AN ABSTRACT OF THE THESIS OF

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Title STUDIES OF THE BIOLOGY AND EFFECTIVENESS OF LARICOBIUS ERICHSONII ROSENH. (COLEOPTERA:DERODONTIDAE), AN EUROPEAN PREDATOR OF THE BALSAM WOOLLY APHID, ADELGES PICEAE (RATZ.)(HOMOPTERA:ADELGIDAE).

Signature redacted for privacy.

Abstract approved ____________________
(Major Professor)

The balsam woolly aphid (*Adelges piceae* (Ratz)), an European pest of conifers, was first discovered in the Pacific Northwest shortly after 1930. Control measures of a chemical, silvicultural, or biological nature have been proposed. However, present control methods are either too costly or do not result in satisfactory control of the aphid.

Several insect species were reported as predaceous upon the balsam woolly aphid in Europe, eastern Canada, and the Pacific Northwest. European predators of this pest have been imported into eastern Canada in an effort to find a satisfactory control measure. Several species of insects from Europe were imported into the Pacific Northwest from 1957 through 1959. *Laricobius erichsonii* was successful in becoming at least temporarily established in this region and was chosen for further study. The purpose of the thesis project was to obtain information on the establishment, life history, habits, and effectiveness of this beetle in Oregon and Washington. Studies were begun in May of 1958 and terminated in November of 1959.

Two species of the genus *Laricobius* are indigenous to the Pacific Northwest. Franz has studied the life history and ecology of *L. erichsonii* in Europe, and Clark and Brown have made observations of establishment, spread, life history, habits, and effectiveness in eastern Canada.

In 1958 and 1959, 10,125 *L. erichsonii* adults were collected in Czechoslovakia and sent to the Pacific Northwest Forest and Range Experiment Station in Portland,

Oregon, for release in the Pacific Northwest. Predators were released either freely or in cages at eight different areas in Oregon and Washington. Temporary establishment occurred at all of the release areas regardless of varied weather and elevational differences.

Some 52 larvae were collected and mounted on slides in 1959. Of these larvae, no first, one second, four third, and 47 fourth instars were present. First and second instar larvae tend to stay within the aphid's wax masses, while third and fourth instar larvae wander about the bark in search of food. Moulting was observed. At the various release areas, larvae were recovered from May 23 through August 26 of 1959 and adults from May 5 through September 2.

Two pupae were laboratory-reared from five, field-collected fourth instar larvae. Under laboratory conditions, one fourth instar larva consumed or destroyed seven eggs and two adults in a period of one and one-half hours. _L. erichsonii_ adults prefer aphid adults but attack other stages.

Range of observed dispersal, a year following release, ranged from zero to 75 feet from the point of original release.

A study was initiated at Benton-Lane, Oregon, to study the effectiveness of _L. erichsonii_ in reducing balsam woolly aphid populations. Trend of host populations was evaluated at approximately two week intervals on six unprotected and two protected (control) one-inch-square bark plots on a pole-sized grand fir surrounded by a six-foot-cube study cage. On the protected plots, the average aphid population increased from 31 to 131 individuals in the period from May 1 through November 23 of 1959, while on the unprotected plots it increased from 47 to 64 individuals.

A t-test was calculated to see if the differences between protected and unprotected plot populations were significant. The t-value obtained was 4.3, which showed that the differences were significant at the one per cent significance level.

It is felt that populations of the balsam woolly aphid will be greatly reduced when _L. erichsonii_ can combine with other predators that are fairly host specific and that prey on all stages of the aphid.

STUDIES OF THE BIOLOGY AND EFFECTIVENESS OF LARICOBIUS ERICHSONII ROSENH. (COLEOPTERA: DERODONTIDAE), AN EUROPEAN PREDATOR OF THE BALSAM WOOLLY APHID, ADELGES PICEAE (RATZ.) (HOMOPTERA:ADELGIDAE)

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

STUDIES OF THE BIOLOGY AND EFFECTIVENESS OF *LARICOBIUS ERICHSONII* ROSENH. (COLEOPTERA: DERODONTIDAE), AN EUROPEAN PREDATOR OF THE BALSAM WOOLLY APHID, *ADELGES PICEAE* (RATZ.) (HOMOPTERA:ADELGIDAE).

INTRODUCTION

In the early 1900's, the balsam woolly aphid (*Adelges piceae* (Ratz.))(Homoptera:Adelgidae) was discovered in eastern Canada and eastern United States. However, it is believed that the aphid was introduced into North America prior to this time, probably on nursery stock. In the 1930's this European pest was discovered in the Willamette Valley of Oregon. In 1954, the insect appeared in outbreak proportions on 276,000 acres of true fir forests in the Pacific Northwest.

By 1957, suitable control methods were not available to reduce the damage done by this aphid, so the Pacific Northwest Forest and Range Experiment Station imported and released several species of European predators of this pest in cooperation with Oregon State College and Weyerhaeuser Company.

One of these predators, a small derodontid beetle (*Laricobius erichsonii* Rosenh.)(Coleoptera:Derodontidae), was chosen by the author for further study because of its preying-ability in Europe and eastern Canada and its success in becoming at least temporarily established in the Pacific Northwest.

The purpose of the thesis project was to obtain information of the establishment, life history, habits, and effectiveness of L. erichsonii in Washington and Oregon. General observations were made throughout the field seasons of 1958 and 1959, while the author was employed by the Forest Insect Research Division of the Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service.

A predator-effectiveness study was begun on May 1, 1959 at Benton-Lane, Oregon, and concluded on November 2, 1959.

The following report describes the introduction and colonization of L. erichsonii in the Pacific Northwest, as well as methods and results of the aforementioned study. Pertinent literature from Germany and eastern Canada is reviewed, and some comparisons are made between habits of this predator in these countries and the Pacific Northwest.

THE BALSAM WOOLLY APHID

The balsam woolly aphid, Adelges piceae (Ratz.), is an European insect that was first found on the Pacific Coast in 1928 in the San Francisco Bay area of California. Shortly after 1930, Keen collected the insect on grand fir (Abies grandis (Dougl.) Lindl.) in the Willamette Valley of Oregon (10, p. 9). It is possible that this pest was introduced into the Pacific Northwest on nursery stock from Europe, because early collections were made on European species of true fir in parks and arboretums (15, p. 1). Chermes[1/] was first discovered in outbreak proportions in the Pacific Northwest in 1954. During 1957, this insect pest infested around 600,000 acres of timber in this area (18, p. 11).

A review of literature pertaining to the balsam woolly aphid revealed that several measures have been tried to control this forest pest. These measures can be placed in three categories: chemical, silvicultural, or biological.

The use of insecticides in controlling chermes damage is limited by cost and existing methods. Usually the insecticides must be applied to the entire tree for adequate

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1/ Chermes is usually used as a common name of the balsam woolly aphid.

control, thus increasing cost considerably. Also, the chemicals must come in direct contact with the insect, but the waxy "wool" covering the adult and its egg clutch makes this almost impossible (Figures 1 and 2). Sufficient control was obtained in eastern Canada with the use of several insecticides. However, the concentrations and number of applications were too great to result in an economically feasible control method under forest conditions (1, p. 72).

Balch (1) points out that initial infestations in balsam fir (*Abies balsamea* (L.) Mill.) usually obtain their impetus on larger trees (Figure 3), which makes it possible to gain at least partial control by cutting the mature and overmature trees that are infested. Balch suggests that shorter growing cycles should reduce the danger of loss between cuts.

The following recommendations for logging infested trees were made by Rudinsky (15) in his review of current European literature:

1. Fell infested trees away from neighboring healthy trees;
2. Cut and remove infested trees in winter when chermes is inactive;
3. Refrain from transporting infested logs through uninfested stands.

Figure 1.- Adelges piceae bole infestation on a subalpine **fir** in **Wind** River Arboretum near Carson, Washington.

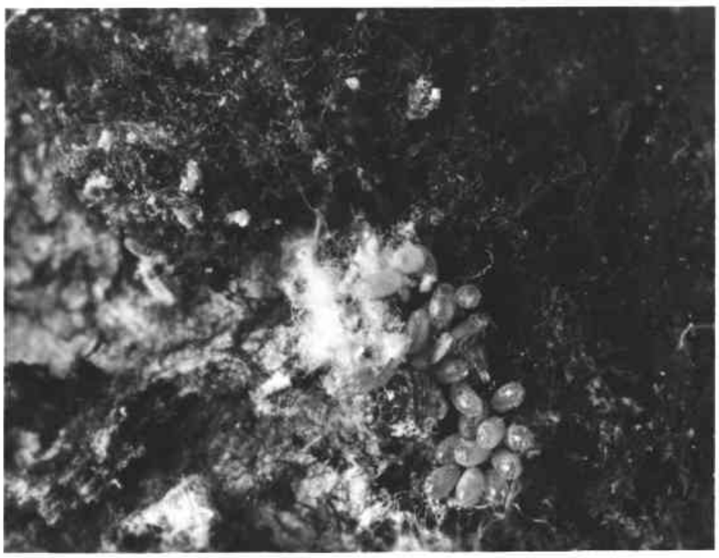

Figure 2.- Adelges piceae eggs, nymph, and adult and waxy exudation. 25X.

Figure 3.- Chermes-damaged mature and overmature Pacific silver fir trees on the Gifford Pinchot National Forest in Washington.

Johnson and Wright (10) suggest replacing Pacific silver fir (*Abies amabilis* (Dougl.) Forbes) and subalpine fir (*A. lasiocarpa* (Hopk.) Nutt.) at higher elevations with seemingly resistant true firs such as noble fir (*A. procera* Rehd.) or Shasta red fir (*A. magnifica* var. *shastensis* Lemm.). No research on silvicultural control of the balsam woolly aphid in the Pacific Northwest has been undertaken to date because the insect has become an important pest only recently (10, p. 22).

Since the balsam woolly aphid is native to Europe, its biotic controls were left behind when it was introduced on this continent. In Europe, Pschorn-Walcher and Zwölfer named six dominant species of predators of *Adelges piceae*: *Aphidoletes thompsoni* Möhn; *Cremifania nigrocellulata* Cz.; *Neoleucopis obscura* (Hal.); *Cnemodon dreyfusiae* DeLucchi and Pschorn-W.; *Laricobius erichsonii* Rosenh.; and *Pullus impexus* Muls. Five other species of insects and an unknown mite species were listed as being subdominant predators. Some 16 other species were recorded as occasionally feeding on the aphid (14, Vol. 39, p. 67). According to these writers, the influence of the predators is closely related to the density of the host population (14, Bol. 39, p. 73). In other words, the greater the number of aphids, the greater the number of predators. With such a complex of predators, at times the egg population alone is reduced by 50 per cent (15, p. 9).

Entomologist R. G. Mitchell of the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, has found five dipterous species, three neuropterous species, and one mite species as being known native predators of _A. piceae_ in this region. Several other species of Diptera, Neuroptera, Coleoptera, and Trombidiformes are also suspected as being predaceous (13, p. 4). Studies of the effectiveness of these predators were begun in 1959, but the results will not be reported until a later date.

Since 1933, the Biological Control Unit of the Division of Entomology and the Commonwealth Bureau of Biological Control of Canada have introduced 19 species of European predators of the balsam woolly aphid into eastern Canada in an effort to find some control measure for _Adelges_ spp. on balsam fir (6, Vol. 15, No. 6, p. 1). Studies following liberation show that four species, _Neoleucopis obscura_, _Laricobius erichsonii_, _Pullus impexus_, and _Cremifania nigrocellulata_, are well established. Of these four species, only _L. erichsonii_ has shown the ability to reduce stem infestations sharply before the tree is killed. Also, this derodontid beetle began feeding in the spring earlier than the other abundant species, which is an advantage when competing for food (2, Vol. 4, p. 814-816).

Brown and Clark (4) have listed many native species of insects and mites as active, possible, or probable predators of chermes in eastern Canada. The effectiveness of these species in controlling the population level of the balsam woolly aphid has not been reported.

Beginning in 1957, European predators were provided to the Pacific Northwest Forest and Range Experiment Station by the Canadian Department of Agriculture, Science Service, through arrangements made by the U. S. Forest Service and the Entomology Research Division of the U. S. Agricultural Research Service, U. S. Department of Agriculture (19, p. 1). From 1957 through 1959, 14 insect species of foreign predators of the balsam woolly aphid were released in Oregon and Washington (5, p. 9).

In 1958, when this thesis project was begun, only two species, *Aphidoletes thompsoni* and *L. erichsonii*, showed promise of establishment in this region. Because of the success of *L. erichsonii* in Europe and eastern Canada in establishing itself and reducing chermes populations, this beetle was chosen for further study.

LARICOBIUS ERICHSONII

Taxonomic Description

L. erichsonii is placed in the small family, Derodontidae. The members of this family are commonly called tooth-necked fungus beetles. Only about a half dozen species of this family occur in the United States, and they occur on fungi and under the bark of rotting logs (3, p. 363). Rosenhauer described *L. erichsonii* in 1847 in his *Broscosoma u. Laricobius, etc., Erlingen*, from species collected in Europe (11, p. 202).

Two species of *Laricobius*, *L. laticollis* Fall and *L. nigrinus* Fend., have been described from Oregon and Washington. The adult of *L. erichsonii* can be distinguished from the two indigenous species in that it has a generally rufotestaceous color, but the appendages and broad lateral and sutural margins of the elytra are black. *L. laticollis* is entirely testaceous or rufotestaceous, and *L. nigrinus* is entirely black or piceous.[2/]

Biology and Effectiveness in Other Countries

Franz (9) has studied the life history and ecology of *L. erichsonii* in Europe, and Clark and Brown (7) have

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2/Personal communication with M. H. Hatch, Professor of Zoology, University of Washington, Seattle, Washington.

studied this beetle in eastern Canada. The following two sections tell some of the results of their studies.

In Europe - Franz (9) suggests that the distributional increase of L. erichsonii was caused by the increase in the extent of coniferous forest in Europe. The study area used by Franz was located near Munich, Germany, where A. piceae has infested Abies pectinata D. C. (9, Vol. 3, 117-118).

In Germany, the adults appear on the infested stems about the middle of April after overwintering in the forest floor. Mating occurs between the time of emergence and the first of June, and oviposition occurs from the end of April until the end of June. The eggs are deposited singly on or in chermes egg clusters. The average egg production per female is estimated to be more than 50 eggs. The overwintering adults generally die in June and July following egg deposition. The length of the egg stage usually varies with temperature and lasts from seven to 14 days.

After hatching, the first instar larva crawls into the egg cluster near or in which it was laid and begins feeding. The length of the first stadium ranges from two to six days, and then moulting takes place. The durations of the second, third, and fourth stadia are two to six, three to four, and ten to 15 days, respectively. The first and second instar larvae usually stay in the egg mass in which they hatched, while the third and fourth instars wander about the bark in search of prey. The fourth instar larvae move down the stem of the infested tree toward the end of their larval development and pupate in the soil. The first young beetles appear on chermes-infested stems at the end of June or beginning of July. These beetles are incapable of reproduction because the genital organs are undeveloped. They feed for a short while and then, from the end of July to the end of September, re-enter the soil to overwinter (9, Vol. 3, p. 121-136).

Franz also studied the preying habits of these beetles and found that the adults of *L. erichsonii* consume all stages of *A. piceae*, but the adult aphids are preferred. First and second instar larvae prefer the eggs of *A. piceae*, while the third and fourth instar larvae prey upon eggs, larvae (including occasionally the first instar), and adults (9, Vol. 3, p. 124-136).

In a test conducted by Franz to determine the preying-ability of *L. erichsonii*, individual larvae were placed in glass or celluloid tubes and fed with eggs and adults spread on pieces of bark. Most of the tests, however, were carried out using *A. piceae* eggs. The following table gives the average number of chermes eggs and adults consumed in each *L. erichsonii* larval stage (9, Vol. 3, 139-141).

Instar of *L. erichsonii*	Average *A. piceae* Consumed
L I	24.5
L II	65.8
L III	117.2
L IV	157.5

L. erichsonii adults consumed an average of 29.0 individuals per day in tests similar to the preceding one. The body contents of the *A. piceae* individuals are usually sucked out by the *L. erichsonii* larvae and adults, but some individuals may be swallowed completely. The number of prey consumed by one *L. erichsonii* during its lifetime is estimated to be about 2,970 eggs (9, Vol. 3, 127-158).

In Europe, a species of parasitic Hymenoptera, *Echthrolaricobius paradoxus* Franz, and a disease known as "Black Spot Disease" are known to inflict appreciable mortality to this derodontid. Also, several predators that attack *A. piceae* prey occasionally on larvae of *L. erichsonii* (9, Vol. 3, 144-149).

Franz lists the advantages of *L. erichsonii* as a predator as:

1. It is able to concentrate feeding in the relatively short period which coincides with the main egg production of the host;

2. It is able to find the host even at low population levels;

3. It has the ability to disperse;

4. It shows a slight host specificity for adelgids.

Franz notes that the value of L. erichsonii in reducing chermes populations will be only slight if this predator appears by itself. However, a complex of predators may be of considerable importance towards the biological control of A. piceae, especially if L. erichsonii is abundant (9, Vol. 3, p. 162).

In Eastern Canada - From 1951 through 1955, over 43,000 L. erichsonii were released in the Atlantic Provinces (New Brunswick, Nova Scotia, and Newfoundland) of Canada (6, Vol. 15, No. 6, p. 1). Since 1951, observations have been made of the establishment, spread, life history, habits, and effectiveness of these beetles.

Adult L. erichsonii were collected in Europe and sent to Canada, where they were released in areas of heavy A. piceae stem infestations on balsam fir. The insects were released either freely at the base of an infested tree or in a sleeve-type cage attached to an infested tree. The purpose of the latter release method was to confine the predators temporarily to the tree trunk in an attempt to insure mating before dispersal occurred. A few adults were confined in large, cubical cages to study development, seasonal history, and predator-prey interaction (7, Vol. 90, p. 659).

Establishment occurred at seven of the nine release areas, but spread from the release points was very slow. In the year following release, the observed maximum spread ranged from none to 495 yards (7, Vol. 90, p. 661-662).

In eastern Canada, mature adults appear on the tree from the first of May until the last of June, although most eggs are laid by the end of May. Observed larval occurrence on the stem of chermes-infested trees was from the last of May until the last of June, although the actual period may be longer. The time spent in the ground after the completion of larval development was from the last of June until the last of July. The newly-emerged adults were present on the chermes-infested stems from the middle of July until the latter part of August. Most of these dates given by Clark and Brown are approximately two weeks later than those given by Franz (9) in his study of the life history of this derodontid beetle in Europe. The active period of the callow adults in Europe, however, extends into September (7, Vol. 90, p. 664-666).

Population levels of prey and predator were also studied by Clark and Brown in order to assess the relative value of the predators in limiting _A. piceae_ populations. Three slightly different methods were used in the population counts, but only the last one will be described here because it is the one presently used. A five-foot section of a L. erichsonii release tree was marked off into the four cardinal sectors (N, E, S, and W), and then five, one-inch-square plots were established, 12 inches apart vertically, within each sector. To facilitate the counting of the same area each time, a metal grid with a one-square-inch opening was hung from two aluminum nails, which were driven into the tree above the location of each plot. The nails were far enough apart to prevent the flow of resin from affecting the sampling area (7, Vol. 90, p. 667).

Weekly or twice-weekly counts were made on each sampling area of the number of A. piceae intermediates 2nd and 3rd instars) and adults with the aid of a hand lens. The general abundance of crawlers and dormant neosistentes was also noted. At the same time, a careful count was made of all predator stages within the five-foot sampling area, and the presence of the different instars was noted. Counts of the predators were made by the naked eye, but a hand lens was used when positive identification was difficult (7, Vol. 90, p. 667).

Several trees free from L. erichsonii predation were used as "check" or control trees and were marked off and counted by the same methods previously described (7, Vol. 90, P. 667).

The results of this study showed that on all of the "check trees" there was an increase of _A_. _piceae_ from the hiemosistens to the aestivosistens generation averaging 186 per cent. On all trees with _L_. _erichsonii_ present, however, there was a decrease of 61 per cent. These findings were statistically significant and appeared to be due solely to the presence or absence of the predator (7, Vol. 90, p. 669).

In eastern Canada, _L_. _erichsonii_ larvae occur when the prey is most numerous, and the predator larvae prefer eggs but also consume other stages of the aphid. For these two reasons, _L_. _erichsonii_ reduces the prey population much greater than _Neoleucopis_ _obscura_ does. _N_. _obscura_ occurs three weeks later than _L_. _erichsonii_, and the larvae of this chamaemyiid fly seldom feed on _A_. _piceae_ eggs (7, Vol. 90, p. 669).

The feeding habits of _L_. _erichsonii_ in eastern Canada are similar to those reported by Franz in Europe. No parasites or diseases were found to limit _L_. _erichsonii_ populations in eastern Canada. The only predation observed was by an ant, _Myrmica_ _lobicornis_ _fracticornis_ Emery, seen feeding on a larva (7, Vol. 90, p. 666).

Introduction and Colonization in the Pacific Northwest

In 1958 and 1959, 10,125 adults of *L. erichsonii* were released at eight different areas in Oregon and Washington (Table 5, Appendix). These insects were collected in Europe by the Commonwealth Institute of Biological Control and sent to the Pacific Northwest Forest and Range Experiment Station by the Canadian Department of Agriculture's Entomology Research Institute of Biological Control at Belleville, Ontario.

Collection and Shipment - The 8,525 *L. erichsonii* adults released in 1958 were collected in the vicinity of Cemjata, near Presov, Czechoslovakia, by Dr. H. Zwölfer of the Commonwealth Institute of Biological Control and his assistants. The predators were hand-picked in the adult stage from chermes-infested stems and then were placed in shipping boxes for transport to Canada, after an adequate number was obtained. The shipping containers were the standard wooden type used by the Commonwealth Institute of Biological Control (Figure 4) (8, Vol. 4, p. 893).

The interior sides of the double-wall boxes were made of wood, while the bottoms were covered with a very fine metal screen, and the removable tops were of heavy,

Figure 4.- Shipping box used to hold Laricobius erichsonii during transit from Europe to Portland, Oregon, via Belleville, Ontario, Canad

Figure 5.- Shipping box showing drops of honey-agar used for food by Laricobius erichsonii during transit.

clear plastic. Damp cotton or moss was placed between the screening and the bottom of the box to provide a favorable humidity for the beetles during transit.

A sheet of porous paper approximately 2.5 by 4.0 inches was stapled on each of two interior sides of the box. Drops of honey-agar about one-fourth inch in diameter were added at about one-half inch intervals on the paper to provide food for the beetles (Figure 5). When the shipping boxes were opened, several beetles were congregated on this material and apparently were feeding.

The shipments in 1958 were sent by Air Freight from Presov, Czechoslovakia, to the Entomology Research Institute of Biological Control at Belleville via London and Montreal. At Belleville, the beetles were fed a honey-agar mixture and stored at a temperature of approximately 68° F. for two to three days before reshipment by Air Express to Portland. Upon arrival in Portland, the predators were taken to the Experiment Station's Sellwood laboratory for inspection and storage under refrigeration at 48° F., until they were taken into the field for release.

When the shipping boxes were opened at Sellwood laboratory, the beetles appeared to be quite active. Some were observed to be in flight, occasionally, within the shipping box. Upon closer examination, the beetles appeared to have suffered very little mortality in transit from Europe to the Pacific Northwest. Several pairs of L. erichsonii were observed in copulation within the box.

Shipments of L. erichsonii in 1959 were collected in the Black Forest around the Freiburg-Breisgau area in Germany by Dr. H. Zwölfer and his assistants. Two shipments were received in Portland in 1959. The first shipment was sent by Air Freight from Basel, Switzerland, to Belleville via London and Montreal, and the second shipment was sent from Stuttgart, Germany, to Belleville also via London and Montreal. Both shipments were Air Expressed to Portland from Belleville. Collection, shipping, and handling procedures were the same as in the previous year.

Methods of Release - The predators were transported to the release sites by automobile. The shipping boxes were placed in an ice chest at about 50° F. for transportation to the field. This allowed the beetles to be at a fairly cool temperature while in transit to the release areas. Temperatures within the automobile sometimes reached 90° F. during the three or four hour trip from Sellwood to the release areas. It was thought that these high temperatures could have caused appreciable mortality before release if some cooling device had not been used.

Upon reaching the pre-determined area, the insects were released in one of two ways -- freely or in a cage

(Table 5, Appendix). Both release methods were used in 1957 in releasing a itonidid, Aphidoletes thompsoni.

Free Release - In the free-release method, the shipping box was either placed on the ground at the base of a chermes-infested tree, or the box was attached to the stem by means of a wooden platform or string (Figures 6 and 7). In either case, one of the ends of the box was removed to allow the insects to escape. This method allowed the predators rapid dispersal and abundant prey material in forests of heavy infestations. The predators usually began crawling from the shipping box onto the bole of the chermes-infested tree immediately after one of the ends of the box was removed. However, some of the L. erichsonii adults immediately took flight to surrounding trees. Upon reaching a chermes-infested bole, the predators began sticking their heads into chermes egg masses and feeding, while others wandered about the bark for a short time before they began feeding. Mating was also observed immediately following release.

Cage Release - The cage-release method was designed after one used in eastern Canada. The cages were "sleeve-type" and were made completely of 32-mesh plastic screen, except for the top and bottom panels,

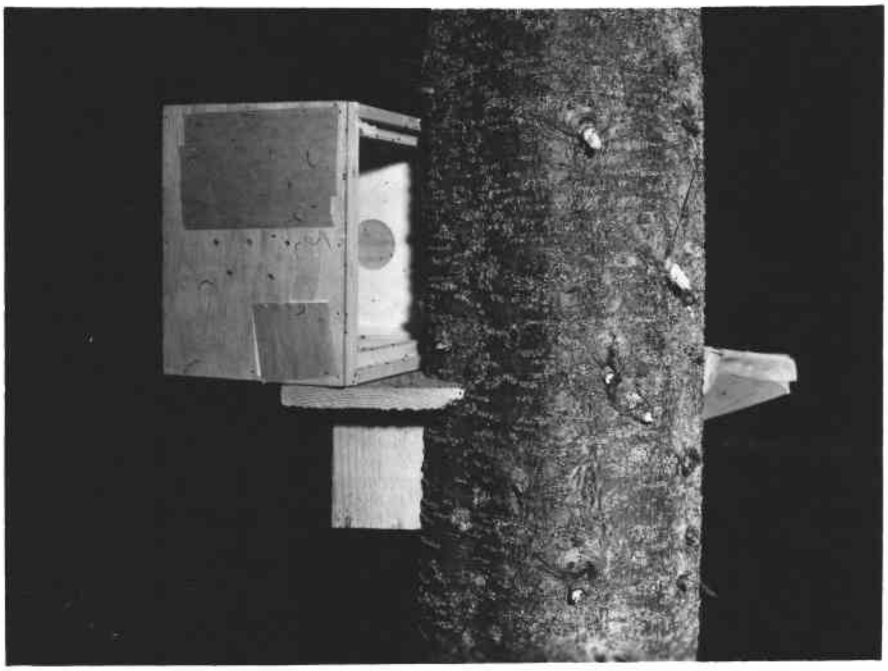


Figure 6.- Free release of Laricobius erichsonii at Willamette Pass, Oregon, using a wooden platform to hold the shipping box to the tree.

Figure 7.- Free release of Laricobius erichsonii at Black Rock, Oregon, using string to hold the shipping box to the tree.

which were made of unbleached muslin and served to fit the cage to the tree (Figure 8). A cotton batting gasket was placed at the top and bottom limits of the cage to insure a tight fit between the muslin and the tree. Heavy string was used to fasten the cage to the tree at the point of the two gaskets, and an eight-gauge wire hoop was inserted near the top and bottom to hold the screen away from the tree. A zipper was sewed longitudinally into the screen to provide a means of adequate access to the caged area of the bole.

At time of release, the shipping boxes containing *L. erichsonii* were opened and placed at the bottom of the cage. The beetles usually left the boxes soon after release and wandered about the bark of the release tree. Many of the beetles were still alive when the cages were removed several weeks after the original release to allow the beetles' progeny more prey material. Another purpose of removing the cages was that *L. erichsonii* larvae drop to the ground for pupation and development into adults. It would have been impossible for this to occur if the cages had been left attached to the tree.

The cage-release method prevents dispersal before mating occurs and confines the predators to a small area of *A. piceae* infestation during oviposition. For a short period following cage removal, the resulting progeny were

Figure 8.- Cage release of Laricobius erichsonii at Black Rock, Oregon.

usually found in the chermes egg masses in this area. This allowed making intensive observations in smaller areas, which saved a great deal of the examiner's time.

In remote areas, cage removal required a great deal of time. This proved to be a disadvantage because only a limited amount of time was left available for observations of habits and life history.

Release Locations - *L. erichsonii* adults were released at eight different areas during 1958 and 1959 (Fibure 15, Appendix). The number of specimens released at each area in Oregon and Washington during this period are shown in Table 1. (Also see table 5 in the Appendix for actual release date by area.)

Table 1. Number of *Laricobius erichsonii* adults released by areas in 1958 and 1959.

Release Area	Number Released in 1958	in 1959	Total
Corvallis, Oregon	1705		1705
Black Rock, Oregon	1550		1550
Willamette Pass, Oregon	1200		1200
Benton-Lane, Oregon		800	800
Monroe, Oregon		800	800
Coldwater Creek, Washington	1320		1320
Green River, Washington	1600		1600
Wind River, Washington	1150		1150
Total	8525	1600	10125

The following sections include generalized information about the release areas and the _A. piceae_ population level at each of these locations at time of release. (See Figure 15 in the Appendix for location of these areas.)

Corvallis - The two release trees at this area are located in a young stand of grand fir in Avery Park, which is owned by the City of Corvallis. Most of the trees in this stand harbor infestations of the balsam woolly aphid, and the prey population on the two release trees at time of release was heavy (about 50 wax masses per square inch).

Black Rock - _L. erichsonii_ adults were released on two Pacific silver firs in a large, mature stand of this species located northwest of Dallas, Oregon, in the Coast Range. Severe fir mortality has occurred in this area due to chermes attacks, and stem populations at time of release were heavy. Salvage logging is being carried on near the release area, so that chermes-killed timber can be utilized before decay takes its toll.

Willamette Pass - This release area is located 2.2 miles east of the Salt Creek Falls tunnel on the Willamette Pass Highway in the Cascade Mountain Range of Oregon. It is in a mixed stand of Pacific silver fir, subalpine fir, and Engelmann spruce (_Pices engelmanni_ (Parry) Engelm.). The release tree was a subalpine fir which was heavily infested with chermes at time of release. This tree died in the fall of 1958. Other infested firs occur throughout this area, however. The elevation at Willamette Pass is 4,000 feet, the highest point that *L. erichsonii* adults were released (Table 3).

Monroe - This release tree is in a grand fir woodlot along the bank of the Long Tom River near the town of Monroe, Oregon. Several trees in the area have heavy balsam woolly aphid stem infestations.

Benton-Lane - *L. erichsonii* adults were released on one chermes-infested tree in this area. The tree is situated in a pole-sized stand of grand fir just north of Washburn State Park on the Benton and Lane County lines. Several foreign predators were released here in 1958 and 1959. *L. erichsonii* specimens were released in a 6 foot by 6 foot by 6 foot cage in order to exclude all other predators in the area, whether they are of foreign or native origin. Bole infestations of *A. piceae* are numerous, and the prey population at time of release was heavy.

Coldwater Creek and Green River - These two release areas can be treated as one because both are located slightly northwest of Mount St. Helens, Washington, on Weyerhaeuser Company's St. Helens Tree Farm. All three release trees are located in almost pure stands of

Pacific silver fir. The prey populations on the stems of the release trees were heavy at time of release. Many of the true firs in this area have been killed by the aphid. A salvage logging program is being carried out.

Wind River - The release tree at this site is located within Wind River Arboretum near Camas, Washington. The release tree, a subalpine fir, died in 1958 due to a heavy infestation of chermes. However, there are a few stem-infested trees in the immediate area including several European silver firs (*Abies alba* Mill.).

Establishment Following Release - *L. erichsonii* larvae and/or adults were recovered at 10 of the 11 original release trees, either immediately following release or during the next year (Table 2). This predator has survived through the winter in at least five of the six 1958 release areas (Table 6, Appendix). Corvallis was the only release area at which establishment failure may have occurred. Only one mangled larva was recovered on the release tree at that location in 1959, and that larva was found in a mass of pitch.

Progeny of this derodontid were recovered at each of the two 1959 release points, but these insects have not survived a winter as yet (Table 6, Appendix). However, the results of the 1958 releases show that this predator

Table 2. Recoveries of *Laricobius erichsonii* on release trees in Oregon and Washington during 1958 and 1959.

Release Area	Number of Release Trees	Number of Release Trees on which *L. erichsonii* was recovered	Stage recovered	
			Larva	Adult
Coldwater Cr., Wn.	1	1	X	X
Green River, Wn.	2	1	X	X
Wind River, Wn.	1	1	X	X
Benton-Lane, Oreg.	1	1	X	
Black Rock, Oreg.	2	2	X	
Corvallis, Oreg.	2	2	X	
Monroe, Oreg.	1	1	X	
Willamette Pass, Oreg.	1	1	X	X
Totals	11	10		

has overwintered successfully in most locations and is able to withstand the climatic conditions of Oregon and Washington.

Examinations were made no higher than 12 feet up the bole of chermes-infested trees. It was felt that some of the beetles would be present in this area if any were on the tree at all. However, the balsam woolly aphid can be found either on the bole or on the buds of lateral and terminal branches or at both places. Presence of aphids on buds usually causes gouting, which results from insertion of the aphids' stylets into succulent tissue. This is followed by secretion of saliva which is thought to contain a growth stimulator. Presence of this pest on the bole can cause the development of a dark, brash wood that is considered inferior for use as lumber or pulp (10, p. 17). Tree killing can be caused by either type of infestation. Therefore, it is important for predators of A. piceae to reduce populations of this pest at both locations.

The following sections summarize observations made during 1958 and/or 1959 of establishment of L. erichsonii at each of the different release locations. (See Table 6 in the Appendix for a briefer summary of observations by year and area.)

Corvallis - Numerous larvae were found on one of the release trees one month after release in 1958. At this time several larvae were seen on adjacent trees. However, no stages were found on the other release tree. By fall, no adult L. erichsonii had been obtained. In 1959, only one, badly mangled larva was seen on either of the release trees, and this predator was stuck in a mass of pitch as was previously mentioned. In a thorough search of chermes bole infestations on near-by trees, no other larvae or adults were recovered. Only future observations will tell whether L. erichsonii has become successfully established at this location.

Black Rock - At approximately one month from the release date in 1958, some 15-20 L. erichsonii larvae were counted in a one-foot square area on each of the two release trees. No adults were seen in the fall, but towards the last of June in 1959, numerous larvae were recovered on two trees near the original points of release. At this time, the *A. piceae* population on both release trees was almost nil, and no stages of the predator were obtained on these trees. However, the fact that *L. erichsonii* was recovered on other trees in 1959 shows that this predator has overwintered successfully and can withstand the climatic conditions at Black Rock.

Willamette Pass - Several *L. erichsonii* larvae were found preying on *A. piceae* at this location towards the end of July in 1958, approximately two weeks after the original release of adults of this predator. Two adults were seen on the bole of the release tree about two months later. The release tree was dead when 1959 observations were begun, but numerous larvae were present on three adjacent trees that harbored heavy bole infestations of the balsam woolly aphid. In September, several *L. erichsonii* adults were seen feeding on chermes on several other trees in the area.

The elevation at Willamette Pass is the highest of all release areas being 4,000 feet (Table 3). Although annual precipitation is about average, the summer is characterized by having several long, warm periods which lack precipitation. Snowfall is quite heavy during the winter months and stays on the ground as late as the middle of May. However, it appears that *L. erichsonii* can live and reproduce under these conditions, because it has become well-established at this area.

Monroe - In 1959, the first release of *L. erichsonii* adults was made at this area. At approximately six weeks following release, several larvae were recovered on the bole of the release tree. Three months later, several cast larval skins of this predator were found on the release tree and on an adjacent tree, but no living larvae or adults were seen. Because this insect has not yet overwintered at this area, it can not be concluded that it is successfully established. Future observations will decide this.

Benton-Lane - *L. erichsonii* adults were released in a six-foot-square study cage at this location in 1959. Four weeks after the release, numerous larvae were seen on the bole crawling over the bark and feeding on chermes. Two months later, several larvae were still present on the bole. No adults were found in the fall, although observations were continued until November 23, 1959. As at Monroe, observations during 1960 will determine whether these predators can live and reproduce in the Willamette Valley where high temperatures and long periods without rainfall are common during the summer.

Coldwater Creek - Six weeks after the original release of *L. erichsonii* at this area, numerous larvae were seen on the bole of the release tree. Subsequent adults were not recovered during that year. At the time of the first observation in 1959, the release tree was dead, but several other trees in the area harbored heavy *A. piceae* bole infestations. No *L. erichsonii* larvae were found, but in August several adults were recovered on a tree about 20 feet from the original release point. Although no larvae of this predator were seen at Coldwater Creek in 1959, the presence of adults indicates that these insects have become established. Timing of observations may not have coincided with the larvae's presence on the bole.

Green River - In 1958, *L. erichsonii* adults were released on two different trees in the Green River drainage. Observations following release showed that this predator had become at least temporarily established on one of these trees. Approximately 20 larvae were counted within a one-foot-square area on this tree about six weeks from time of original release. One adult was seen on the same tree in early August. At the area which showed no establishment in 1958, the release tree was dead in 1959, and no stages of *L. erichsonii* could be found on adjacent *A. piceae* infested trees during a thorough search of the area. At the other area, the chermes population on the release tree had disappeared either because of predation, formation of secondary periderm by the tree, or a combination of factors. A few *L. erichsonii* larvae were recovered in the middle of August, however, on a tree about 20 feet from the point of original release. An adult was found at this same time on a tree 50 feet from this point.

It appears as though *L. erichsonii* has become established in one of the two release areas at Green River. An itonidid, *Aphidoletes thompsoni*, had been released in 1957 on the tree that failed to show establishment. In 1958, this tree harbored a very heavy population of the larvae of this fly at approximately ten weeks after *L. erichsonii* was released. Perhaps the *A. thompsoni* larvae consumed the freshly laid eggs of *L. erichsonii*, and thus interfered with its development. However, it is possible that some derodontids escaped to other trees. Only future observations will shed any light on this hypothesis.

Wind River - After release in 1958, *L. erichsonii* stages were not found on the original release tree or on adjacent chermes-infested trees. The *A. piceae* population on this release tree dropped off sharply by midsummer, and by fall, the tree was dead. In May of 1959, two adults were recovered on the bole of a tree next to the original release point. Toward the last of May and first of June, L. erichsonii larvae appeared in large numbers on this tree and on an Abies alba 75 feet from the release point. A coccinellid, Aphidecta obliterata, had been released on the latter tree in May of 1959, but L. erichsonii did not seem to suffer from the competition of this beetle. In July, several adults were found on both trees. The recovery in 1959 of L. erichsonii at this area shows that just because the predators are not recovered immediately following release does not always mean they have not survived.

L. erichsonii and A. obliterata have reduced the population of Adelges piceae considerably. It is hoped that there is enough chermes in the area to allow these predators enough food for development, although the situation does not look promising from the standpoint of raising large predator populations.

Studies of Biology and Effectiveness in the Pacific Northwest

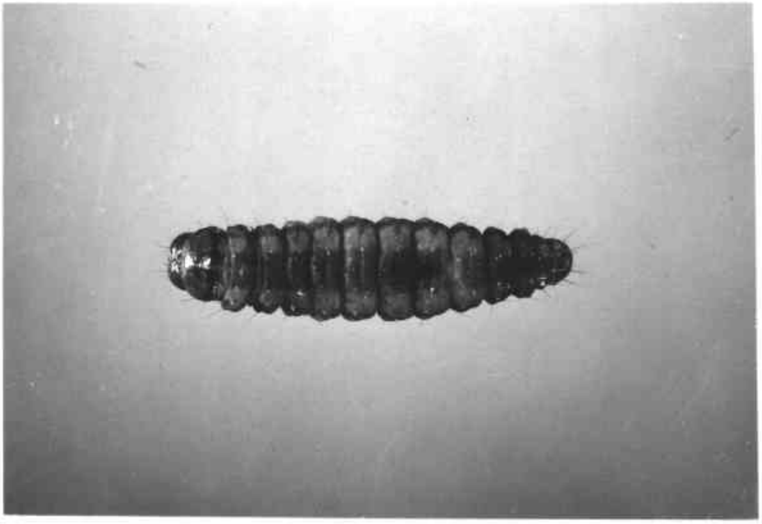
Directly following the first releases of L. erichsonii in 1958, it was felt that some observations should be made of the insect's development and preying-ability on infestations of A. piceae in Oregon and Washington. The following sections summarize the studies begun and the results gathered through November of 1959.

Periodic Collection of Life Stages - During 1958 and 1959, observations of the habits of L. erichsonii were made and recoveries of life stages recorded at each of the release areas. Visitations were usually scheduled, so that each area was visited every two weeks from the first of June until the middle of September, although random observations were made at other times.

Field Collection of Larvae and Adults - At the time of each visit, the stem of the release tree and other chermes-infested trees in the immediate vicinity were examined for the presence of L. erichsonii larvae and adults. If any of these stages were found, the particular stage, date found, approximate density, and distance from the original release tree were recorded. A few larvae were collected at time of each recovery of this stage in 1959 and brought to the laboratory for mounting on slides. All adults were left on the chermes-infested trees.

The different larval instars of L. erichsonii were separated by measuring the width of head capsule of the slide-mounted larvae and comparing the measurements with those used by Franz (9) in Europe to separate instars. Of the 52 larvae collected from May 23 through August 26 in 1959, no first instar larvae were present. Only one second and four third instars were found. Absence or scarcity of early instars in these collections bears out the following hypotheses: (1) first and second instar larvae are too small to be observed readily with the naked eye; and (2) they stay mainly within the egg masses of the aphid that are covered by the wax masses. Third and fourth instar larvae (Figure 9), however, leave the wax masses and wander about the bark in search of more prey where they are more readily seen. These habits of the different larval instars were also observed by Franz (9) in Europe.

In several instances, _L. erichsonii_ cast larval skins were seen on the bark of a chermes-infested tree. Two third instar larvae were seen in the process of moulting. This begins when the dorsal cuticle in the middle of the three thoracic tergites ruptures. Then, the frontal cephalic suture splits. The last abdominal segment appears to be fastened to the bark during this process, and then the head and thorax gradually work out of the old skin. After some struggling, the abdomen frees itself, and a fourth instar larva of a pale yellow color emerges. Franz (9) noted this same type of process in



(a) 4th instar larva (23X)

(b) pupa (15X)

(c) adult (13X)

Figure 9.- Laricobius erichsonii life stages: (a) larva; (b) pupa; and (c) adult.

Europe.

L. erichsonii adults (Figure 9) were found on infested stems from the first of May until the first of September (Table 3). Although L. erichsonii was found to be a univoltine species in Europe and eastern Canada, it is thought that the larvae found at Green River, Black Rock, and Willamette Pass in August and at Monroe in the last of July could be the result of a second generation occurring in the Pacific Northwest due to mild climatic conditions. However, more work should be done on this point in order to determine the correct life history of the predator in Oregon and Washington.

As can be seen in Table 3, L. erichsonii larvae were recovered almost a month earlier in the lowland release areas of Wind River and Benton-Lane than they were at most of the higher elevation release points. Mean summer temperatures at Wind River, Benton-Lane, Corvallis and Monroe are usually greater than at the other areas. This is probably why development of the predator was earlier at the two areas previously mentioned.

Establishment and development does not appear to be directly related to rainfall (Table 3). Benton-Lane, Corvallis, and Monroe have the least annual rainfall, and long periods without rain occur during the summer. The hardening of the soil caused by this lack of rainfall and

Table 3. Observations and recoveries of *Laricobius erichsonii* stages by area in 1959, and the elevation, annual rainfall, and mean annual temperature of each area.

Release Area	Elevation feet	Annual[1/] Rainfall inches	Mean Annual[1/] Temperature degrees F.	Span of Observations	Span of Recovery of *L. erichsonii* Larvae	Adults
Coldwater Cr.	2500	60.96	52.7	6/4-8/26	-	8/13
Green River	3500	60.96	52.7	6/4-8/26	8/13-8/26	6/4-8/26
Wind River	1000	103.75	50.7	5/5-7/31	5/23-6/26	5/5-7/10
Benton-Lane	350	42.72	54.5	5/15-11/23	5/29-7/21	-
Black Rock	2800	130.64	52.7	6/24-8/18	6/24-8/14	-
Corvallis	230	42.72	54.5	7/21-9/3	7/21[2/]	-
Monroe	350	42.72	54.5	6/17-9/3	6/17	
Willamette Pass	4000	55.74	43.3	6/22-9/2	6/22-8/6	9/2

1/ Annual rainfall and temperature taken from records of the closest U. S. Weather Bureau Station to each release area (16, Vol. 64, No. 13, p. 215-227)(17, Vol. 62, No. 13, p. 219-230).

2/ One badly mangled larva found in pitch mass.

high temperatures during the summer may have some effect upon the time the adults emerge from the ground in the fall. However, the predators have become at least temporarily established at two of these three areas. Black Rock has the greatest amount of annual rainfall, and, at times during the winter, water is left standing on the ground after a heavy rain. _L. erichsonii_ does not seem to be hampered by this, however, because establishment has occurred. Time of recovery of larvae at this area was about the same in 1959 as at Willamette Pass, an area that is 1200 feet higher in elevation and has considerably less precipitation.

Laboratory Rearing of Pupae - An effort was made in 1959 to collect _L. erichsonii_ pupae for study and photographic purposes. On July 15, five fourth instar larvae, collected the day before at Black Rock, were placed in a small can of moist, sterilized sand. The can was placed in a small rearing cage which was made of a wooden frame with three sides of muslin and a fourth side of plexiglass. The plexiglass was modified into a sliding door which provided easy access to the cage. The bottom and top of the cage were made of plywood. The sand was kept moist by spraying distilled water on it from time to time. By using sterilized sand and distilled water, it was hoped that the growth of fungus and mold could be held to a minimum.

On July 27, the material was examined. One larva had turned black and was desiccated, two were still healthy, and two had transformed into pupae. Photos were taken of the pupae (Figure 9), and then they were returned to the sand. The two remaining living larvae were dead at the time of the July 29 examination. By August 11, adults had not emerged from the pupae. Upon examination, one discolored, dried-out pupa was found, but the other pupa was not seen nor was an adult found, so the rearing was discontinued.

General Observations of Feeding Habits and Dispersal - From time of release of these derodontid beetles through the collection of life stages, various habits of these predators were noted. Among these were the feeding habits and dispersive power.

Feeding Habits - *L. erichsonii* adults appear to stick their heads into the wax mass of the aphid and feed (Figure 10). The adults do not always go directly from one wax mass to another, but will wander about the bark before again sticking their head into a mass. At times they walk over chermes egg masses and adults before feeding is resumed. The adult *L. erichsonii* seem to prefer adult aphids, although other stages are consumed.

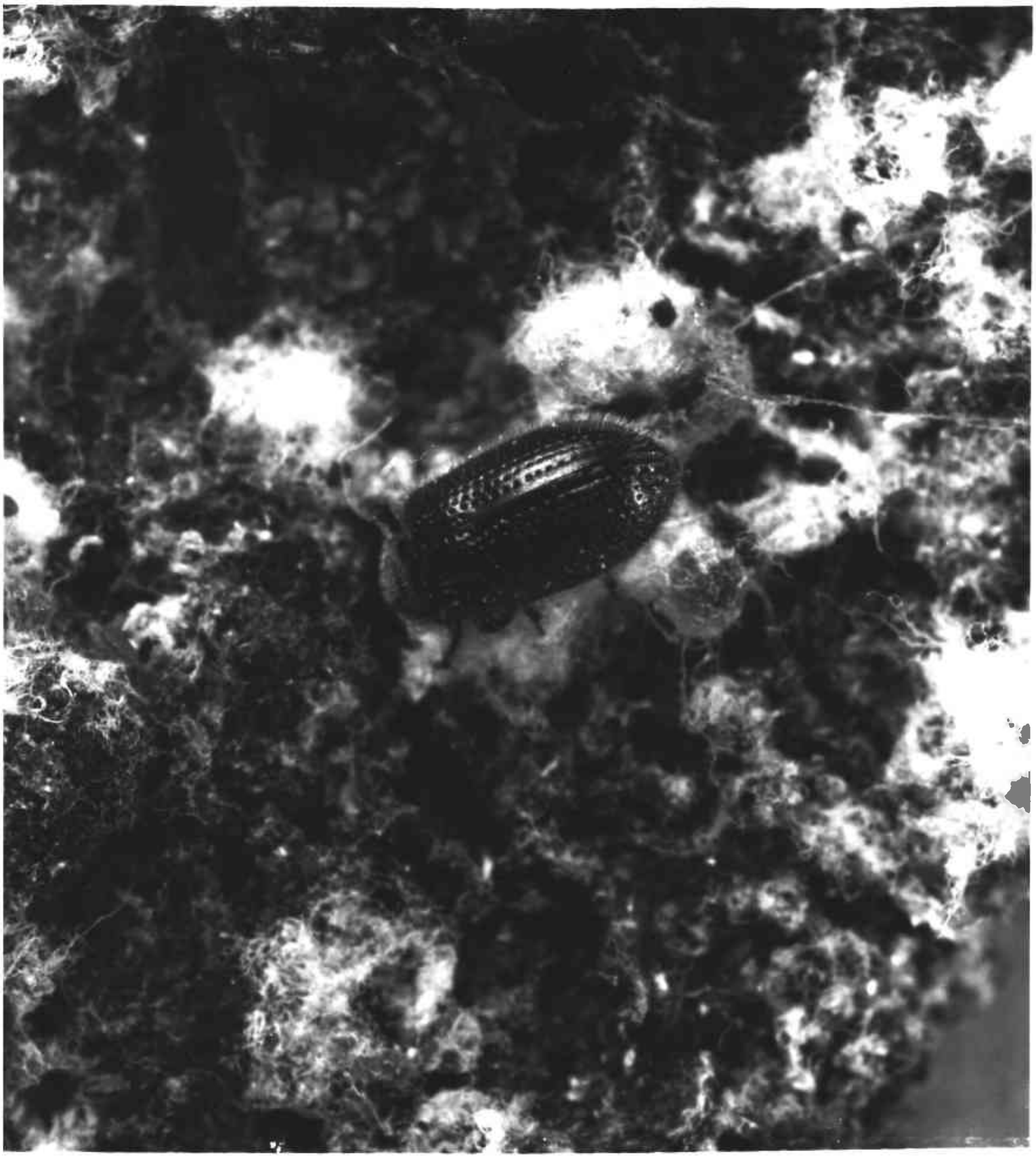


Figure 10.- Laricobius erichsonii adult feeding on Adelges piceae.

The fourth instar larvae move about the infested stem poking their heads in and out of wax masses. Some are found completely covered with wax of the aphid. Franz (9) reports this occurrence in Europe and says that dorsal epidermal glands produce a glue-like substance to which the wax adheres. When the larvae are touched, they regurgitate a droplet of brown fluid around the mouthparts, which Franz (9) also noticed and said was the contents of the fore-gut. As the larvae move about the bark they tend to tear apart the wax masses. A heavily attacked bole section, then, appears as though most of the wool has been pulled away from the bark. Also, many discolored, emptied aphid eggs can be seen on an attacked stem section. The characteristic behavior of attack of this predator is very striking.

A small laboratory experiment was conducted in July of 1958 to determine the feeding habits of a _L. erichsonii_ fourth instar larva. This larva was starved for about 12 hours and then placed on a bark chip infested by the balsam woolly aphid. The observations were made with the aid of a microscope in the basement of Sellwood Laboratory, while the temperature was 70°F., and the relative humidity was 50 per cent.

The larva wandered about the bark at first and passed over two wax masses before finally attacking the third. The larva stuck its mouthparts into the dorsal side of an adult aphid and started sucking out the aphid's body contents. While feeding, the larva moved forward and backward in a jabbing movement with its whole body. The larva was completely motionless between these jabs. This type of feeding continued for 6.5 minutes, and then the larva began searching about the egg clutch for another victim. After a half minute of this, the L. erichsonii larva returned to the adult to feed for 1.5 minutes more. The larva then left the wax mass, even though several eggs were present, and wandered about on the bark for two minutes until another egg mass was attacked.

This time the larva chose an aphid egg. The derodontid spread its mouthparts apart to grasp the egg and puncture it from both sides. Feeding motions occurred in the same manner as described before. Although several other eggs and an adult were available, the predator moved on in search of other prey when this egg was finished. After wandering about for one minute, the larva sank its mouthparts into another adult. The aphid was moved away from its egg clutch when the larva burrowed under the adult and backed away after biting it several times. This series of motions succeeded in tearing up the wax mass. Five eggs in this clutch were then attacked in this same manner.

In a period of about one and one-half hours, the larva destroyed seven eggs and two adults. The larva consumed the contents of each of the seven eggs in the following times: 8.5 min.; 3.0 min.; 4.5 min.; 5.5 min.; 8.25 min.; 6.5 min.; and 9.25 min. In every instance the fluid was completely drained from the eggs, but the chorion was not eaten. The remaining egg shells were quite flattened but still retained an orange color. However, they could be differentiated from the untouched eggs. The adult aphids attacked appeared to be only half-drained of their body fluids and not materially changed due to predation. In a few days, though, the adults became shriveled and dried up.

Although this study was conducted for only a very short period, it can be seen that _L_. _erichsonii_ has the potential to destroy large numbers of eggs and adults of _A_. _piceae_. One shortcoming, however, is that the predators do not move directly from one egg mass to another but may pass over several masses before feeding is continued.

It is very important that _L_. _erichsonii_ larvae and adults prey upon and destroy large numbers of _A_. _piceae_ eggs and adults, and that these forms are attacked early in the season, because the balsam woolly aphid has such a tremendous reproductive potential. The average egg production for each parthenogenetic female for the overwintering form (hiemosistens) is 100 and for the summer form (aestivosistens) 50 (1, p. 34). Disregarding mortality, then, one adult can be responsible for 5,000 (100 x 50) progeny in a location with one summer and one overwintering generation of the aphid. However, in some locations in the Pacific Northwest, more than one generation occurs during the summer; therefore, an adult is responsible for more progeny than 5,000. Two generations during the summer would produce 250,000 (100 x 50 x 50) sistentes per adult per year. If the eggs or adults of the aphid are destroyed in the overwintering form, then, subsequent generations will be reduced to a greater extent than if the predation occurs during the summer generation (s). It can be concluded that time of attack as well as number of aphids destroyed is an important factor in reducing *A. piceae* populations.

Observations of Dispersal - Dispersal of *L. erichsonii* occurred over only very short distances in the Pacific Northwest. This same trend was noticed in eastern Canada.

The following table shows the maximum distance of dispersal found at each release area.

Although dispersal occurred over these relatively short distances, it is interesting to note that at least some spread occurred at every release area except

Benton-Lane, where the study cage held dispersal in check.

Release Area	Maximum Distance from Release Point
Benton-Lane, Oregon	0[3/]
Black Rock, Oregon	35 feet
Corvallis, Oregon	15 feet
Monroe, Oregon	20 feet
Willamette Pass, Oregon	72 feet
Coldwater Creek, Washington	20 feet
Green River, Washington	50 feet
Wind River, Washington	75 feet

A year following release, the maximum observed spread in Oregon and Washington ranged from zero to 75 feet. At Willamette Pass, adults were found on three trees ranging from 10 to 72 feet from the original release point. Balch, Clark, and Brown (2) stated that the dispersive power of the predator must equal that of the prey in order to be an effective control factor. Because the winged-form of A. piceae does not occur in the Pacific Northwest, this pest depends mainly on wind for dispersal. Although wind currents sometimes carry insects several miles, dispersal of chermes occurs readily only within a very short distance. Also, this pest can spread only in the egg and nymphal stages. Because of these two factors, the slow dispersive power of L. erichsonii should not hamper its effectiveness greatly.

3/ Cage is still around the release tree, thus preventing dispersal.

In eastern Canada, the maximum observed spread of this predator found in the year following release ranged from zero to 485 yards (7, Vol. 90, p. 661). In Europe this insect is known to fly some distance. Several _A_. _piceae_ infestations are known that are well isolated from other infestations and that have _L_. _erichsonii_ populations present (9, Vol. 3, 157). It appears as though the predator has a greater dispersive power than has been found in the Pacific Northwest. An exact survey would have to be carried out to find the true distance of spread in this area.

Benton-Lane Predator-Effectiveness Study - On May 2, 1959, 800 _L_. _erichsonii_ adults were released in a 6 foot by 6 foot by 6 foot screened, walk-in study cage at Benton-Lane, Oregon. Besides limiting the dispersal of the introduced predators, the cage excluded the native predators and other foreign predators in the area. The cage surrounded a six-foot section at the base of a grand fir heavily infested with _A_. _piceae_ (Figure 11). The diameter of the study tree at breast height was 6.8 inches. The tree was located in a woodlot of pole-sized grand fir (Figure 12).

Objectives - The predators were released in this cage, so that some of the habits and the

Figure 11.- Predator-effectiveness study at Benton-Lane, Oregon, showing study cage, study tree, 5-foot study area, aluminum template and caged (protected) plots.

Figure 12.- Study cage in the pole-sized grand fir stand at Benton-Lane, Oregon.

effectiveness of the insects could be studied within a confined area on a chermes-infested tree. Benton-Lane was selected as the study site because it was close to Corvallis, and it was far enough from main travel routes that it would not be disturbed by other people.

Methods - The method of evaluating predator effectiveness was modified from the system used by Clark and Brown (7) at the Fredericton, New Brunswick, Forest Biology Laboratory. A five-foot section of the stem of the study tree was marked off with string and designated as the study area. Then, eight one-inch-square bark plots were established within this area. These eight plots were located in four vertical rows of two each, which were located six and 36 inches from the top of the study area on each of the four cardinal sides of the tree. These particular plot locations were chosen for two reasons: (1) it was thought that a wider variety of prey populations could be sampled; and (2) the two heights allowed comfortable positions for the observer, a point that is very important in obtaining an accurate count. Two of the plots were chosen at random to serve as check plots and were covered with small screen cages to exclude *L. erichsonii*.

At the time of each evaluation, an aluminum template with a one-inch-square inside area was hung on two aluminum nails, which were driven into the tree directly above each plot (Figure 11). Because the position of the nails was permanent, the template covered the same area each time, and the same one-inch-square of bark was evaluated.

The number of eggs per wax mass, crawlers, dormant neosistentes, intermediate stages, and adults of *A. piceae* were counted on each of these one-inch-square plots. Counts were made with the aid of a microscope mounted on an elevator-type camera tripod (Figure 13). The tripod steadied the microscope and left the hands free for probing when necessary.

The number of *L. erichsonii* within the five-foot study section was tallied at the time of each evaluation. However, the amount of time available after each chermes population count was completed was so small that the number of *L. erichsonii* larvae within the study area could not be counted.

The first count was made on May 1, one day before the predators were released in the cage. This rating showed the population level before predation on all plots. The plots were then evaluated at approximately two week intervals from this time through November 23, with the exception of the period from June 11 to July 21. The time required for other research prohibited counts during

Figure 13.- Method of rating plots on a study tree with the use of a microscope mounted on an elevator-type camera tripod. (This particular study tree was used in conjunction with other biological studies of the balsam woolly aphid.)

that time.

Results - Two weeks after release, several pairs of beetles were seen in copulation. The copulatory position was the same as was noted by Franz (9). That is, the female rests in a normal perpendicular or transverse position, and the male lies lateral to the female. Copulation of some pairs continued for an hour or longer. At times adults of *L. erichsonii* were seen under pieces of loose bark and moss on the stem of the tree. This hindered the taking of accurate count.

The first larvae of *L. erichsonii* were noticed 27 days after release, but these were third and fourth instar larvae; obviously, the other larval instars were present earlier. A gradual reduction in the *A. piceae* population resulted on the unprotected plots in the weeks following release of the predator (Table 7, Appendix). The wax masses were torn apart and many dried, empty eggs appeared in clutches that were originally untouched. The change in the *A. piceae* population was evident to the naked eye. On the protected plot the prey population increased noticeably (Table 8, Appendix), and the appearance of the wax masses was normal.

Results of the evaluations were graphed showing the comparison between the average number of neosistentes, intermediate stages, and adults of the balsam woolly aphid on the protected and unprotected plots (Figure 14). The number of L. erichsonii adults found on the bole at each evaluation is also plotted.

Neosistentes, intermediate stages, and adults of A. piceae were selected to represent the trend of this insect. These stages are the ones that cause gouting and/or inferior wood and subsequent tree killing. Although environmental conditions may have caused some mortality, it was felt that the effects of these would be equally felt on the protected and unprotected plots because the whole study area was confined in a single cage.

Figure 14 and Table 4 show that the average aphid population on the protected plots increased from 31.0 to 131.0 individuals, while the average population on the unprotected plots only increased from 46.5 to 63.8 in the period from May 1 through November 23. No adult predators were seen on the study area after the June 11 evaluation.

As can be seen by Figure 14 and Table 4, the average number of chermes neosistentes, intermediate stages, and adults were different on the protected and unprotected plots before the beetles were released. The average

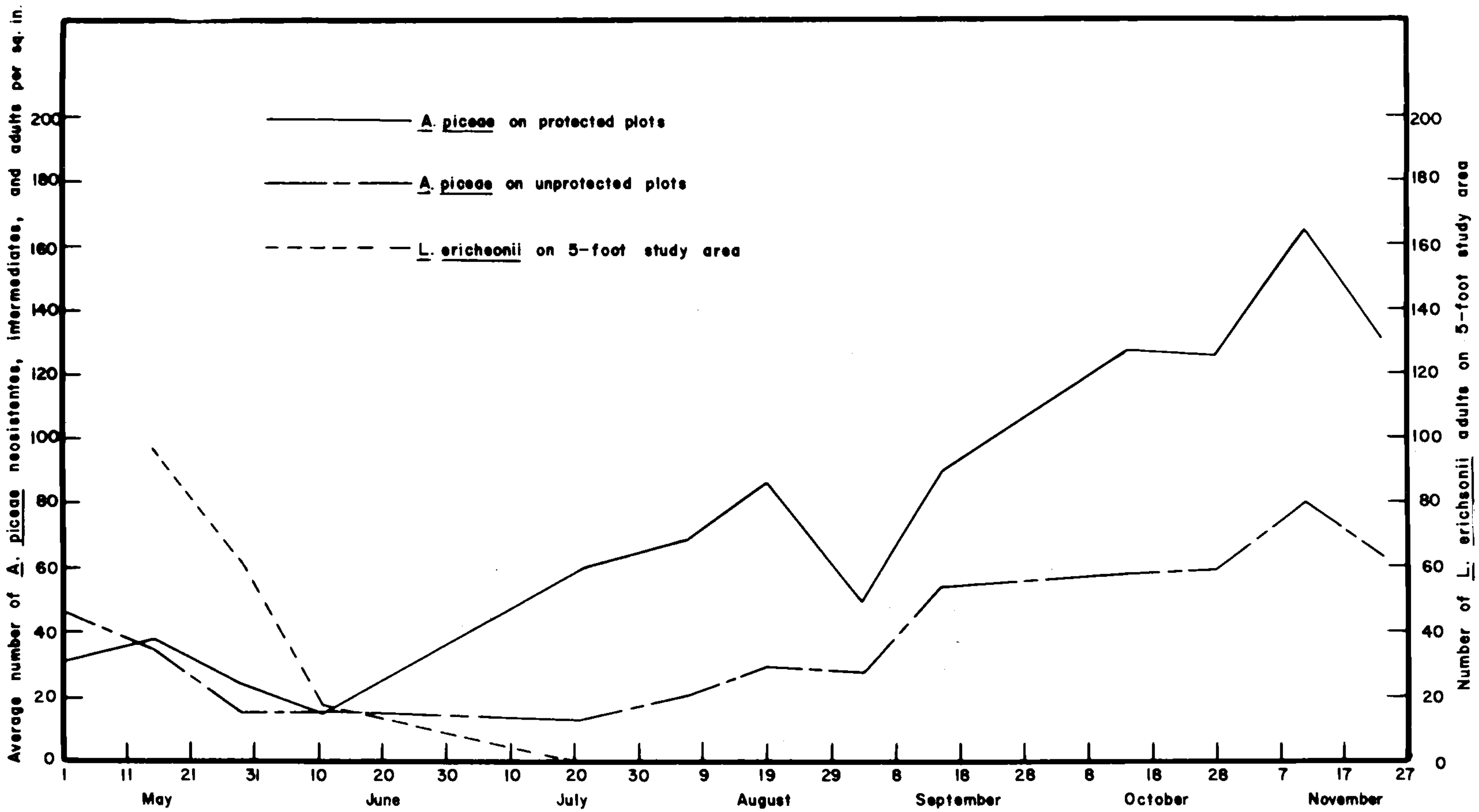


Figure 14. — Population trend of Adelges piceae on protected and unprotected plots and trend of Laricobius erichsonii adults on the study tree at Benton-Lane, Oregon, from May 1 through November 23, 1959.

population on the unprotected plots was greater (46.5 as compared with 31.0). This beginning difference could not be avoided because a random method of plot selection was used. Chermes populations were different on upper and lower plots and on plots on the different cardinal directions of the tree. The protected plots were selected by assigning a number to each plot, placing each number on a piece of paper, and placing all the numbers in a hat, and drawing out two numbers. As it turned out, one of the protected plots was in the upper and one was in the lower row of plots. Also each protected plot was on a different side of the tree. By using the random selection method, it was felt that personal bias could be avoided.

For the most part, the populations on the protected and unprotected plots took surges up and down due to the changes from one generation to the next at nearly the same time (Figure 14).

By July 21, the average population on the protected plots was over four times greater than on the unprotected ones (Table 4). Although both populations increased during subsequent generations, the average of the *A. piceae* population on the protected plots was a little over two times that of the average on the unprotected ones. Figure 14, therefore, shows that although the average of the chermes populations on the two protected plots began below the average of the populations on the six unprotected plots, it ended far above the unprotected plot average. This difference was due to the preying of L. erichsonii.

The greatest reduction in balsam woolly aphid populations on the unprotected plots occurred during a part of the host tree's growing season. It would appear that the reduction of aphids by the predators at this time would decrease damage to the tree during the rest of this growing season and probably the next one. However, chermes-host relationship studies on affected trees should be made during this period to provide information on this point.

Daily temperature and relative humidity were measured and recorded for May and June on a hygrothermograph placed in the study cage. The temperature ranged from 42° to 77°F. and relative humidity from 20 to 90 per cent during this time.

A t-test was computed to see if the difference between the average of the A. piceae populations on the protected and unprotected plots were statistically significant (Table 4). The t-value obtained was 4.3 with 12 degrees of freedom, which showed that the difference between the two types of plots was highly significant

Table 4. T-test[1/] of average adult, intermediate, and neosistens *Adelges piceae* population trend on protected and unprotected plots at Benton-Lane, Oregon, in 1959.

Observation	Average of sistentes on Protected Plots	Average of sistentes on Unprotected Plots	Difference
May 1	31.0	46.5	-15.5
May 15	38.0	34.7	3.3
May 29	24.0	15.7	8.3
June 11	14.5	15.4	-0.9
July 21	59.0	13.4	45.6
August 7	68.0	20.3	47.7
August 19	86.0	29.5	56.5
September 3	49.0	27.5	21.5
September 15	89.0	54.0	35.0
October 14	127.0	58.0	69.0
October 28	125.5	59.7	65.8
November 11	165.0	80.9	84.1
November 23	131.0	63.8	67.2

$n = 13$

$\Sigma y = 487.6$

$\bar{y} = 37.51$

$(\Sigma y)^2 = 237{,}753.76$

$\frac{(\Sigma y)^2}{n} = 18{,}288.7508$

$\Sigma y^2 = 30{,}234.28$

$SS = 11{,}945.5292$

$s^2 = 995.4608$

$\frac{s^2}{n} = 76.5739$

$\sqrt{\frac{s^2}{n}} = 8.7507$

$$t = \frac{\bar{y} - 0}{\sqrt{\frac{s^2}{n}}}$$

$t = 4.2865$ with 12 degrees of freedom

1/ Methods and symbols for this t-test taken from Li (12).

at the one per cent significance level (12, p. 520).

Although this sample was a small one, the results show that *L. erichsonii* has greatly affected *A. piceae* populations on the study plots at Benton-Lane under the specified conditions. If this predator can reduce population of *A. piceae* over large areas, as it has on the sample areas, then *L. erichsonii* will become an important factor in the biological control of the balsam woolly aphid in Oregon and Washington.

It is felt that *L. erichsonii* will not satisfactorily control the balsam woolly aphid by itself, but it must combine with other predators that are also fairly host specific and attack all stages of *A. piceae*. At Willamette Pass, *L. erichsonii* is established along with two species of foreign predators, *Aphidoletes thompsoni* and *Neoleucopis obscura*, and several species of native predators. At Wind River, *L. erichsonii* and *Aphidecta obliterata* were observed preying on chermes stages on the same tree at the same time. In most of the other locations, the derodontid appears on chermes-infested trees that have small populations of native predators present. If such a predator complex can build up into heavy populations, a suitable control for *Adelges piceae* in the Pacific Northwest may be found. *L. erichsonii* will probably be one of the most important species in this complex because of its ability to prey on all stages of the aphid except the nymphs and because of its host specificity.

SUMMARY

The balsam woolly aphid, Adelges piceae (Ratz.), is an European insect that was first discovered in the Pacific Northwest shortly after 1930. Adequate control measures have not been developed to check the wide-spread tree killing caused by this insect. Grand fir, Pacific silver fir, and subalpine fir are the main species infested in Oregon and Washington.

Several insect species were reported as being native predators of this aphid in Europe, eastern Canada, and the Pacific Northwest. Nineteen species of European predators were introduced into eastern Canada in an effort to find some effective control measure, but only four species have become well established. From 1957 through 1959, 14 species were imported into Oregon and Washington. At the time this thesis project was begun, only Aphidoletes thompsoni and Laricobius erichsonii had shown promise of becoming established in this region. L. erichsonii was chosen for further study by the author.

Two species of the genus Laricobius are indigenous to the Pacific Northwest. Habits, effectiveness, and life history of L. erichsonii in Europe and eastern Canada are discussed. It was estimated that an individual L. erichsonii consumes about 2,970 aphid eggs during

the predator's lifetime. This beetle also feeds on aphid adults.

In 1958 and 1959, 10,125 *L. erichsonii* adults were released at eight different areas in Oregon and Washington. These insects were collected in Czechoslovakia and Germany and sent to Belleville, Ontario, Canada, and on to Portland, Oregon, by Air Freight or Air Express in a wooden shipping container. Predators were released either freely or in cages. Five of the release areas were in Oregon and three in Washington. Each area was heavily infested with *A. piceae* at time of release.

L. erichsonii stages were recovered on 10 of the 11 original release trees. A year following release, establishment was observed at both 1959 release areas. *L. erichsonii* seems to be able to survive at each of these areas even though elevation, rainfall, and temperature vary considerably.

Recovery dates of *L. erichsonii* life stages were noted and larvae were collected from time to time at each area during 1959. Of 52 larvae collected in 1959, no first, one second, four third, and 47 fourth instar were present. First and second instar larvae usually stay within the aphid egg masses, and the third and fourth wander about in search of food. Moulting was observed. Larvae were recovered from May 23 through August 26 and adults from May 5 through September 2 at the various release areas.

Two pupae were reared from five, field-collected fourth instar larvae. One fourth instar larva consumed or destroyed seven eggs and two adults in one and one-half hours in a laboratory test.

Dispersal of L. erichsonii occurred over only very short distances. Maximum observed spread a year following release ranged from zero to 75 feet.

A study was initiated at Benton-Lane, Oregon, to study the effectiveness of L. erichsonii in controlling populations of A. piceae. Eight hundred adults were released in a study cage in May of 1959. The trend of aphid populations on six unprotected and two protected (control) one-inch-square bark plots was measured. Population counts were made at approximately two week intervals. On the protected plots, the average aphid population increased from 31.0 to 131.0 individuals in the period from May 1 through November 23, while on the unprotected plots it increased from 46.5 to 63.8 individuals.

A t-test was computed to determine whether the differences between populations on protected and unprotected plots were significant. The t-value obtained was 4.3, which showed that the differences were significant at the one per cent level.

It is concluded that _L. erichsonii_ has the ability to reduce _A. piceae_ populations significantly. This predator could prove to be an important factor in controlling the balsam woolly aphid, if large populations of the beetle develop, and if other fairly host specific predators that feed on all stages of the aphid combine with _L. erichsonii_.

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A P P E N D I X

Table 5. Shipments and releases of *Laricobius erichsonii* in Oregon and Washington in 1958 and 1959.

Year of release	Source	Shipment no. and no. predators	Arrival date in Portland	Condition on arrival
1958	Czecho-slovakia	1 - 1250	5/19	Good - Less than 5% mort.
		2 - 2580	5/24	Fair - est. 10% mort.
		3 - 3670	5/27	Fair - est. 15% mort.
		4 - 1150	5/29	Excellent est. 2% mort.
	Subtotals	8650		
1959	Germany	1 - 840	5/1	Fair - est. 10% mort.
		2 - 800	5/6	Good
	Subtotals	1640		
	Totals	10290		

Table 5. Shipments and releases of *Laricobius erichsonii* in Oregon and Washington in 1958 and 1959. (Cont'd)

Date of release	Location of release	No.[1/] released	Type of release	Species of release tree
(a) 5/20	Black Rock, Or.	400	Cage	*Abies amabilis*
(b) 5/20	Corvallis, Or.	325	Cage	*A. grandis*
(c) 5/21	Green River, Wn.	400[2/]	Cage	*A. amabilis*
(a) 5/26	Corvallis, Or.	1380	Free	*A. grandis*
(b) 5/26	Willamette Pass, Or.	1200	Free	*A. lasiocarpa*
(a) 5/27	Coldwater Cr. Wn.	1320	Free	*A. amabilis*
(b) 5/27	Green River, Wn.	1200	Free	*A. amabilis*
(c) 5/28	Black Rock, Or.	1150	Free	*A. amabilis*
5/30	Wind River, Wn	1150	Free	*A. lasiocarpa*
Subtotals		8525		
5/2	Benton-Lane Ore.	800[3/]	Study cage	*A. grandis*
5/7	Monroe, Ore.	800	Free	*A. grandis*
Subtotals		1600		
Totals		10125		

1/Numbers are not corrected for mortality, which was generally low and could not be accurately assessed because of the urgency of prompt release.

2/125 adults were kept for photographic reasons, etc.

3/40 adults retained in Corvallis for experimental use.

Table 6. Summary of observations of *Laricobius erichsonii* in Oregon and Washington in 1958 and 1959.

Year of Release	Release Area	No. Released (Adults)	1958 Observations	1959 Observations
1958	Black Rock, Ore.	1550	Found numerous larvae on both release trees.	Found larvae on several trees from 5-40 ft. from the release trees.
	Corvallis, Ore.	1705	Found larvae on one of the two release trees and on several other trees in the vicinity.	Found one larva imbedded in pitch. No other recoveries made.
	Willamette Pass, Ore.	1200	Found a few larvae and adults on the release tree.	Found larvae and adults on several trees up to 72 ft. from the original release point.
	Coldwater Cr., Wn.	1320	Found many larvae on the bole of the release tree.	Release tree dead; found several adults on a tree 20 ft. away.
	Green River, Wn.	1600	Found larvae on one of the two release trees.	Found larvae and adults on two trees up to 50 ft. away from the release tree that harbored a predator population in 1958.

Table 6. Summary of observations of *Laricobius erichsonii* in Oregon and Washington in 1958 and 1959. (Cont'd)

Year of Release	Release Area	No. Released (Adults)	1958 Observations	1959 Observations
1958	Wind River, Wn.	1150	No evidence of establishment.	Release tree dead; found numerous larvae and adults on two trees 6 and 75 ft. from the original release point.
1959	Benton-Lane, Ore.	800	-	Many larvae found on release tree. Tree is surrounded by a cage to the height of six feet.
	Monroe, Ore.	800	-	Several larvae found on release tree, and several cast larval skins found on an adjacent tree.

Table 7. Summary of average number of chermes stages on six unprotected, one-inch-square plots at Benton-Lane, Oregon, in 1959.

Date of Observation	Ave. No. Crawlers	Ave. No. Dorm. Neosistentes	Ave. No. Inter. Stages	Ave. No. Adults	Total
May 1	18.2	0.2	0.3	46.0	64.7
May 15	8.3	6.0	0.2	28.5	43.0
May 29	2.5	9.7	0.7	5.3	18.2
June 11	0.3	12.7	1.2	1.5	15.7
July 21	0.8	8.0	2.2	3.2	14.2
August 7	2.0	13.3	1.8	5.2	22.3
August 19	1.7	17.2	4.3	8.0	31.2
September 3	5.5	6.0	6.5	15.0	33.0
September 15	20.3	22.0	10.5	21.5	74.3
October 14	17.0	41.2	0.5	16.3	75.0
October 28	6.2	47.5	3.5	8.7	65.9
November 11	1.7	69.8	2.3	8.8	82.6
November 23	0.7	50.5	0.8	12.5	64.5
Average	6.5	23.4	2.7	13.9	46.5

Table 8. Summary of average number of chermes stages on two protected, one-inch-square plots at Benton-Lane, Oregon, in 1959.

Date of Observation	Ave. No. Crawlers	Ave. No. Dorm. Neosistentes	Ave. No. Inter. Stages	Ave. No. Adults	Total
May 1	13.0	0.5	0.0	30.5	44.0
May 15	5.5	8.5	0.0	29.5	43.5
May 29	5.5	12.0	0.0	12.0	29.5
June 11	0.5	13.0	0.5	1.0	15.0
July 21	8.5	36.0	14.5	8.5	67.5
August 7	6.0	48.0	9.0	11.0	74.0
August 19	4.0	43.5	8.0	34.5	90.0
September 3	11.0	10.0	2.0	37.0	60.0
September 15	26.0	40.5	13.0	35.5	115.0
October 14	18.5	73.0	2.0	33.5	127.0
October 28	8.0	93.0	4.5	28.0	133.5
November 11	0.0	137.0	2.5	25.5	165.0
November 23	0.0	105.5	0.0	25.5	131.0
Average	8.2	47.7	4.3	24.0	84.2

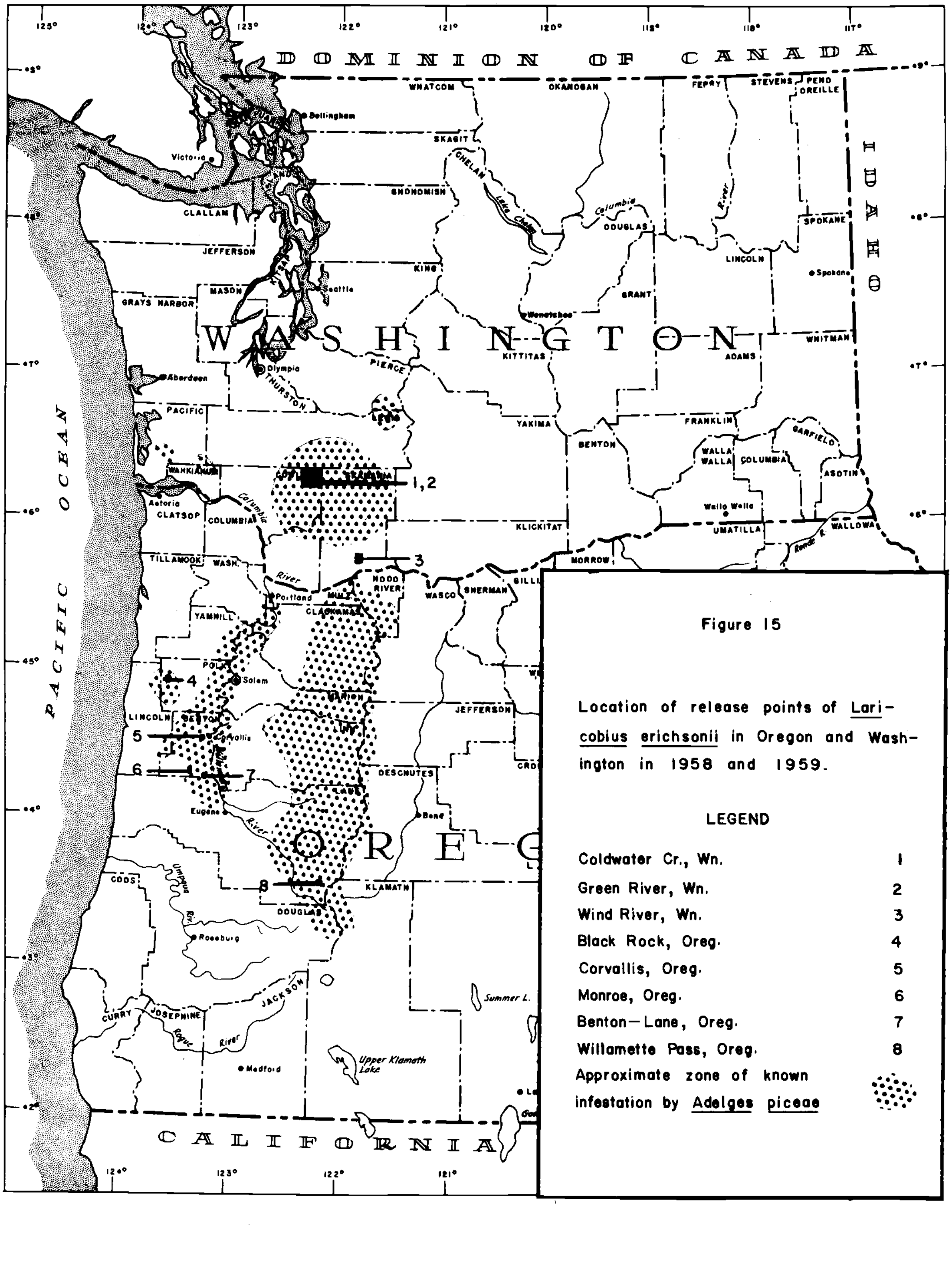

Figure 15

Location of release points of *Laricobius erichsonii* in Oregon and Washington in 1958 and 1959.

LEGEND

Coldwater Cr., Wn.	1
Green River, Wn.	2
Wind River, Wn.	3
Black Rock, Oreg.	4
Corvallis, Oreg.	5
Monroe, Oreg.	6
Benton–Lane, Oreg.	7
Willamette Pass, Oreg.	8
Approximate zone of known infestation by *Adelges piceae*	