BIONOMICS OF *APHIDECTA OBLITERATA* (L.) (COLEOPTERA: COCCINELLIDAE), A PREDATOR INTRODUCED FOR CONTROL OF THE BALSAM WOOLLY APHID ON MT. MITCHELL, NORTH CAROLINA

by

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INTRODUCTION

The balsam woolly aphid, Adelges piceae (Ratzeburg) (Homoptera: Phylloxeridae), was introduced in North America around 1900 on nursery stock imported from Europe (Balch, 1952). The aphid was first identified in North America at Brunswick, Maine, in 1908 (Kotinsky, 1916). The aphid was not detected in the Southern Appalachians until 1956 when it was found near Skyland, Virginia (McCambridge and Kowal, 1957). Speers (1958) reported that the balsam woolly aphid was infesting Fraser fir, Abies fraseri (Pursh) Poir., at Mt. Mitchell State Park in October of 1957. Subsequent surveys showed that the aphid was distributed throughout most of the spruce-fir type in the Mt. Mitchell area and that extensive mortality of thousands of Fraser fir had occurred (Nagel, 1959). The aphid has killed over 2 million trees in this area since 1957 and has now spread throughout most of the Southern Appalachians. Fraser fir grows naturally only on high mountain peaks in the Southern Appalachians where it has a high scenic value. It is highly prized as a Christmas tree and is frequently planted for that purpose.

Insecticides have been used with fair success in controlling the aphid along the roads in the Mt. Mitchell State Park. Biological control studies, utilizing foreign and native predators, were started in 1959 to provide some degree of aphid control in inaccessible stands.

In 1960 and 1963, the introduced coccinellid predator, Aphidecta obliterata (L.), was released near Mt. Mitchell (Amman and Speers, 1964).

It was able to complete the summer generation and also survive winter conditions following both years. Amman and Speers reported that *A. obliterata* larvae, pupae, and adults were recovered on these release sites when they were examined in June 1964. The data obtained suggest that *A. obliterata* can (1) survive on light aphid populations, (2) be established by releasing relatively few adults, and (3) after one year in the field become as abundant as native insect predators in the vicinity of the release. After 4 years of survival, *A. obliterata* appears to be a permanent addition to the predator complex of the balsam woolly aphid in the Mt. Mitchell area (Amman, 1966a).

This study was undertaken to determine the life history and habits of *A. obliterata* in North Carolina and to determine its feeding habits.

LITERATURE REVIEW

Nomenclature

This species was first described by Linnaeus in 1758 as *Coccinella obliterata* and later was placed in the genus *Adalia* (Wylie, 1958b). In 1893, Weise placed it in the genus *Aphideita* and in 1899 placed it in the genus *Aphidecta* (Weise, 1899).

Distribution and Hosts

According to Wylie (1958b), *Aphidecta obliterata* (L.) occurs throughout Western Europe, including Southern Scandinavia and the British Isles. It is a predator of *Adelges piceae* (Ratzeburg) on silver fir, *Abies alba* Miller (Van Dinther, 1951; Delucchi, 1953; Wylie, 1958b; Pschorn-Walcher and Zwölfer, 1960). It is also a predator of *Adelges nusslini* Borner on silver fir (Schneider-Orelli, 1939; Wylie, 1958b; Pschorn-Walcher and Zwölfer, 1960). *A. obliterata* is also a predator of *Cinara pinicola* Walker on larch, *Larix* sp., and of *Adelges cooleyi* (Gillette) on Douglas fir, *Pseudotsuga menziesii* (Mirb.) Franco, and Sitka spruce, *Picea sitchensis* (Bong.) Carr. (Wylie, 1958b).

Canadian entomologists have imported *A. obliterata* since 1941 for release against the balsam woolly aphid (Brown and Clark, 1959). They reported 6 separate introductions of the predator into New Brunswick since 1941. It has been observed to complete a generation during the year of release, but overwintered progeny have not been recovered, apparently due to the adults' inability to survive the winter conditions of New Brunswick.

Pschorn-Walcher (1964) was surprised that A. obliterata had not been found in Canada following releases, since it had a much wider distribution and broader ecological range in Europe than either Laricobius erichsonii Rosenhauer (Coleoptera: Derodontidae) or Pullus impexus Mulsant (Coleoptera: Coccinellidae), both of which became established in Canada. A. obliterata adults overwintered in Europe mainly under bark scales of spruce and maple. He reported that it may have migrated from the release areas to suitable hibernation quarters and then changed over to other sites or even other hosts.

A. obliterata was released in Oregon and Washington during 1958 and 1959 (Dowden, 1962). It completed a generation during the year of release, but overwintered progeny have never been recovered (Wright and Mitchell, 1960).

Life History

Seasonal History

Delucchi (1953) and Wylie (1958b) both observed one generation of A. obliterata each year. Van Dinther (1951) mentioned the possibility of a second generation on some other species of aphids during the summer, but there was no direct evidence to support this assumption. Wylie (1958b) reported that adult females appeared on the infested trees in the Vosges Mountains of France in early April and began feeding on the developing aphids. He stated that oviposition began in mid-April, reached a peak early in May, and ended about mid-June. Larval activity started in late April and lasted to late June. Pupation began in early June and the adults began to emerge by mid-June. The adults dispersed from the infested fir trees in early July and were not observed on the trees infested with Adelges piceae until the following spring. Wylie (1958b) also stated that the behavior of the adults after they left the infested trees in July was not known. Nicholson (1912), Murray (1931), Buck (1955), and Varty (1956) observed A. obliterata in the fall on Adelges infested conifers in Great Britain. Murray (1931) observed large numbers of adults hibernating gregariously on Scotch pine, Pinus sylvestris L., in Scotland in the fall. Wilson (1938) has observed A. obliterata both on Adelges infested and noninfested conifers in the fall.

Duration of Immature Stages

Wylie (1958b) studied the duration of immature stages by isolating freshly laid eggs individually in 2-inch vials. He supplied the larvae with an abundant supply of aphid-infested twigs. The temperature in the room ranged from 15-19° C. The durations of each of the immature stages were: egg, 7-8 days; first instar larva, 4-5 days; second instar larva, 3-4 days; third instar larva, 3-4 days; fourth instar larva, 9-12 days; and pupa, 10-12 days. Total developmental time was 38-41 days. Wylie stated that his results would probably be modified somewhat in nature by wider temperature fluctuations and by low host population densities that would increase time spent by the beetle larvae searching for food.

Description of Stages

The eggs were oval, bright yellow to orange in color, and were laid singly or in linear groups of up to 10 in an upright position on the infested bark or needles (Wylie, 1958b). Smith (1958b) observed an average of 4 eggs per group, and stated that the distribution of eggs showed no direct relationship to the distribution of larvae and adults of *Adelges piceae*. Van Emden (1949) and Van Dinther (1951) have described the 4 larval instars. The last instar larva attached itself to the bark with an exudation from the anus about one day before pupation (Wylie, 1958b; Smith, 1958b). Pupal morphology was described by Van Dinther (1951). Weise (1892) and Portevin (1931) have published detailed descriptions of the adults.

Oviposition

Smith (1958b) reported that each female laid an average of 52 eggs while feeding on *Adelges piceae*, but that the oviposition period observed probably was shorter than usual because females were 3 weeks old when released in Canada. Wylie (1958b) reported that the number of eggs laid per female ranged from 153-293 and oviposition period from 40-53 days, but the adults were fed mainly on *Adelges cooleyi*.

Parasites

Two parasites attacked *A. obliterata* in Europe. They were *Phalacrotophora berolinensis* Schmitz (Diptera: Phoridae), a pupal parasite, and *Hexamermis* sp. (Nematoda: Mermithidae), a larval parasite (Delucchi, 1953; Wylie, 1958b).

Feeding Behavior

Feeding Studies

Smith (1958b) and Wylie (1958b) reported that larvae and adults of *A. obliterata* will feed on all stages of the balsam woolly aphid except the first instar. Smith reported that *A. obliterata* adults and large fourth instar larvae will attack the first instar crawler of *Adelges piceae*. Wylie stated that first and second instar larvae of *A. obliterata* pierced the egg chorion with their mandibles and drew out the contents, while leaving the empty shell on the bark. The third and fourth instars ingested the whole egg. The crawlers were completely consumed, while the adults and developing larvae were pierced and sucked, with the empty skin remaining on the bark.

Smith (1958b) observed, microscopically, 1-inch bark sections at intervals of 24 hours and the number of prey destroyed was estimated. This procedure was followed both in the field and in the laboratory. The first and second instar larvae consumed an average of 41 eggs and 10 adults and 77 eggs and 22 adults, respectively. The third and fourth instar larvae consumed an average of 222 eggs and 42 adults and 347 eggs and 82 adults, respectively.

Searching Ability

Smith (1958a) reported that *A. obliterata* distribution was at random at high prey densities, while the other foreign predators of the balsam woolly aphid either remained in one section as long as food remained or were found only in the higher density sections.

Pschorn-Walcher (1964) stated that A. obliterata had a remarkable ability to search out hosts even at very low density, especially those aphids in small colonies along the twigs and the buds. Smith (1958a) reported that air temperature appeared to exercise a greater influence on both the number of larvae in movement and the distance moved than either relative humidity or light intensity. Smith also stated that A. obliterata showed more movement and for greater distances than most of the other predators studied.

Cannibalism

Wylie (1958b) observed cannibalism in laboratory rearings. A. obliterata eggs were attacked occasionally by freshly hatched larvae, and mature inactive larvae were occasionally eaten by third or fourth instar larvae. The larvae did not feed for at least an hour after hatching. Wylie reported that most of the eggs were laid on the needles and that the searching for food by larvae was limited mainly to the bark. Most of the eggs in each mass hatched almost simultaneously. Because of the above factors, he stated that egg destruction in nature was probably negligible.

Smith (1958b) reported that egg mortality of A. obliterata was 68 per cent and most was caused by cannibalism. He reported that larval mortality was 19 per cent and some of this was also due to cannibalism.

Amman (1966b) observed cannibalism of eggs by newly emerged larvae of Mulsantina hudsonica (Casey), a native coccinellid predator of the balsam woolly aphid at Mt. Mitchell, North Carolina. Amman stated that cannibalism in M. hudsonica would be beneficial, because the larvae were in a much better condition to search for prey after feeding on the unhatched eggs.

Banks (1956) studied cannibalism in 3 species of coccinellids and reported that the amount of cannibalism was related to the number of eggs in a group and the greater variation in hatch time that occurred in the larger egg masses. Kaddou (1960) stated that cannibalism in the coccinellid, Hippodamia quinquesignata (Kirby), was beneficial because it aided in preserving the species during times of food shortage. However, he did not find any correlation between cannibalism and size of egg mass. Pienkowski (1965) reported that cannibalism was not advantageous in the coccinellid, Coleomegilla maculata lengi, because cannibalistic larvae were slower to disperse from egg mass and less active than noncannibalistic larvae. Thus, the chance of larvae finding prey was reduced.

Effectiveness of Predators

Delucchi (1953) stated that A. obliterata was not a valuable predator of the balsam woolly aphid. Smith (1958b) stated the value of predators in the control of the balsam woolly aphid was limited because few of their stages attacked the crawler or the sessile-first instar larva. Brown and Clark (1959) stated that the control value was not known for Eastern Canada, since the predator had not become established. They gave as an example of its potential control value the fact that in 1952, Adelges piceae was reduced 52-92 per cent on infested trees in which A. obliterata was released. A similar reduction did not occur on other infested trees adjacent to the trees on which the predator was released. Amman (1966a) mentioned that no attempts had been made to determine the effectiveness of free A. obliterata populations in the control of the balsam woolly aphid. He also found that the predator greatly reduced aphid populations under caged conditions in North Carolina field studies.

Franz (1958) stated that two mortality factors together, predators and exhaustion of bark, caused the termination of an outbreak of Adelges piceae in Europe after a few years of heavy infestation. Eichhorn (1965) reported that each tree showed its own patterns concerning the population dynamics of its aphid population. He reported that the predators modified the aphid population, but the most important regulating factor was the physiology of the tree, especially the condition of the parenchyma.

Many researchers have made attempts to evaluate the effectiveness of predators on the balsam woolly aphid. Clark and Brown (1958), Buffam (1962), and Mitchell (1962) made counts of aphids on protected and unprotected areas of bark and then compared the two to show the effect of predation. Franz (1958) photographed areas of the bark periodically and made comparisons. The above methods were not satisfactory because of one or more of the following reasons: (1) Insects under wax and bark scales cannot be seen, (2) the adverse effect of cages on aphid populations, (3) dead aphids cannot be differentiated from living ones, (4) accurate estimate of eggs and first instar nymphs cannot be made, and (5) the use of separate trees as controls which disregarded the effect of the tree. Pschorn-Walcher and Zwölfer (1958) removed samples of bark from the infested trees and counted all aphid forms. Their sample was too small to give an accurate estimate of population.

Amman (1966b) used a sampling technique of 16 one-half-inch diameter samples of bark from each tree to evaluate the effect of native predators on aphid populations on 10 trees. His sample gave population estimates within ±10 per cent of the mean 2 out of 3 times. He reported that native predators were of little benefit in regulating the aphid populations, because they fed on stages which were not important in determining trends in the aphid population.

METHODS AND RESULTS

Life History

Life Cycle In Laboratory

The life cycle of *A. obliterata* was studied in the laboratory. Freshly laid eggs were separated from the egg cluster and placed individually in 5x25-mm. glass vials. A Parafilm[1/] cover was placed on top of the vial to prevent the small larva from escaping when it hatched. Small pin holes were punched in the Parafilm cover to give added ventilation. The individual larva was transferred to a 2.8-square-cm. plastic box after hatching. It was supplied with fresh balsam woolly aphid eggs or adults and several drops of water daily. All larvae were observed daily and changes in size, color, and molts were recorded for 12 replications. The length of the larva was measured from the anterior margin of the head to the posterior of the abdomen. The width of the pronotum was also measured.

All life cycle laboratory studies were conducted at 15° C. and a relative humidity of 75 per cent, which were close to the averages for Mt. Mitchell, North Carolina, during the developmental time of *A. obliterata* in the field. The vials and boxes were placed over saturated sodium chloride (table salt) solution in closed desiccators to maintain 75 per cent relative humidity (Wexler and Hasegawa, 1954). The desiccators were kept in a cabinet which maintained a constant temperature of 15° ± 0.5° C.

[1/] Marathon, A Division of American Can Company, Menasha, Wisconsin.

Measurements of the stages of A. obliterata were made with a microscope which had a reticle graduated to equal units from 0.040-0.165 mm., depending upon the magnification used. The drawing of the fourth instar larva was made with a camera lucida. Photographs of the stages of A. obliterata were made with an Exakta camera attached to a photographic tube on a Wild microscope.

The eggs of A. obliterata hatched in an average of 7.6 days (range 6-9). The larvae which were fed on eggs or adults of the balsam woolly aphid completed the 4 larval stadia in the following average number of days: first stadium, 6.2 (range 5-8); second stadium, 5.3 (range 4-7); third stadium, 6.8 (range 5-8); and fourth stadium, 9.5 (range 9-10). The average prepupal period was 4.1 days (range 3-6) and the pupal period was 13.1 days (range 12-14). The difference in developmental time between the larvae that fed on eggs, as compared to the larvae that fed on adults of the balsam woolly aphid, was not statistically significant. The life cycle, from egg hatch to adult emergence, was completed in 45.8 days (range 43-48) (Table 1).

Measurements of specimens reared in the laboratory are given in Table 2. A brief description of each stage is as follows:

Egg. Average length 1.05 mm. (range 0.90-1.15), average width 0.48 mm. (range 0.41-0.57). Eggs were a shiny yellow when first laid, became yellowish orange as embryogenesis proceeded, and finally gray with 10 darker gray lines as embryo neared maturity (Fig. 1).

First instar larva. Average length 2.23 mm. (range 1.64-2.79), average width 0.59 mm. (range 0.45-0.74). Dark brown with spots on

Table 1. Life cycle of *Aphidecta obliterata* (L.) reared on the balsam woolly aphid at 15° C. and 75 per cent relative humidity

Stage	Duration in days				Number of observations
	Minimum	Maximum	Average	S.D.	
Egg	6	9	7.61	0.88	31
First Instar	5	8	6.17	1.06	12
Second Instar	4	7	5.31	0.95	13
Third Instar	5	8	6.83	0.98	12
Fourth Instar	9	10	9.50	0.52	12
Prepupa	3	6	4.08	1.08	12
Pupa	12	14	13.08	0.49	13
Life Cycle*	43	48	45.83	1.58	12

*Does not include egg stage.

Table 2. Measurements of *Aphidecta obliterata* (L.) reared on balsam woolly aphids at 15° C. and 75 per cent relative humidity

Stage		Size				Specimens measured*
		Minimum	Maximum	Average	S.D.	
		mm.				Number
Egg	Length	0.90	1.15	1.05	0.05	25
	Width	0.41	0.57	0.48	0.04	25
First Instar	Length	1.64	2.79	2.23	0.36	7
	Width	0.45	0.74	0.59	0.09	7
Second Instar	Length	2.17	4.02	3.17	0.46	11
	Width	0.66	0.94	0.80	0.32	11
Third Instar	Length	2.40	6.00	4.21	0.70	12
	Width	0.64	1.44	1.06	0.17	12
Fourth Instar	Length	4.40	7.60	6.14	0.75	12
	Width	1.12	2.08	1.56	0.22	12
Pupa	Length	3.08	3.90	3.45	0.23	12
	Width	1.52	2.48	2.07	0.26	12
Adult	Length	3.04	4.21	3.88	0.34	12
	Width	1.60	2.48	2.24	0.26	12

*In most cases each specimen was measured once each day in every stage.

Fig. 1. Aphidecta obliterata (L.) eggs (18X).

abdominal segments barely visible and a little darker than rest of body.

Second instar larva. Average length 3.17 mm. (range 2.17-4.02), average width 0.80 mm. (range 0.66-0.94). Head shiny and brownish yellow. Thorax grayish white. Abdomen gray with 6 white spots on each abdominal segment.

Third instar larva. Average length 4.21 mm. (range 2.40-6.00), average width 1.06 mm. (range 0.64-1.44). One characteristic yellow spot appeared on each lateral edge of first abdominal tergum within 24 hours after molting to third instar.

Fourth instar larva. Average length 6.14 mm. (range 4.40-7.60), average width 1.56 mm. (range 1.12-2.08). Gray with a yellow margin and yellow median dorsal line (Fig. 2).

Pupa. Average length 3.45 mm. (range 3.08-3.90), average width 2.07 mm. (range 1.52-2.48). Yellowish brown with white spots and dark orange markings (Fig. 3).

Adult. Average length anterior margin of head to posterior of elytra 3.88 mm. (range 3.04-4.21), average width of pronotum 2.24 mm. (range 1.60-2.48). Elytra light brown to dark brown. Most specimens had a black longitudinal mark near posterior end of elytra (Fig. 4).

Egg Hatch Study

The effect of different temperatures on the incubation period and hatching of *A. obliterata* eggs was determined in the laboratory. Temperatures between 5° and 25° C. were chosen, because this covered

Fig. 2. Drawing of fourth instar Aphidecta obliterata (L.).

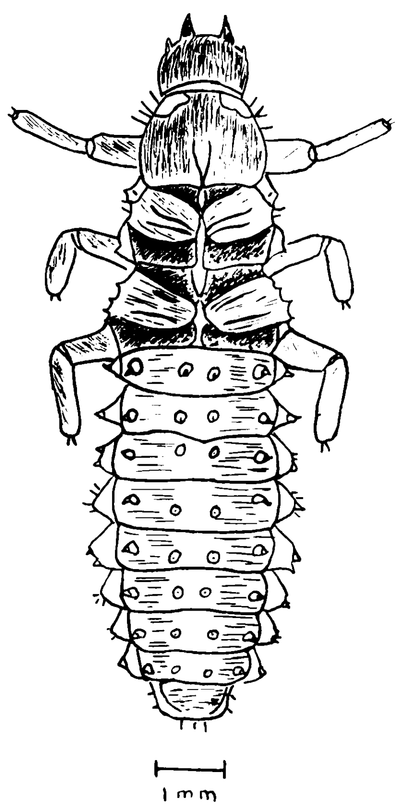

1 mm

Fig. 3. Aphidecta obliterata (L.) pupa (18X).

Fig. 4. Aphidecta obliterata (L.) adult (18X).

the entire range of temperatures that were encountered on Mt. Mitchell during April and May when oviposition of _A. obliterata_ adults occurred. Studies were conducted at the following temperatures: 5°, 7°, 10°, 13°, 15°, 17°, 21°, and 25° C. Temperatures and relative humidity were maintained by the same methods as described in the previous section.

Two methods were used in the laboratory to obtain eggs from _A. obliterata_ adults. In the first method, 7 round laboratory cages were placed in the insectary and 25 adults placed in each cage. A freshly cut Fraser fir bolt heavily infested with the balsam woolly aphid was placed in each cage and changed twice a week. The Fraser fir bolts were 12-18 inches in height and averaged 5 inches in diameter. Water was sprayed into the cage and honey placed on cotton balls daily. Freshly laid _A. obliterata_ eggs were collected daily from the bolts by using a dissecting scalpel.

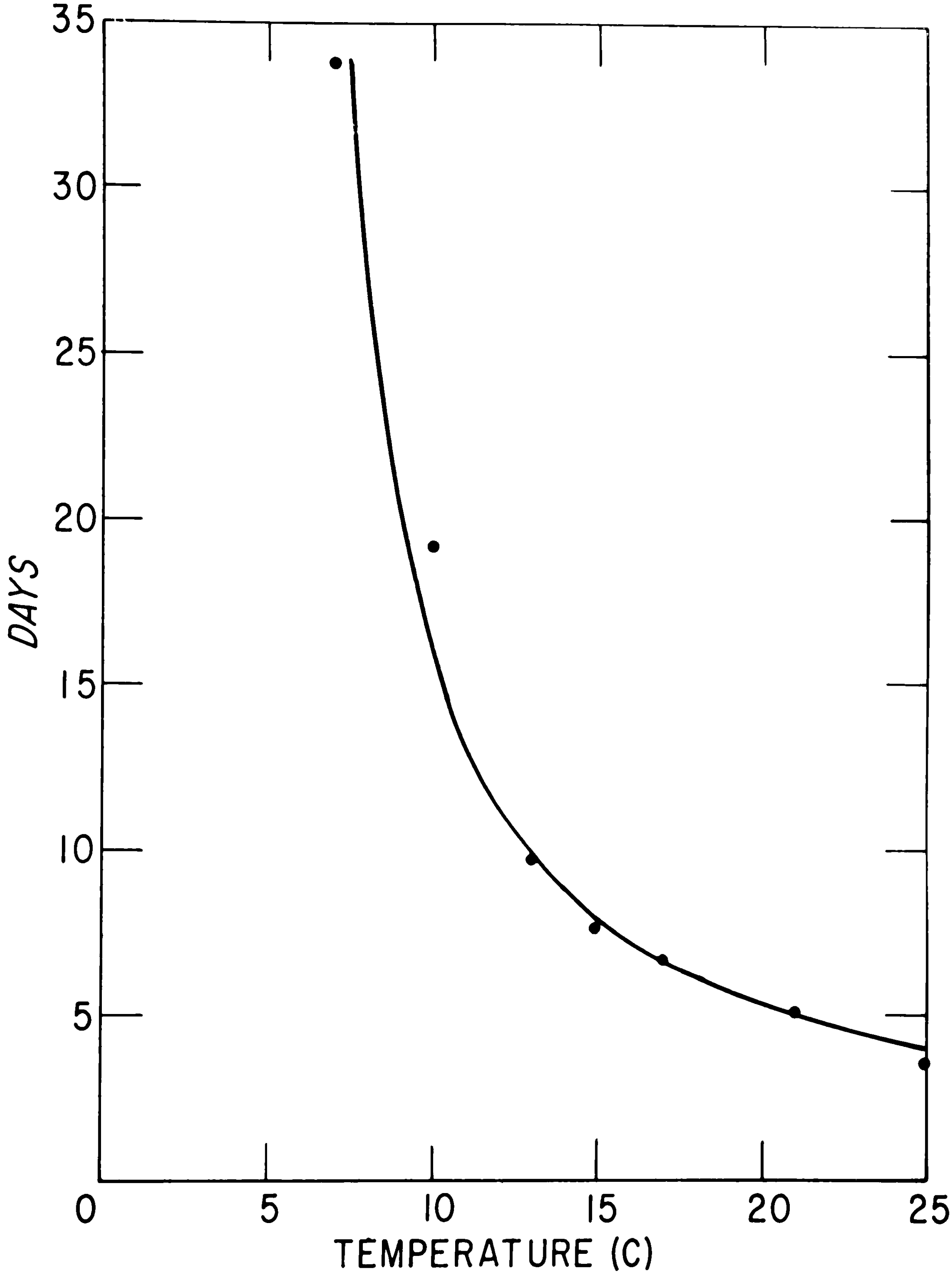
In the second method, 10 adults were placed in an 8-inch diameter pot containing a Fraser fir seedling. Fourteen replications were used. Two 7x2-inch pieces of infested fir bark were placed in the pot. A 1-gallon jar with the bottom removed was placed over the seedling, bark, and beetles. The bottom of the jar was removed by soaking a piece of 16-ply butcher's twine in a kerosene-oil mixture and then tying the string to the jar at the level where the break was desired. The string was then lighted and the jar was turned slowly to obtain an even burn around the entire jar. When this was reached, the bottom of the jar was placed in cold water to obtain a clean break. The bottom of the jar fitted solidly into the pot. A screen cloth was placed over the top of the jar and fastened into place by a rubber band. The bark was changed daily. The seedling, gallon jar, and the bark were checked daily for freshly laid eggs which were removed with a pair of forceps. Individual eggs were removed from the egg mass by using a No. 00 artist's brush. The eggs then were placed individually in glass vials and checked daily for hatch.

The incubation period of _A. obliterata_ eggs was studied in the laboratory to determine the effect of constant conditions of temperature and humidity on hatching. The incubation period varied from 3.61 days (range 3-5) at 25° C. to 33.83 days (range 24-42) at 7° C. (Table 3). Eggs failed to hatch at 5° C. and had a much reduced hatch at 7° C. This would place the developmental hatching threshold between 5° and 7° C. The developmental curve for _A. obliterata_ eggs at various temperatures and 75 per cent relative humidity is presented in Fig. 5. The highest per cent hatch, 90 per cent, occurred at 25° C., while the lowest, 68 per cent, occurred at 7° C. (Table 3). The per cent hatch was approximately identical for all temperatures between 10° and 25° C. except for the 15° C. hatch which was 69 per cent. This difference probably was due to the method used in choosing the eggs that were placed in the individual vials at the different temperatures. The eggs were separated from each egg cluster and placed in individual vials. In many cases, all of the eggs in one cluster were placed at

Table 3. Incubation period and per cent hatch of *Aphidecta obliterata* (L.) eggs at 75 per cent relative humidity and 8 constant temperatures

Temperature	Incubation period				Egg hatch	Observations
	Minimum	Maximum	Average	S.D.		
°C.	Days				Per cent	Number
5	--	--	--	--	0	25
7	24	42	33.83	4.96	68	44
10	17	20	19.27	1.03	88	25
13	8	14	9.76	1.68	83	35
15	6	9	7.61	0.88	69	45
17	6	7	6.77	0.43	88	25
21	4	8	5.10	0.72	87	24
25	3	5	3.61	0.62	90	31

Fig. 5. Developmental curve for eggs of _Aphidecta obliterata_ (L.) at various temperatures and 75 per cent relative humidity.


35
30
25
20
15
10
5
DAYS
0
5
10
15
20
25
TEMPERATURE (C)

the same temperature. If one cluster of 6 eggs contained mainly infertile eggs, this would have caused a decrease in per cent hatch as occurred at 15° C.

The eggs that did not hatch fell into four classes: (1) infertile eggs--stayed yellow; (2) eggs that developed but did not hatch--turned gray with 10 lines formed in embryo; (3) eggs that turned black; and (4) eggs that dried up. Ninety-eight per cent of the eggs that did not hatch fell into the first 2 classes. They occurred at an equal rate in the first 2 classes. Only 3 eggs turned black and this was at 7° C.; only 2 eggs dried up and this was after 4 days at 25° C.

The first method used to obtain eggs in the laboratory did not work well, because the adults laid eggs both on the screen of the cages and on the bark of the bolts. It was very difficult to remove the eggs from the screen without breaking a majority of them. The second method used to obtain eggs worked quite well because no eggs were laid on the screen, bark, or jar container. Ninety-nine per cent of the eggs were laid on the side of the fir needles. Most of these were laid on the bottom side of the needle. In the laboratory, the egg cluster size varied from 1 to 8 with an average of 2.10 eggs.

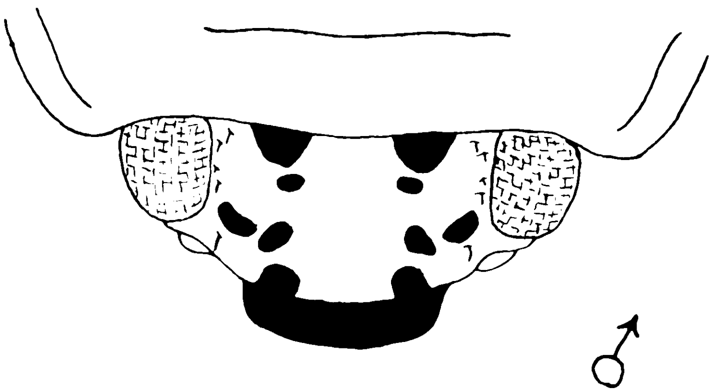
Sex Identification

One hundred adults were studied under the microscope for possible sex differences. The adults were classified as male or female by their head markings. Each adult was dissected after being classified to determine if it was identified correctly. The size of both adult males and females was measured to determine if there was a correlation between body size and the sex of the insect.

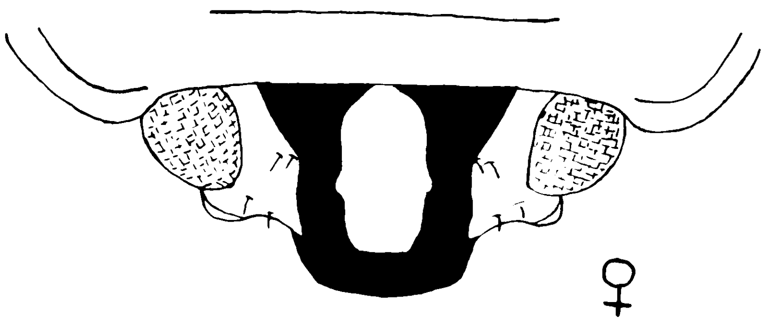
Ninety-three per cent of the adults were identified correctly to sex by using head marking differences only. The typical male had broken markings down the center of the dorsal view of the head and the markings were light brownish black (Fig. 6). The male markings were not always broken but were always lighter in color than the female markings. The typical female had a solid mark down the center of the dorsal view of the head (Fig. 6). The female marking was dark brownish black to black. The female mark was not always solid but was always darker in color than the male markings.

The length of the adult from the anterior margin of head to the posterior of elytra and the width of the pronotum were measured to determine if there was any correlation between body size and the sex of the insect. The average length of the male was 3.98 mm. with a range of 3.84-4.12 mm. The average length of the female was 4.25 mm. with a range of 4.13-4.37 mm. A distinct correlation between the length and the sex of the adult was found. The average width of the male was 2.52 mm. with a range of 2.35-2.69 mm. The average width of the female was 2.65 mm. with a range of 2.51-2.79 mm. There was a slight difference in the width of the adult of each sex but not enough to use it as an identification tool. One hundred per cent of the adults, 50 replications, was identified correctly to sex by using both the head marking characteristics and the length of the adult.

Fig. 6. Drawings of head of both sexes of Aphidecta obliterata (L.) adult.



50 X



50 X

1966 Aphidecta Releases

A pilot test to release 10,000 adult beetles was planned for 1966 (Amman, 1965). One thousand adult beetles were to be released at 10 sites in the Mt. Mitchell area. The releases of large numbers of A. obliterata adults were needed to evaluate their effectiveness in controlling the balsam woolly aphid under natural field conditions. Because of collection difficulties in Europe and sharing of beetles with the Canadian Forest Service, only 3,875 A. obliterata adults were shipped from the Commonwealth Institute of Biological Control to the Southeastern Forest Experiment Station (Table 4). The plans for the pilot test were changed from 10 to 3 release sites of 1,000 beetles each.

Shipments of A. obliterata adults from Austria were received by the Station on February 25 and March 14, 1966. The beetles were immediately placed in gallon jars containing peat moss and covered with nylon mesh. Small drops of honey were placed on the mesh and the jars stored at 41° F. The beetles were to be free released in the field near Mt. Mitchell in late March or April, depending on prey conditions.

During laboratory studies in early April, a parasite puparium was found. The adult emerged in 15 days and was later identified as Medina luctuosa Meig. (Diptera: Tachinidae). Several additional puparia were collected during this time. Communications were received notifying us of the discovery and identification of this same parasite by the Canadians (Kelleher, 1966a).

Table 4. *Aphidecta obliterata* (L.) adults received in 1966

Date received	Country of origin	Shipped	Dead upon arrival	Alive upon arrival
		- - - - - - - -	Number	- - - - - - - -
February 5	Austria	1,635	3	1,632
March 14	Austria	2,240	48	2,192
Total		3,875	51	3,824

In the first method, adult beetles were X-rayed to determine if they were parasitized. One hundred active adults were taken out of 41° F. storage and X-rayed on April 28. The use of X-ray to detect predators which were parasitized was found to be possible. This was confirmed by dissections. An error of commission showed up in the first X-ray. On the X-ray film, 20 of the 100 adults appeared to be parasitized. Eleven of the 20 adults that appeared to be parasitized were parasitized. None of the remaining 80 adults was parasitized. We thought that we might increase our interpretation accuracy by holding the adults at room temperature for a week. This gave the parasite a chance to develop to a larger size. However, once the adult had fed, the full gut could not be differentiated from the parasite by our X-ray technique.

In the second method, adults were held in the laboratory under special conditions for 3 weeks so that *M. luctuosa* would emerge from the adult beetle before the beetles were released in the field. *A. obliterata* adults were placed in pint cartons with screen tops and bottoms. A hole was punched in the side of the carton and a piece of cotton soaked in honey was inserted for food. The carton was placed on filter paper and a gallon jar inverted over it. A pint jar of demineralized water was inverted onto another piece of filter paper in contact with the one under the carton. The beetles were held at 68° F. and high humidity for 3 weeks.

In preparation for field release of the predators, 25 adult beetles were dissected after 2 weeks. One parasite was found. All of the beetles were held a third week as a precautionary measure, because parasites were still present after 2 weeks in a few of the beetles. Ten per cent of all living beetles was dissected for parasites after the third week. No parasites were found in the beetles dissected after 3 weeks. All living beetles were then free released in the field.

M. luctuosa prepupa was transparent and yellowish white in color when it emerged from the parasitized *A. obliterata* adult. The gut was dark brown. The length and width of the prepupa were 3.6 and 1.2 mm., respectively. The prepupa was very active and most of its movements were back and forth. Within 24 hours, the prepupa formed a puparium.

The puparium and pupa of *M. luctuosa* were also transparent and light brown with a darkened spot near the end of the pupa. Average length and width of the pupa were 2.90 mm. (range 2.55-3.75) and 1.44 mm. (range 1.39-1.56), respectively. The pupal period was 18.07 days (range 14-21) at 15° C. and 75 per cent relative humidity.

Dr. L. P. Mesnil, a leading European tachinid specialist (Kelleher, 1966b), reported that the attack of *M. luctuosa* on *A. obliterata* was more or less accidental. He also stated that there were some records of Coccinellids as hosts of *Medina* but mainly phytophagous Coccinellids such as *Subcoccinella*. *M. luctuosa* like other *Medina* usually lived on Chrysomelids.

Forty-three per cent of the 3,824 A. obliterata adults that arrived alive was released in the field (Table 5). Two hundred were used for laboratory work and 100 X-rayed and dissected. One hundred and fifteen were dissected for parasites to determine if the adults could be released in the field. Forty-six per cent of the adults died in the laboratory while we were eliminating the parasite. Our records showed 1.6 per cent parasitism from M. luctuosa of all A. obliterata adults that were alive upon arrival at the Station.

From the first dissections made on May 3, 1966, before any death of adults occurred, A. obliterata females comprised 61 per cent of the shipment. The number of females in the entire shipment, based upon the total number of adults alive upon arrival, was 61 per cent of 3,824 or 2,333. The sex ratio after adult beetles were held for 2-3 weeks was 84 per cent female (Table 6).

The majority of the adults that died during the 3-week holding period at room temperature and high humidity was males. Observations showed that A. obliterata adults mate soon after emerging from the pupa in early July. The adults overwintered in crevices of the bark, and the females began laying eggs after feeding on the aphid in early spring.

Observations showed that 84 per cent of the beetles released in the field was females. Thus, the total actual loss of ovipositing adults was only 40 per cent (Appendix).

Table 5. Disposition of Aphidecta obliterata (L.) adults

Disposition	Number	Per cent
Released in field	1,642	43
Used for laboratory studies	200	5
X-rayed for parasites and dissected	100	3
Dissected	115	3
Adults that died while getting rid of parasite	1,767	46
Total number adults alive upon arrival	3,824	100

Table 6. Per cent parasitism and sex ratio of

Aphidecta obliterata (L.) adults

Removed from storage (41° F.)	Dissection made	Dissected	Parasitism	Sex ratio	
				Female	Male
Date		Number	Per cent		
April 27	May 3	99	11	61*	39
April 28	May 16	25	0	80**	20
May 3	May 19	25	4	80**	20
May 3	May 23	20	0	90**	10
May 6	May 23	20	0	85**	15
May 9	May 27	20	0	90**	10
May 11	May 27	5	0	80**	20
Total				84**	16

*Sex ratio upon arrival of beetles.

**Sex ratio following laboratory conditioning period.

All remaining living beetles were taken into the field in pint cartons and free released near Mt. Mitchell. The beetles were removed from the carton with a No. 5 artist's brush and placed on the boles of Fraser fir trees that were medium to heavily infested with the balsam woolly aphid. Observations were made on the movements of the adults as they were released and on their life cycle in the field. The total length of the boles of the release trees was checked twice a week by using a Swedish ladder and safety belt. The surrounding trees were checked in the same manner during late summer and early fall to determine the ecology and longevity of the adults.

Seven hundred and fifty A. obliterata adults were free released on Commissary Ridge near Mt. Mitchell, North Carolina, on May 16, 1966, and 209 additional beetles were released at the same location on May 27, 1966 (Table 7). These beetles were liberated on 3 Fraser fir trees that were medium to heavily infested with the balsam woolly aphid. When the beetles were released on May 16, the temperature was 49° F. and the relative humidity 59 per cent. The weather was cloudy and calm. No flying was observed when the beetles were released. The majority of the beetles randomly searched the bark around the spot on the tree where they were released. Six adults were observed as they traveled 5-6 feet up the tree in 15 minutes.

Six hundred and eighty-three adults were released near Clingman's Peak, North Carolina, on May 23, 1966. The 3 release trees were heavily infested with the balsam woolly aphid.

Table 7. *Aphidecta obliterata* (L.) adults released in Mt. Mitchell area during 1966

Date	Released in field	Location
	Number	
May 16	750	Commissary Ridge
May 23	683	Clingman's Peak
May 27	209	Commissary Ridge
Total	1,642	

Field observations were made from the time the adults were released until the first of October. Eggs were observed in the field from June 2-June 13, 1966. Groups of eggs laid on the Fraser fir needles varied from 7-12, and 12 groups averaged 8.0 eggs. All eggs were found between 16 and 30 feet from the ground. Most of the eggs were laid on the bottom sides and at the tips of the needles. The majority of the egg clusters were found on needles within 2 feet of the bole. Eighty-five per cent of the field collected eggs hatched. The adults were observed feeding and resting mainly in the upper portion of the bole, branches, and the needles of the tree, but a few were observed on the lower part of the bole. For example, on June 3, 28 _A. obliterata_ adults were observed on the upper portions of 1 release tree, while 4 were found on the lower portions of the release tree. The foreign predator had cleaned over 95 per cent of all aphids from the release trees by July 1. Larvae were present from June 15 to late July. On July 11, 2 third instar larvae and 1 fourth instar larva were found on one of the release trees. Both _A. obliterata_ larvae and adults were found on surrounding trees infested with the aphid on July 11. One _A. obliterata_ adult was collected on August 18 from a tanglefoot trap placed in the release area. No adults were observed after this time.

Amman (1966a) reported that oviposition of _A. obliterata_ eggs was observed on April 29, 1960, following the April 21, 1960, release. Larvae were present by May 20 and eggs were found until May 31. All larval instars were present by June 7, and many pupae were found on June 21. Only new adults and a few pupae were found on July 1, and by late July all stages had disappeared.

The life cycle of *A. obliterata* was correlated extremely well with the spring generation of *Adelges piceae*. The overwintering adults fed on the aphid in early spring and this promoted oviposition. The seasonal history of the aphid varies each year, depending on weather conditions. *A. obliterata* adults were released in the field a little later than usual in 1966 because of the parasite recovery, but this was not a problem because the aphid also was delayed in developing due to a late spring. Thus, the seasonal history of *A. obliterata* will vary each year, but the information obtained in 1960 and 1966 is of value in making plans for evaluation of the effectiveness of the predator.

Feeding Behavior

Laboratory Feeding Studies

A feeding study was conducted in the laboratory with 12 replications. The method of rearing *A. obliterata* was the same as described for the life cycle study. The only difference was that the number of aphids supplied to the predator was tallied daily. After each 24-hour period, the aphids remaining were counted. The predator was removed with a No. 00 artist's brush at this time and placed in another box containing aphids. This was repeated daily throughout the entire life cycle of the beetle.

While looking through a microscope, eggs and adults of Adelges piceae were removed from the bark with a dissecting needle and placed in a plastic box. Two Forestry Aids developed a rapid method of obtaining eggs by holding the bark over 6-8 thicknesses of nylon mesh which were stretched tightly over the top of a glass funnel (Gentry and Wilson, 1966). The infested bark was brushed lightly with a No. 5 artist's brush. Eggs were collected in a plastic box as they passed through the mesh, while adult aphids, wax, and large particles of bark remained on the mesh. Both methods were used to obtain eggs during this study.

Larvae and adults of A. obliterata which were fed eggs or adults of Adelges piceae in the laboratory consumed the following average number of eggs per day: first instar, 20.8; second instar, 37.0; third instar, 56.2; and fourth instar, 115.3 (Tables 8, 9, 10, and 11). They consumed the following average number of adults per day: second instar, 17.4; third instar, 20.4; and fourth instar, 43.2 (Tables 12, 13, and 14). A. obliterata adults consumed an average of 34.9 eggs and 11.8 adults daily (Table 15).

The large standard deviations indicated considerable variations in daily consumption of aphids. However, much of this variation was attributable to the small number of aphids that was consumed when the larvae were about to molt. The number of eggs consumed daily varied only slightly for the following number of days: first instar, 4; second instar, 3; third instar, 5; and fourth instar, 6.5.

Table 8. Number of balsam woolly aphid eggs consumed by first instar *Aphidecta obliterata* (L.) in the laboratory at 15° C. and 75 per cent relative humidity

Duration	Average number eggs offered per day	Number eggs consumed per day			S.D.
		Minimum	Maximum	Average	
Days					
7	39.9	0	42	19.1	
5	48.6	20	49	32.4	
6	48.8	7	40	21.2	
7	50.4	12	47	26.6	
6	57.7	3	54	23.5	
5	48.8	13	48	28.0	
4	36.8	15	38	24.5	
7	26.3	0	28	11.3	
6	38.2	12	42	23.2	
7	43.7	1	50	17.0	
7	46.3	4	34	16.3	
8	38.8	2	38	14.9	
Total	43.4	0	54	20.8	14.4

Table 9. Number of balsam woolly aphid eggs consumed by second instar *Aphidecta obliterata* (L.) in the laboratory at 15° C. and 75 per cent relative humidity

Duration	Average number eggs offered per day	Number eggs consumed per day			S.D.
		Minimum	Maximum	Average	
Days					
5	61.4	7	70	38.6	
4	66.2	30	74	52.5	
4	66.8	17	71	46.8	
6	52.0	5	65	32.0	
7	38.3	2	58	19.3	
5	54.0	8	70	36.4	
5	53.6	17	58	33.4	
5	81.4	13	72	50.2	
Total	57.7	2	74	37.0	23.1

Table 10. Number of balsam woolly aphid eggs consumed by third instar Aphidecta obliterata (L.) in the laboratory at 15° C. and 75 per cent relative humidity

Duration	Average number eggs offered per day	Number eggs consumed per day			S.D.
		Minimum	Maximum	Average	
Days					
8	95.6	21	97	60.2	
7	96.1	0	100	58.4	
7	90.9	0	92	49.7	
7	99.6	8	95	57.6	
8	93.2	0	99	56.4	
8	67.0	0	85	48.4	
8	95.0	0	81	51.6	
6	124.8	0	130	70.2	
Total	94.3	0	130	56.2	32.0

Table 11. Number of balsam woolly aphid eggs consumed by fourth instar <u>Aphidecta obliterata</u> (L.) in the laboratory at 15° C. and 75 per cent relative humidity

Duration	Average number eggs offered per day	Number eggs consumed per day			S.D.
		Minimum	Maximum	Average	
Days					
8	202.8	19	218	123.6	
11	218.5	6	288	152.2	
11	204.5	15	259	130.8	
9	192.0	15	164	111.3	
12	160.8	5	175	93.7	
8	275.2	8	299	138.4	
9	186.2	13	160	96.3	
10	142.0	2	179	78.8	
Total	195.3	2	299	115.3	75.1

Table 12. Number of balsam woolly aphid adults consumed by second instar *Aphidecta obliterata* (L.) in the laboratory at 15° C. and 75 per cent relative humidity

Duration	Average number adults offered per day	Number adults consumed per day			S.D.
		Minimum	Maximum	Average	
Days					
4	32.2	15	31	21.2	
6	34.5	13	28	21.7	
7	23.4	4	18	12.0	
5	26.2	9	23	16.8	
Total	28.7	4	18	17.4	6.4

Table 13. Number of balsam woolly aphid adults consumed by third instar *Aphidecta obliterata* (L.) in the laboratory at 15° C. and 75 per cent relative humidity

Duration	Average number adults offered per day	Number adults consumed per day			S.D.
		Minimum	Maximum	Average	
Days					
5	37.4	8	38	25.2	
6	32.8	17	37	26.5	
6	25.7	0	26	13.3	
6	25.8	9	23	17.5	
Total	30.1	0	38	20.4	10.6

Table 14. Number of balsam woolly aphid adults consumed by fourth instar *Aphidecta obliterata* (L.) in the laboratory at 15° C. and 75 per cent relative humidity

Duration	Average number adults offered per day	Number adults consumed per day			S.D.
		Minimum	Maximum	Average	
Days					
10	50.9	4	69	41.5	
10	54.1	23	58	41.9	
10	55.1	11	69	43.1	
10	58.7	15	79	46.4	
Total	54.7	4	79	43.2	19.4

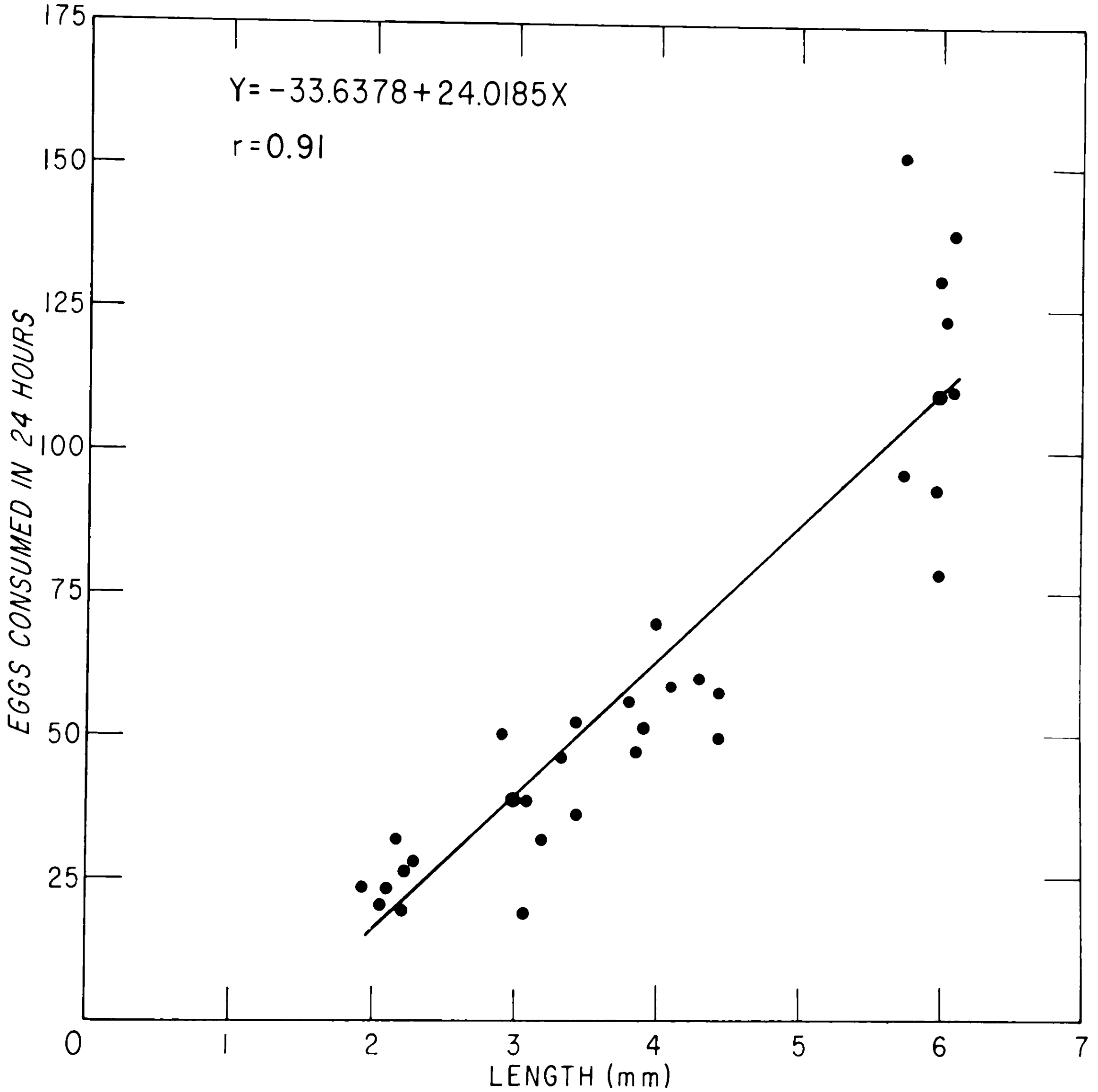
Table 15. Number of balsam woolly aphids consumed by adult *Aphidecta obliterata* (L.) in the laboratory at 15° C. and 75 per cent relative humidity

Duration	Average number aphids offered per day		Number aphids consumed per day						S.D.	
			Minimum		Maximum		Average			
Days	Eggs	Adults	Eggs	Adults	Eggs	Adults	Eggs	Adults	Eggs	Adults
5	89.2	34.2	21	18	47	30	35.8	22.2		
4	144.2	33.8	11	9	104	22	48.5	16.2		
5	124.2	32.6	15	8	50	23	33.8	14.8		
5	112.2	31.2	22	6	38	26	29.2	13.6		
5	104.4	23.4	0	5	36	14	28.0	7.2		
5	109.0	24.2	29	11	55	16	42.2	12.6		
Total	112.8	29.8	0	5	104	30	34.9	11.8	18.3	8.2

A straight line relationship with a correlation coefficient of 0.91 existed between larval length and the number of eggs consumed in 24 hours (Fig. 7). The fourth instar larva consumed more eggs than the other 3 instars combined (Fig. 8). The average number of eggs consumed during A. obliterata development was 1,853 with a range from 1,579-2,456. At an aphid density of 96 eggs and 8 adults per square inch, the mean number in a field plot in early June 1964 (Amman, 1966b), one A. obliterata during the larval period could eliminate the aphid from 19 square inches of bark surface.

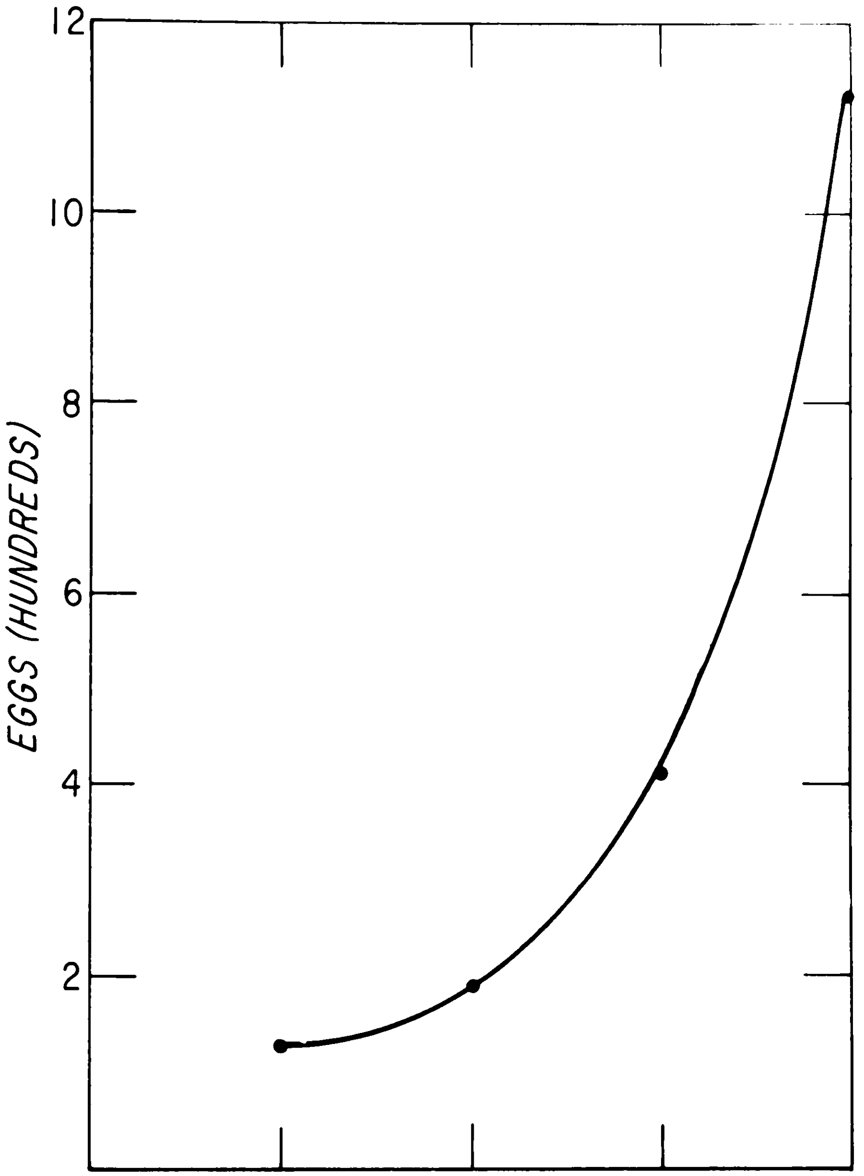
The first instar larva took 9 minutes to pierce the egg chorion with its mandibles and draw out the contents. The second instar larva had the same feeding habits as the first instar larva but only took 3 minutes. The third instar larva consumed the entire egg in 30 seconds, while the fourth instar larva consumed 5 eggs in 20 seconds when feeding. The adult aphids were pierced and sucked by the first and second instar larvae, with the empty skin remaining on the bark. The third and fourth instar larvae usually consumed the entire adult. The larvae were sometimes observed feeding on their own cast skin within 24 hours after molting. A second instar larva completely consumed its cast skin, but this was not a common occurrence. Cannibalism was observed in the laboratory studies. Eggs were attacked by freshly hatched larvae, and larvae were eaten by other larvae. A. obliterata adults consumed both eggs and adults of Adelges piceae. The adults also fed on cabbage aphids, Brevicoryne brassicae (L.), in the laboratory.

Fig. 7. Relationship between larval length of Aphidecta obliterata (L.) and number of eggs of Adelges piceae (Ratz.) consumed in 24 hours.



Y= −33.6378 + 24.0185X
r = 0.91
EGGS CONSUMED IN 24 HOURS
175
150
125
100
75
50
25
0
1
2
3
4
5
6
7
LENGTH (mm)

Fig. 8. Relationship between larval instar of *Aphidecta obliterata* (L.) and average number of eggs of *Adelges piceae* (Ratz.) consumed.


12
10
8
6
4
2
0
EGGS (HUNDREDS)
1
2
3
4
LARVAL INSTAR

Artificial Diets For Adult Beetles

The fecundity and longevity of *A. obliterata* adults as affected by synthetic foods were studied in connection with the egg hatch study. Synthetic foods that would increase or promote egg production were needed. Five synthetic foods were studied against the control. The control was a 0.5x4-inch piece of Fraser fir bark infested with the balsam woolly aphid. All adults used in this study were taken out of storage and fed on honey for 10 days. They were then placed in individual 1x4.5-inch plastic tubes with a plastic cap on each end. A hole with an inside diameter of 0.5 inch was punched into each tube. The synthetic food was placed on a cotton ball and inserted into the hole. Each plastic tube contained a Fraser fir twig. The diets and fir twigs were changed daily. Ten replications were run on each of the 6 diets for 2 weeks. Each plastic tube and fir twig was checked daily for *A. obliterata* eggs.

Diet one was 100 per cent clover honey. The second diet consisted of 90 per cent clover honey and 10 per cent yeast. The third diet contained 40 per cent casein, 10 per cent yeast, and 50 per cent sucrose (Smith, 1965). The fourth diet contained 4 g. enzymatic protein hydrolysate of yeast, 10 mg. choline chloride, and 7 g. of levulose in 10 ml. distilled water (Hagen and Tassan, 1965). The fifth diet consisted of 90 per cent bananas (baby food),[2/] 9 per cent

---

[2/] Bananas, sugar, tapioca starch, orange juice, salt, vitamin C, and citric acid. Gerber Products Company, Fremont, Michigan.

casein, 0.9 per cent wheat germ oil, and 0.1 per cent B vitamins. The B vitamins contained 20 mg. niacinamide, 10 mg. D-calcium pantothenate, 6 mg. thiamin hydrochoride, 4.8 mg. riboflavin, 4.8 mg. pyridoxine hydrochoride, 0.4 mg. folic acid, 0.08 mg. D-biotin, 0.008 mg. vitamin B12 added for each 10 g. of diet, and 4 mg. abscorbic acid. This diet was very similar to the one Smith (1965) tested on Coleomegilla maculata.

The adults fed on all of the diets, but none of the 5 synthetic foods would trigger oviposition. Hagen (1962) reported that synthetic diets composed of carbohydrate solutions, plus a mixture of "required" B vitamins, plus a standard nutritional salt mixture were not conducive to fat synthesis in Hippodamia convergens but greatly increased longevity over nonfed beetles. Adding protein to the diet permitted fat to be produced and stored in newly emerged Hippodamia spp. It would not induce ovigenesis in newly emerged beetles. However, the diet would induce ovigenesis in H. convergens that overwintered, and adding cholesterol and choline chloride improved fecundity. Adults did lay eggs when fed on the control diet, so this would rule out the conditions that the experiment was run under as a limiting factor in oviposition. From this study, these 5 synthetic diets would not induce oviposition and it is unlikely that A. obliterata adults will lay eggs before feeding on their natural host in early spring.

Predator-Prey Study

The effects of predator and prey densities on interactions between *A. obliterata* and *Adelges piceae* were studied in the laboratory. Predator densities of 1, 2, 3, 4, and 5 larvae per 4.5-square-cm. plastic box were used. Prey densities of 50, 100, 150, and 250 *Adelges piceae* eggs were used per individual per day with the first, second, third, and fourth instar larvae, respectively. The methods used in obtaining aphid eggs and in counting the eggs were the same as those described in the laboratory feeding studies.

Table 16 shows the per capita consumption per day and total consumption per day for each predator density and each instar. The per capita consumption per day for the first instar at predator densities of 1 to 5 were as follows: 20.8, 18.7, 17.5, 15.5, and 13.7, respectively (Table 16). The per capita consumption per day for the second instar at predator densities of 1, 2, 3, and 5 were as follows: 38.6, 33.3, 30.8, and 34.3, respectively. The per capita consumption per day for the third and fourth instars at predator densities of 1 and 2 were 56.2, 62.1, and 115.3, 109.5, respectively.

Chant and Turnbull (1966) reported that 4 factors affected the number of prey captured in their study on the interactions between goldfish and *Daphnia pulex*: (1) the number of prey required to satiate the predator; (2) the effect on the efficiency of prey discovery of decreasing prey density as the prey were removed by predation; (3) the number of prey available to each predator; and (4) the effect of 1 predator on the activities of another when more than 1 was present.

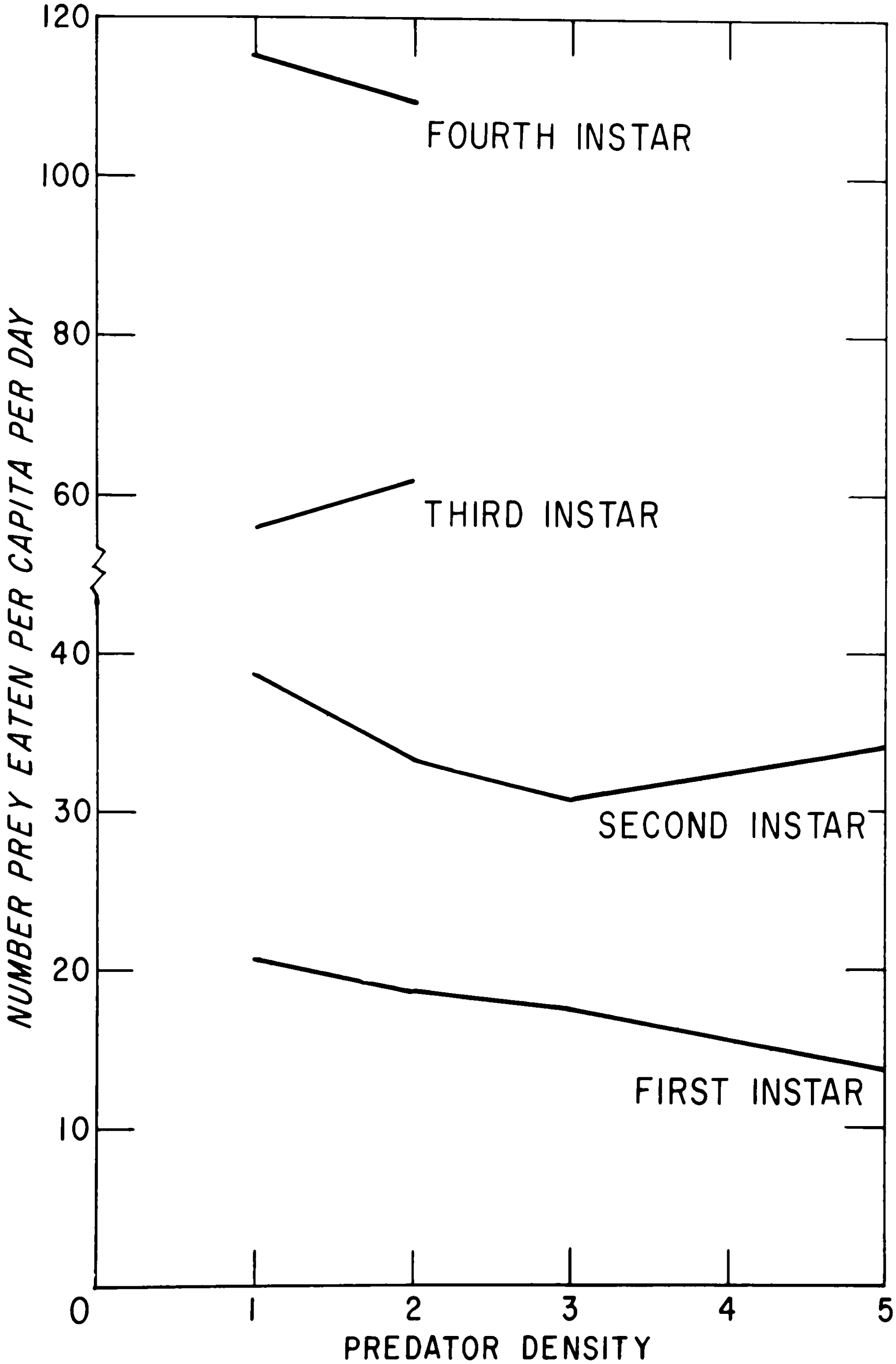
Table 16. Number of balsam woolly aphid eggs consumed by each instar of *Aphidecta obliterata* (L.) in the laboratory at different predator densities

Predator density	Instar							
	First		Second		Third		Fourth	
	Per capita consump-tion per day	Total consump-tion per day	Per capita consump-tion per day	Total consump-tion per day	Per capita consump-tion per day	Total consump-tion per day	Per capita consump-tion per day	Total consump-tion per day
1	20.8	20.8	38.6	38.6	56.2	56.2	115.3	115.3
2	18.7	37.4	33.3	66.6	62.1	124.1	109.5	219.0
3	17.5	52.5	30.8	92.3	--	--	--	--
4	15.5	61.9	--	--	--	--	--	--
5	13.7	68.6	34.3	171.3	--	--	--	--

Factors 1 and 4 applied to the interactions between A. obliterata and Adelges piceae. Factors 2 and 3 did not apply, because the prey density used for each instar was more than the predator needed to be satiated. In the first instar, the number of eggs eaten per capita per day decreased with an increase in predator density (Fig. 9). In the second instar, the number of eggs consumed per capita per day decreased with predator densities of 1, 2, and 3 but showed a slight increase with a predator density of 5 larvae. This increase was caused entirely by the larvae molting at different times, thus, not leaving a "lull period" of feeding during the time that the fastest growing larva was in the second instar. A breaking point for the number of prey eaten per capita per day for each instar had to be chosen. Where this occurred, the group was elevated to the next instar when the first larva in the group molted. A slight increase in the number of prey consumed at a predator density of 2 over 1 larva was noted in the third instar. This increase again was caused by the larvae molting at different times. There was a decrease in the number of eggs consumed per capita per day with predator densities of 1 and 2 in the fourth instar. Predator densities greater than 2 did not occur in this study in the third and fourth instars because of cannibalism.

Cannibalism occurred quite often in this study at about the same time in each replication. With 2 predators in the confined space of a 4.5-square-cm. plastic box with plenty of eggs, cannibalism occurred

Fig. 9. Relationship between number of <u>Adelges piceae</u> (Ratz.) eggs consumed per capita by <u>Aphidecta obliterata</u> (L.) and predator density for each instar.


NUMBER PREY EATEN PER CAPITA PER DAY
120
100
80
60
40
30
20
10
0
FOURTH INSTAR
THIRD INSTAR
SECOND INSTAR
FIRST INSTAR
1
2
3
4
5
PREDATOR DENSITY

immediately after the first of the 2 larvae molted to the third instar. In both replications, both larvae molted to the second instar on the same day. The first larva to molt to the third instar would kill the other by sucking the liquid out of it. In one case, it ate the dead larva by the second day after molting. With 3 predators to a box, 1 larva was killed while in the first instar and the other was killed while either in the second or third instar. With 4 predators to a box, 1 was killed in the first instar by a first instar larva and the other 2 were killed in the second instar by a third instar larva. In one replication with 5 predators to a box, only 2 larvae were left after the second instar and they survived to adults. In the second replication at a predator density of 5, all 5 larvae made it to the second instar, but only 3 were able to molt to the third instar. One of the third instar larvae was eaten by another third instar larva. Again, only 2 larvae were able to complete their life cycle.

Within the limits of the study, the per capita consumption of prey was reduced by increasing predator density. It was not due, however, to prey density but probably caused by crowding or interference.

DISCUSSION

Control Possibilities For The Balsam Woolly Aphid, Stressing The Use of Aphidecta Obliterata

The complete destruction of the only Fraser fir stands that exist by the balsam woolly aphid is entirely possible within the next 20-30 years. Fraser fir is important as a Christmas tree species. The Fraser fir stands in the Southern Appalachians are important from the recreational, aesthetic, and watershed sides of the multiple use program of our forests and as a seed source for Christmas trees. Chemical control, biological control, and silvicultural control have been tried against the balsam woolly aphid in the Appalachians.

Chemical control involving the spraying of contact insecticides is impractical under most forest conditions (Amman and Speers, 1965). However, special conditions exist in certain areas of the Southeast which make it possible to protect certain trees. This is possible because Fraser fir is isolated, is only moderately tall, and is high in aesthetic value. Three hundred acres of Fraser fir have been sprayed at Mt. Mitchell, North Carolina. Some areas were sprayed with 1/8 per cent benzene hexachloride; others were sprayed with lime sulfur. This was economically feasible because of the high aesthetic value and because the area was accessible. The areas must be resprayed every 4-5 years for control to be effective.

Silvicultural control, by cutting all Fraser fir trees around spot infestations, to prevent the spread of the aphid has been tried without much success. This may slow down the spread but is ineffective as a control agent, because it is virtually impossible to discover all the infested trees in a new area. Infestations in the upper portions of individual trees cannot be detected without question, unless each tree is climbed and the top checked individually. Because this is economically impossible, some infested trees are missed and the area cut does not include these trees.

The third method of control being employed against the balsam woolly aphid is biological control. The greatest chance for success along this line is to establish predators with high searching ability and predators that are capable of attacking the dormant larva and egg under conditions of light to moderate infestation. The Southern Appalachians offer an excellent situation for the use of predators, since the effort of predators is concentrated in a relatively small area.

Work on using foreign predators to aid in control of the balsam woolly aphid was started in North Carolina in 1959 by the Southeastern Forest Experiment Station (Amman and Speers, 1965). Twenty-two species of predators have been studied and released since that date. Four species have overwintered successfully and appear to be able to establish themselves in the Mt. Mitchell area. They are as follows: (1) *Laricobius erichsonii* (Coleoptera: Derodontidae), (2) *Aphidecta obliterata* (Coleoptera: Coccinellidae), (3) *Pullus impexus* (Coleoptera: Coccinellidae), and (4) *Aphidoletes thompsoni* (Diptera: Cecidomyiidae) (Amman and Speers, 1965). *L. erichsonii* and *A. obliterata* are the 2 most promising predators released so far. The purpose of the Station's releases of foreign predators is to establish the same predator complex of the balsam woolly aphid that is present in Europe, which is the native habitat of Adelges piceae.

The preceding discussion was presented so that the real purpose behind my research on the life history and feeding habits of A. obliterata in North Carolina would be understood. The information on the life history and feeding habits of A. obliterata and other foreign predators established in North Carolina will be used by the Station in setting up the sampling study that will be conducted in 1967 and 1968. The objective of this study will be to determine the effectiveness of the foreign predators released in the Mt. Mitchell area.

The chief attributes of A. obliterata are: individual prey consumption rate, searching ability, synchronization of life cycle with spring generation of Adelges piceae, and adaptation to environmental conditions in the Mt. Mitchell area.

The feeding experiments in the laboratory study indicated that one A. obliterata during the larval period could eliminate the aphid from 19 square inches of bark surface at an aphid density of 96 eggs and 8 adults per square inch. The released adults and the larvae they produced were able to remove over 95 per cent of the aphids from the release trees in 1966. The larvae of A. obliterata also attacked all stages of the balsam woolly aphid except the sessile-first instar.

The outstanding searching ability of A. obliterata was observed as very few aphids could be found on the release trees 2 months after the predators were released. Many of the A. obliterata adults seemed to stay on the release trees until the food supply became very scarce. A. obliterata larvae and adults were also observed on surrounding trees infested with the balsam woolly aphid.

The life cycle of A. obliterata is synchronized extremely well with the spring generation of Adelges piceae. A. obliterata adults mate soon after emerging from the pupal stage in late June to late July. They overwinter mainly under bark scales and begin oviposition in early spring after feeding on one of their natural hosts. In the Mt. Mitchell area, Adelges piceae is the only known host that is present in early spring. A. obliterata adults lay their eggs on needles in the upper portions of Fraser fir trees that are infested with the balsam woolly aphid. Observations made in 1960 and 1963 by Amman (1966a) and the field data collected in 1966 show that the hatching of A. obliterata eggs coincided very closely with the oviposition of Adelges piceae adults. A. obliterata adults could also be late in starting their spring feeding without upsetting the synchronization of the life cycles of the 2 insects; the reason being that A. obliterata eggs hatch quicker than Adelges piceae eggs under the same environmental conditions. As an example, A. obliterata eggs hatch in 7.6 days (Table 2) while Adelges piceae eggs hatch in 12.5 days (Amman, 1966b) at 15° C. and 75 per cent relative humidity.

The fact that *A. obliterata* adults have survived winter conditions for 4 years (Amman, 1966a) indicated that they were able to adapt to most of the environmental conditions of the Mt. Mitchell area.

The main weakness of *A. obliterata* is its potential rate of increase. The fact that *A. obliterata* has 1 generation a year while *Adelges piceae* has 2-3 generations a year is a major obstacle for any potential predator to erase. The decrease in population density of *Adelges piceae* caused by the feeding of *A. obliterata* could be erased during the second generation if other environmental factors were the same as in the first generation.

Many workers consider host specificity as an attribute of a good biological control agent (DeBach, 1964). *A. obliterata* is a general feeder in Europe but seems to prefer *Adelges*. So far, no other hosts of *A. obliterata* have been found at Mt. Mitchell in early spring. The balsam twig aphid, *Mindarus abietinus* Koch, is present in the Mt. Mitchell area from early June to late July. *A. obliterata* adults probably feed on this since many other coccinellids have been observed feeding on it. *A. obliterata* larvae have been observed feeding almost exclusively on *Adelges piceae* at Mt. Mitchell. The other interesting habit of this coccinellid at Mt. Mitchell is that it tends mainly to stay on the release trees until the food supply is nearly extinguished before migrating to nearby infested trees. These 2 facts lead me to believe that being found on several hosts and being a general feeder in Europe are not a hindrance to this predator in North Carolina.

It is my opinion that there will not be a great change in the population of Adelges piceae in the Mt. Mitchell area because of the presence of A. obliterata. Its effects, however, are quite noticeable on individual trees and in release areas. The infestation in this area is at the point where it is almost impossible for a predator or a complex of predators to build up a high population density to control the aphid before the main damage is done to the area. A detail sampling study into areas where A. obliterata and other foreign predators have been released is in the future plans of the Station. This will give us a much better idea of how effective A. obliterata and other foreign predators have been in the Mt. Mitchell area.

A. obliterata and some of the other established foreign predators would have a better chance to be effective if they were released into an area as soon as possible after the balsam woolly aphid became present in the area. The use of tanglefoot traps in survey work which records the presence of the motile-first instar stage will now enable the spread of the aphid to be detected several years earlier than in the past. Any additional predator release work should follow this course.

A. obliterata habits would favor its release into areas of Virginia, such as Shenandoah National Park or Mt. Rogers because of the differences in attack of the balsam woolly aphid on balsam fir, Abies balsamea var. phanerolepis. The balsam fir is less susceptible to aphid attack and infestations are more concentrated on twigs and branches. A. obliterata favors twigs, branches, and the upper portions of the tree for feeding if aphids are present there. The fir in the Shenandoah National Park has been infested since 1957 and some mortality is occurring. The limited area and scattering of trees will present somewhat of a problem from the economic viewpoint, but releasing A. obliterata adults into the area should be considered highly because conditions are more suitable there for the beetles than in many places in North Carolina. The aphid as of now is not present at Mt. Rogers, but the possibility of an infestation occurring there during the next few years is very likely. The release of A. obliterata adults at Mt. Rogers would be advised as soon as the infestation is discovered in that area.

SUMMARY

A study of the bionomics of *Aphidecta obliterata* (L.), a predator introduced for control of the balsam woolly aphid, was conducted during 1965 and 1966. The study was undertaken to determine the life history and habits of *A. obliterata* in North Carolina and to determine its feeding habits.

In the laboratory, *A. obliterata* completed its life cycle in 53 days. The number of days in each stage was as follows: egg, 7.61; first instar, 6.17; second instar, 5.31; third instar, 6.83; fourth instar, 9.50; prepupa, 4.08; and pupa, 13.08.

Ninety-three per cent of the adults was identified correctly to sex by using head marking differences only. A distinct correlation was found between the length and the sex of the adult. One hundred per cent of the adults was identified correctly to sex by using both the head marking characteristics and the length of the adult.

An adult parasite, *Medina luctuosa* (Diptera: Tachinidae), was discovered in the 1966 shipment of *A. obliterata* adults from Austria. The use of X-ray to detect predators which were parasitized was found to be possible. All parasitized beetles were collected while holding the beetles in the laboratory at 68° F. and high humidity for 3 weeks.

A. obliterata eggs were observed in the field from June 2 to June 13 with an average of 8.0 eggs per cluster. The adults were observed feeding and resting mainly in the upper portions of the tree. Larvae were present from June 15 to late July. Adults were not seen after August 18.

Larvae of _A. obliterata_ consumed the following average number of eggs per day: first instar, 20.8; second instar, 37.0; third instar, 56.2; and fourth instar, 115.3. _A. obliterata_ adults consumed an average of 34.9 eggs and 11.8 adults daily. A straight line relationship with a correlation coefficient of 0.91 existed between larval length and the number of eggs consumed in 24 hours. The fourth instar larva consumed more eggs than the other 3 instars combined.

The 5 synthetic diets studied would not induce oviposition in _A. obliterata_ females, and it is unlikely that they will lay eggs before feeding on their natural host in early spring.

The effects of predator and prey densities on interactions between _A. obliterata_ larvae and _Adelges piceae_ eggs were studied in the laboratory. Within the limits of the study, the per capita consumption of prey was reduced by increasing predator density. It was not due, however, to prey density but probably caused by crowding or interference which led to considerable cannibalism by the larvae.

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APPENDIX

Per Cent Of Adults Effectively Used In The Field

From the first dissections made on May 3, before any death of adults occurred, we found that female beetles comprised 61 per cent of the shipment:

$$\frac{41}{67} = 61 \text{ per cent females}$$

The number of females in entire shipment based upon the total number of adults alive upon arrival was 61 per cent of 3,824 or 2,333.

The sex ratio after adult beetles were held for 2-3 weeks was $\frac{97}{115}$ = 84 per cent females.

The number of females released in field was 84 per cent of 1,642 or 1,378.

The per cent of females in original shipment that was effectively used in field was $\frac{1,378}{2,333}$ or 60 per cent.

VITA

The author of this thesis was born on September 2, 1943, in Jamestown, New York, the son of Charles J. and Edna Ferguson Witter. He moved to Charlottesville, Virginia, in 1944 and attended public schools in Albemarle County and Charlottesville, graduating from Lane High School in June 1961. He matriculated at Virginia Polytechnic Institute in September 1961 and received the B.S. degree in Forest Management in June 1965. While attending Virginia Polytechnic Institute, he was a member of the Baptist Student Union, Forestry Club, Alpha Zeta, Xi Sigma Pi, and Co-editor of 1964 Virginia Tech Forester. He became a candidate for the Master's Degree in Entomology at Virginia Polytechnic Institute in September 1965. While a graduate student, he became a member of Phi Sigma, Entomological Society of Canada, candidate for Society of American Foresters, and was Associate Forester of Chi Chapter of Xi Sigma Pi.

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BIONOMICS OF *APHIDECTA OBLITERATA* (L.)

(COLEOPTERA: COCCINELLIDAE), A PREDATOR INTRODUCED

FOR CONTROL OF THE BALSAM WOOLLY APHID ON

MT. MITCHELL, NORTH CAROLINA

by

John A. Witter

ABSTRACT

A study of the bionomics of *Aphidecta obliterata* (L.), a predator introduced for control of the balsam woolly aphid, was conducted during 1965 and 1966. The objectives of the study were to determine the life history and habits of *A. obliterata* in North Carolina and to determine its feeding habits.

A. obliterata completed its life cycle in 53 days at 15° C. and 75 per cent relative humidity. The seasonal history of *A. obliterata* was correlated extremely well with the spring generation of *Adelges piceae*. The overwintering adults fed on the aphid in early spring and this promoted oviposition. Eggs were present from May to mid-June and larvae from late May to early July. Adults were identified correctly to sex by using both head marking characteristics and the length of the adult.

An adult parasite, *Medina luctuosa* (Diptera: Tachinidae), was discovered in a 1966 shipment of *A. obliterata* adults from Austria. Various methods of separating the parasitized beetles were tried in

order to eliminate the parasite to enable free release of the remainder of the shipment. X-ray worked best but had to be done prior to feeding. Once feeding occurred, X-ray could no longer be used to detect the parasite. Instead, the beetles were held for 3 weeks at 68° F. and 95 per cent relative humidity to enable the parasite to mature and emerge. Two per cent of the shipment was parasitized.

Feeding studies on A. obliterata conducted in the laboratory showed that a straight line relationship existed between larval length and the number of eggs consumed daily. The fourth instar larva consumed more eggs than the other 3 instars combined.

The 5 synthetic diets studied would not induce oviposition in A. obliterata females, and it is unlikely that they will lay eggs before feeding on a living host in early spring.

The effects of predator and prey densities on interactions between A. obliterata larvae and Adelges piceae eggs were studied in the laboratory. Within the limits of the study, the per capita consumption of prey was reduced by increasing predator density.