, a question arises on the practicality of further study. Is enough information already available to say that native predators are of little value as controlling agents, and that future study time could be spent more profitably in exploring other avenues of control? The writer believes the answer to this question is yes. At present, the most promising fields of C. piceae applied research seem to lie in studies of silvicultural control and in introduction and manipulation of chermid predators from foreign lands. Either study appears more promising than continued work on native predators.

SUMMARY

In 1957, the Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service, joined with Oregon State College in a cooperative study to explore the possibilities of biological control of the balsam woolly aphid, Chermes piceae Ratz., (Hemiptera: Chermidae). Several intermediate objectives were assigned to the project. Three of the objectives were: (1) To investigate the biology and behavior of C. piceae; (2) to identify the native predators attacking the balsam woolly aphid in the Pacific Northwest; and (3) to evaluate the importance of native predators controlling C. piceae. This report presents results of three years of investigation on these objectives.

Life history studies during the three years (1957, 1958, and 1959) showed that different C. piceae populations in the Pacific Northwest have two, three and four generations per year. High elevation areas have two generations, lowland valleys have four generations, and the intermediate elevations have three generations. Egg production was found to vary between females of the first and second generation. Average egg production in the first generation was 61 eggs per individual, while for the second generation the average was 52. It was also found that the chermids living on open-grown and stand-edge trees were more fecund than those insects living in the shade. Fecundity did not vary with the tree hosts.

Motile nymphs were found readily dispersed by air currents; recovery on glass plates varied directly with the distance from the exposed tree. Wind-borne nymphs were consistently collected 80 feet from the

nearest host tree.

C. piceae population losses between different periods in their life cycle was found to be variable. The largest losses were between the first generation adults and their first instar progeny. Calculations showed that the reduction from the expected population ranged from 95 to 97 percent. Population decline from second generation first instar nymphs to second generation adults varied from 2 to 27 percent. In 1959, inclement weather proved to be a significant factor in the reduction of overwintering aphid populations at high elevation areas.

The investigation of native predators affecting C. piceae in the Pacific Northwest revealed 14 insects and two mites as definitely being predaceous on the balsam woolly aphid. Ten of the insects were in the order Diptera, three were in Neuroptera, and one was in Coleoptera. The most important predators were four syrphids: Cnemodon rita Curran, Syrphus vitripennis Mg., S. opinator O. S., and Metasyrphus lapponicus Zett. One hemerobiid, Hemerobius neadelphus Gurney, was also moderately abundant. Descriptions of the immature stages, including drawings and photographs, were presented for most of the insects. Some life history and behavior information was also recorded. In addition to the known predators, nine other species of arthropods which may be predaceous on the balsam woolly aphid were collected.

Evaluation studies on the effectiveness of native predators in controlling the balsam woolly aphid were made at two areas in Oregon. The results showed that no significant predation was effected by the aggregate predator complex.

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