NATURAL ENEMIES OF ADELGIDS IN NORTH AMERICA: THEIR PROSPECT FOR BIOLOGICAL CONTROL OF *ADELGES TSUGAE* (HOMOPTERA: ADELGIDAE)

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ABSTRACT

On eastern hemlock, we found two resident beetles preying on *Adelges tsugae* Annand. One is a coccinellid native to Europe, *Scymnus suturalis* Thunberg, that also feeds on *Pineus* sp. that attack pines. The other is a native derodontid beetle, *Laricobius rubidus* LeConte. The seasonal life history of these two species indicates that their effect on *A. tsugae* will be more complementary than competitive. The effectiveness of these species may be enhanced by the presence of alternative prey that attack other conifers. Among the many species imported for control of the balsam woolly adelgid, the coccinellid *Aphidecta obliterata* (L.) appears to have the best potential for biological control of *A. tsugae*. It is important to assess the incumbent population of natural enemies before introducing biological controls, in order to better understand the kind of biological controls that are most suitable and reduce displacement of native species. A multispecies strategy seems the best approach to achieve biological control of *A. tsugae*.

INTRODUCTION

The two species of hemlock in eastern North America, *Tsuga canadensis* (L.) Carr. and *T. caroliniana* Engelm., are threatened with destruction by the hemlock woolly adelgid, *Adelges tsugae* Annand. Populations of the adelgid often build rapidly to high levels, causing bud abortion and needle drop and a decline in health that often results in tree death. Species of hemlock in Asia and western North America are attacked by *A. tsugae* but are seldom damaged. Apparently, a combination of host resistance and natural enemies maintains the density of *A. tsugae* on these hemlocks below thresholds that cause observable damage (McClure 1992; Cheah and McClure 1996).

Classical biological control is a viable option to reduce the impact of *A. tsugae* on eastern hemlocks. There are several points to consider before initiating a biological control program: (1) Because of the high fecundity of *A. tsugae* on the eastern hemlocks, there must be unusually high mortality from natural enemies. It is likely that a complex of natural enemies will be required to maintain the pest below damaging levels. (2) Previous attempts to control members of the family Adelgidae using natural enemies have been more successful for the genus *Pineus* than for *Adelges*. This situation may reflect a requirement for a stricter phenological match between *Adelges* and its predators. (3) Impacts on nontargets should be considered, including competition with or displacement of native natural enemies.

ASSESSING BIOLOGICAL CONTROLS FOR OTHER ADELGIDS

Members of the family Adelgidae have few natural enemies. No parasites that attack any member of the family are known. Several fungal diseases have been reported for the balsam woolly adelgid, *A. piceae* (Ratz.), though field experiments with these have not been successful (Schooley et al. 1984). Only predators have been used successfully for biological control of adelgids.

More than 30 species of predators have been imported and released in North America to control *A. piceae* on balsam fir, *Abies balsamea* (L.) Miller. None of the predators collected in India and Pakistan between 1961 and 1965 became established in North Carolina (Amman and Speers 1971), eastern Canada, or British Columbia (Schooley et al. 1984). The climate here may not be suitable for these predators; the mean January temperature in the city near the main collection area in Pakistan is above freezing. One of the two predators imported from Japan, *Adalia ronina* (Lewis) (Coleoptera: Coccinellidae), may have become established (Schooley et al. 1984), but its effectiveness and current status are unknown. Canada began importing predators from Europe in 1933, and both Canada and the United States participated in an aggressive program from 1957 to 1969. Of the nine species imported from Europe, all but one were recovered a year or more after their release (Schooley et al. 1984; Clausen 1978). The current status of these is poorly documented; none seems able to effectively reduce damage by *A. piceae* (Schooley et al. 1984). The biology of six of the predators and factors that may influence their success follow.

***Leucopis* nr. *obscura* Hal. (Diptera: Chamaemyiidae).** (Note: the subgenus *Neoleucopis* is undergoing revision. Designations of *L. obscura* in the literature on biocontrol of *A. piceae* may refer to another or to more than one species.) *L. obscura* was introduced from Europe to Canada from 1933 to 1955 and subsequently to the Pacific Northwest and North Carolina from 1959 to 1965. Except for North Carolina, initial releases resulted in local establishment and rapid spread from initial release sites.

Despite the high level of vagility of *L. obscura*, Brown and Clark (1957) listed three factors that limit its effectiveness as a biological control agent for *A. piceae:* (1) inadequate synchrony with the adelgid host; (2) limited searching ability of larvae, which renders them ineffective at low levels of adelgid infestation; and (3) greater overwinter mortality of the predator than the host. In addition, *L. obscura* is subject to parasitism by wasps in the family Pteromalidae. The establishment of *L. obscura* may have displaced the native chamaemyiid *Leucopina americana* (Mall.) (Balch 1952).

L. obscura has effectively controlled *Pineus boerneri* (Annand) on Monterey pine, *Pinus radiata*, in New Zealand (Rawlings 1958), and *P. pini* (Macquart) on *P. pinaster* Aiton in

Hawaii (Culliney et al. 1988). We have observed an abundance of *L. obscura* on heavy infestations of *P. strobi* (Hartzig) in the New England area. Because *P. pini* and *P. strobi* have five overlapping generations per year, there is a fairly continuous supply of all life stages throughout the growing season. *L. obscura* has two generations; larvae are present for much of the season but reach peak numbers in midsummer (Brown and Clark 1957). Both *A. piceae* and *A. tsugae* have two distinct generations per year with a resting stage in midsummer.

Cremifania nigrocellulata **Czerny (Diptera: Chamaemyiidae)** is multivoltine and was introduced annually into eastern Canada between 1952 and 1955. This predator also was released in Oregon and British Columbia between 1958 and 1968. Establishment was achieved in most release areas (Clausen 1978). There are three generations in Europe; the autumn generation is most numerous (Delucchi and Pschorn-Walcher 1954). Predation in eastern Canada was more intense later in the season than in the spring (Clark and Brown 1962). In Canada, the predator was associated mostly with dense infestations (Balch et al. 1958; Mitchell and Wright 1967). It is parasitized by pteromalid wasps (Brown and Clark 1956). The fly still is present, but seems relatively uncommon (Humble 1994). Since this species attacks primarily dense populations on the tree bole, it seems to have little potential for controlling *A. tsugae.*

Aphidoletes thompsoni **Möhn (Diptera: Cecidomyiidae).** This multivoltine fly was introduced from Czechoslovakia and Germany to several localities in North America for control of *A. piceae* between 1955 and 1969. It became established at most release and recolonization sites (Mitchell and Wright 1967; Schooley et al. 1984), but it is unclear whether the species still is present. It has several generations per year, can attain densities as high as 0.1/cm^2, can survive at adelgid densities as low as 1/cm^2, pupates successfully in dry soils, disperses at the rate of 1 km/year, and is active in the Pacific Northwest at the time when other predators wane in abundance (Mitchell and Wright 1967). This species is the most important of those attacking *A. piceae* in Europe and is known to prey on other species of *Adelges* (Clausen 1978). In eastern Canada, as many as half the larvae were parasitized by a wasp in the family Ceraphronidae (Smith and Coppel 1957), but Mitchell and Wright (1967) did not observe parasitism in the western United States.

Laricobius erichsonii **Rosenhauer (Coleoptera: Derodontidae).** More than 90,000 specimens of this beetle were introduced from Europe into eastern Canada between 1951 and 1966. Brown and Clark (1956) reported that *L. erichsonii* became well established in eastern Canada, with larvae killing sufficient numbers of first-generation *A. piceae* nymphs and adults to reduce the second generation substantially. Adult beetles were observed feeding in early spring and midsummer, but they had less impact than larvae on densities of *A. piceae* (Brown and Clark 1956). This univoltine beetle was released in North Carolina from 1959 to 1962. In field cages on boles of Fraser fir (*Abies fraseri* Poir) infested with *A. piceae, L. erichsonii* reduced adelgid populations significantly (Amman and Speers 1965). *L. erichsonii* collected in Maine were released in Oregon and Washington from 1958 to 1962, and establishment was achieved at numerous release sites. Although cage studies showed that the predator significantly reduced adelgid populations compared to a control, there was a net increase in the density of the adelgid (Buffam 1962).

Of the eight species of exotic predators released in British Columbia between 1960 and 1969, *L. erichsonii* was among the four considered established in 1978; however, it was not recovered in later informal surveys (Humble 1994). Some reports of establishment may be erroneous because all stages of *L. erichsonii* are difficult to distinguish from *L. rubidus*, a native species (Clark and Brown 1960). Our inquiries found no one who has seen this beetle in Newfoundland, Maine, or North Carolina in the last 20 years. The beetle has several attributes that may limit its effectiveness: a dependence by larvae on high prey densities, poor survival of pupae during summer droughts, and inadequate temporal synchrony between beetle larvae and *A. piceae* (Mitchell and Wright 1967).

***Aphidecta obliterata* (L.) (Coleoptera: Coccinellidae).** Release of this univoltine beetle from Europe began in 1941 and ended in 1968. It was not considered as having become established in British Columbia after its release (Harris and Dawson 1979), but it was the predator most frequently recovered by Humble (1994) 20 years later. It was reported to have been established in North Carolina (Amman 1966) and the Maritime Provinces (Schooley et al. 1984) in the year after release, but we are unaware of recent sightings in eastern North America. In field cages on boles of Fraser fir, *A. obliterata*, infested with *A. piceae*, reduced numbers of adelgids significantly (Amman and Speers 1965). Both larvae and adults have been observed feeding on all stages of *A. piceae* except mobile crawlers. In Europe, *A. obliterata* attacks most species of Adelgidae and many aphids that infest the twigs of conifers (Wylie 1958). Humble (1994) found this coccinellid associated with several other adelgids and the green spruce aphid in British Columbia.

***Scymnus (Pullus) impexus* (Mulsant) (Coleoptera: Coccinellidae).** More than 100,000 specimens of this beetle were introduced into Canada between 1951 and 1968. This species generally is distributed in Europe in association primarily with *A. piceae.* It has only one generation per year, with adults living a year or more. *S. impexus* oviposits primarily in the late summer, and eggs hatch in early spring. In Europe, larvae appear in April, and development coincides with the active spring generation of *A. piceae* (Delucchi 1954). This species substantially reduced dense infestations of *A. piceae* (Clausen 1978).

S. impexus was released in eastern Canada, British Columbia, the Pacific Northwest, and North Carolina in the 1950s and the 1960s. Establishment was reported in all areas except North Carolina. The last reported recovery was in 1978 in British Columbia (Harris and Dawson 1979). The coccinellid was thought to be promising as a predator because it fed at low prey densities and early in the year. Although *S. impexus* is difficult to locate, Mitchell and Wright (1967) believed it was the most firmly established of the imported species in the Pacific Northwest. Except for the effect of low winter temperatures on its success in eastern Canada (Clark and Brown 1961), the literature provides little indication as to why this predator is scarce. Although *S. impexus* is similar to *S. suturalis* Thunberg (discussed later) in size and biology, the adults can be distinguished visually.

Potential for control of *A. tsugae*. Although post-release monitoring failed to recover it, *Aphidecta obliterata* is now the most abundant exotic predator of *A. piceae* in British Columbia (Humble 1994). This coccinellid was recovered in North Carolina several years after release (Amman and Speers 1964). Low winter temperatures may have limited establishment of this species in other areas. In British Columbia, *A. obliterata* has been recovered in association with *A. tsugae* (Humble 1994). It seems worthwhile to introduce and evaluate *A. obliterata* as a biological control of *A. tsugae*, particularly in areas with moderate temperate climate.

A. thompsoni also has potential as a component of a biological control program for *A. tsugae.* Mitchell and Wright (1967) considered it the next most promising predator after *L. erichsonii*. *A. thompsoni* likely would be unable to reduce populations sufficiently by itself, but its activity in the fall and at low prey densities could complement other predators. Predaceous midges have not been given the attention they may deserve because they are difficult to survey and introduce. The difficulties in handling and colonizing these fragile flies are discussed in Balch et al. (1958).

Leucopis nr. *obscura* quickly moved onto the pine bark adelgid and now is abundant in large colonies of this adelgid throughout the range of white pine. It is unlikely that the incumbent species of *Leucopis* that attacks *P. strobi* will shift to *A. tsugae* since the fly has been in contact with it for many years in several areas of the eastern United States.

Laricobius erichsonii was considered by both Mitchell and Wright (1967) and Amman and Speers (1964) as the most promising of the predators introduced in British Columbia and North Carolina, respectively. It has not been recovered recently. Because this species is easily confused with native species (Clark and Brown 1960), early reports on its effectiveness may pertain to the native species. We have found a native species to be fairly common on *A. tsugae* in Connecticut and report on it later in this chapter. A native species has been reported from *A. tsugae* in British Columbia (Lee Humble, pers. comm.).

INCUMBENT PREDATORS OF ADELGIDS IN NEW ENGLAND

Two years after *A. tsugae* was discovered in Connecticut, McClure (1987) found midges (Cecidomyiidae), flower flies (Syrphidae), and lacewings (Chyrsopidae) associated with it, but at densities too low to significantly reduce populations of the adelgid. With time, endemic natural enemies frequently make host shifts to introduced species. Our surveys found several predators attacking the pine bark adelgid, *P. strobi*, in Vermont, Massachusetts, and Rhode Island. These predators attacked *A. tsugae* in the laboratory. In 1992, we initiated periodic surveys of infested eastern hemlock (*T. canadensis*) growing in mixed stands with eastern white pine (*Pinus strobus* L.) and Scotch pine (*Pinus sylvestris* L.), to determine whether these or other predators had made a host shift to *A. tsugae* and to compare the seasonal history of natural enemies of adelgids on these conifers.

Survey on eastern white pine (1992). The three natural enemies most frequently associated with *P. strobi* were: *Leucopus obscura, Scymnus suturalis* Thunberg, and an anthocorid, *Tetraphelps* sp. (Hemiptera: Anthocoridae).

L. obscura was abundant in dense populations of *P. strobi* that form white mats on the boles of eastern white pine. It was rare in sparse populations of adelgid, characterized as scattered white speckles on the bark or at the base of needles. Larvae of *L. obscura* were present from May to November, though peak abundance was in late May and June. Pupae were scattered in the adelgid colony beneath the mats of woolly wax. Large numbers of these predators were obtained by scraping the white mats of adelgid into cups. These were sorted in the laboratory under a microscope to obtain larvae or placed in cages for adult flies to emerge. Larvae of *L. obscura* fed on all stages of *A. tsugae* and completed development on it. No oviposition was observed when adults were caged on the foliage infested with the hemlock adelgid. In several sites where infestations of *P. strobi* and *A. tsugae* coexist, *L. obscura* was recovered only from *P. strobi*. We conclude that *L. obscura* does not attack *A. tsugae* under natural conditions.

Tetraphelps sp. were observed in large numbers in late June from *P. strobi* in Rhode Island. Nymphs of this species were cryptic whitish-gray, and feeding on eggs of *P. strobi*. They also fed on eggs and nymphs of *A. tsugae* in the laboratory. Our sampling of *A. tsugae* overlooked this active and fragile predator.

S. suturalis was less abundant than *L. obscura* in dense populations of *P. strobi,* but more frequent in small, dime-size clusters. Larvae of *S. suturalis* were found during May and June, and adults were present throughout the spring and summer. In the laboratory, both larvae and adults fed on all stages of *A. tsugae,* and eggs were fed on voraciously. We observed *S. suturalis* ovipositing on *A. tsugae* in the laboratory. This coccinellid seemed to be promising as a biological control of *A. tsugae;* consequently, in 1992, we located several populations of *P. strobi* in Vermont and Massachusetts for collection of *S. suturalis* the following spring for release on eastern hemlock infested with *A. tsugae.*

Survey on eastern hemlock (1993). Populations of *P. strobi* crashed during the winter. Most of April and May was spent intensely searching for populations in New Jersey and states in New England, but we located no dense pine bark adelgid populations, finding only a few black, ovoid "cysts" from which adult adelgids later emerged. In May, we found several adult *S. suturalis* on foliage of eastern white pine. We then surveyed eastern hemlock infested with *A. tsugae* that was growing near white and Scotch pine. Both adults and larvae of *S. suturalis* were abundant on eastern hemlock.

These findings led us to initiate an extensive survey of eastern hemlock foliage for predators. We needed a method that would provide a large number of samples and an indication of relative densities over time in different areas. The standard sampling protocol was to dislodge predators from the distal 0.5 m of a branch by tapping it six times with a stick over an umbrella. Each sample replicate consisted of four branches in each of the four cardinal directions from a minimum of eight trees.

The seasonal occurrence of *S. suturalis* on eastern hemlock is shown in Table 1. The coccinellid was found on several eastern hemlocks at this site. These eastern hemlocks were near the edge of a water reservoir that also had been planted with eastern white pine and Scotch pine. The number of *S. suturalis* declined the farther the eastern hemlocks were from the pines, and no *S. suturalis* were found more than 200 m from the pines.

Table 1. Phenology of *S. suturalis* larvae and adults on eastern hemlock infested with *A. tsugae* at Lake Whitney, Hamden, Connecticut, in 1993.

Date	Average no. (± SE) larvae per branch	Average no. (±SE) adults per branch
26 May	2.9 ±0.6	0.2±0.6
24 June	1.4 ±0.6	0.5 ±0.2
29 June	0.5 ±0.3	0.6 ±0.3
7 July	0.7 ±0.7	0.4 ±0.2
13 July	0	0.6 ±0.2
20 July	0	0.2 ±0.1
26 July	0	0.2 ±0.1
4 August	0	0.2 ±0.1
10 August	0	0
19 August	0	0
25 August	0	0
2 September	0	0

This was the first record of *S. suturalis* feeding on *A. tsugae* (Lyon and Montgomery 1995). Native to Europe, *S. suturalis* was released in Michigan in 1961 for biological control of aphids. It is suspected that it also was brought in on nursery stock around the turn of the century. Previously, *S. suturalis* had been collected from pines and once from spruce. It also has been reported from New York, Pennsylvania, Maryland, Virginia, and Quebec, Canada. There were no prior records of its biology or hosts. We believe that *S. suturalis* is univoltine, with the adult overwintering. The adult is about 2 mm long with a black head and thorax, and dark brown elytra with a black edge. The larvae are covered with a fluffy wax that they secrete. It is not clear whether eggs are laid in late fall or early spring. A related species, *S. impexus*, oviposits in late fall with egg hatch in the spring (Delucchi 1954). An adult *S. suturalis* collected in early spring deposited eggs shortly thereafter in the laboratory. These were destroyed by a small, translucent mite on foliage of eastern hemlock. Both adults and larvae of *S. suturalis* feed on all stages of the adelgid. Eggs are consumed voraciously; adults average 16 eggs, and larvae 6 eggs, per day.

Several other natural enemies were found on eastern hemlock, but in low numbers. Syrphid flies are attracted to the adelgid honeydew, particularly in April. Eggs and first-instar larvae are found during April and May. The larvae fed on the adelgid nymphs but did not complete the first instar. Brown lacewing (Neuroptera: Hemerobiidae) larvae were observed at densities as high as 1/10 m of branch. They fed on the adelgid and other small invertebrates.

Survey on pines and hemlock (1994). In 1994 we became aware of an inconspicuous adelgid feeding at the base of pine needles on eastern white pine and Scotch pine. Subsequently, the weekly sampling was extended to include pine foliage.

Results of seasonal sampling (Fig. 1) indicate that *S. suturalis* is found on foliage of white and Scotch pine, and eastern hemlock. *S. suturalis* likely moves between these trees depending on the presence of adelgid prey. There were no adults on eastern hemlock after July, but they were present on both pine species until the end of the season. Although adults generally were at lower levels on eastern hemlock, larvae were at higher densities on eastern hemlock than on eastern white pine early in the season. Densities of both adults and larvae were highest on Scotch pine. Larvae were much more abundant on eastern hemlock in 1993 than in 1994; peak densities were 2.9 and 0.1 larvae per branch, respectively. The peak on Scotch pine in 1994 was 1.1 larvae per branch. In early June, larvae were observed moving down the boles of Scotch pine to locate pupation sites in deep bark crevices. It was possible to collect more than 300 larvae per hour from the lower bole of several trees.

Both Scotch pine and eastern white pine had sparse, inconspicuous adelgids feeding at the base of needles. The adelgids are likely *P. strobi* and *P. pini*. Their eggs are present from the end of April until November. We believe that *S. suturalis* likely evolved feeding on *P. pini* on Scotch pine in Europe, where both are native. *A. tsugae* represents an alternative prey that may be relatively more plentiful than *Pineus* sp. in early spring, but in late summer or fall the aestivating first-instar nymph present is not attractive to adult *S. suturalis.* We suspect that a collapse of *Pineus* populations on pine in the winter of 1992 resulted in greater than usual dispersal of overwintering adult *S. suturalis* to eastern hemlock infested with *A. tsugae*. Conversely, the unusually high mortality of *A. tsugae* in the winter of 1993 may have led to reduced oviposition by the predator on eastern hemlock.

Laricobius rubidus LeConte (Coleoptera: Derodontidae) is a native predator that was abundant on all three conifers (Fig. 2). We collected only adults. The larvae are covered with woolly wax, and we may have mistaken these for *S. suturalis.* This beetle probably is found wherever eastern white pine and *P. strobi* occur (Brown 1944). We found adults on eastern hemlock as soon as the ground thawed in the spring; they were absent by the end of May. Adults are present several weeks earlier than are those of *S. suturalis.* In the spring, *L. rubidus* was more abundant on eastern hemlock than on eastern white pine, and least abundant on Scotch pine. It is active early and late in the season when the overwintering generation of *A. tsugae* is active. Peak feeding of *L. rubidus* and *S.*

suturalis is on different generations of the adelgid; thus, their impact on the adelgid would be complementary.

CONCLUSION

The attempt to achieve biological control of *A. piceae* was not successful (Schooley et al. 1984). The prevalent strategy seemed to be to collect the guild of adelgid predators present on conifer adelgids in Europe and in Pakistan, and to release them in North America with a minimum of prior assessment. Most of these were released in numbers (> 500) likely to be sufficient. Explanations for failures include: an inability to survive the winter conditions, lack of seasonal synchrony between host and prey, and different niche requirements.

One of the exotic introductions for *A. piceae*, the relatively large coccinellid *A. obliterata*, seems promising for biological control of *A. tsugae*. It is a good candidate for reintroduction in the more southern areas where *A. tsugae* is found.

There is evidence that two predators, *S. suturalis* and *L. rubidus*, currently established in the geographic region where eastern hemlock is found, are exploiting *A. tsugae* as a new host. The apparent need by adult *S. suturalis* for a source of adelgid eggs throughout the summer may limit its effectiveness as a predator of *A. tsugae*. Mixed plantings of pines with eastern hemlock may enhance the activity of *S. suturalis* on *A. tsugae* by providing an alternative food source for *S. suturalis* during the summer. Although our observations of *L. rubidus* are insufficient to predict its impact, we conclude that its presence early and late in the season should complement the effect of *S. suturalis* on the adelgid.

It seems likely that successful biological control of *A. tsugae* will involve multiple species. Unfortunately, theoretical guidelines for determining which species or combination of species should be introduced are lacking despite 100 years of practical application of biological control (Ehler 1990). Biological control programs remain largely empirical; that is, the natural enemies available are released in the hope that field selection will result in the establishment of the best single or combination of species. A more predictive approach would assess the incumbent fauna and exotic fauna before beginning a program of introductions.

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LITERATURE CITED

AMMAN, G.D. 1966. *Aphidecta obliterata* (Coleoptera: Coccinellidae), an introduced predator of the balsam woolly aphid, *Chermes piceae* (Homoptera: Chermidae), established in North Carolina. J. Econ. Entomol. 59:506-511.

AMMAN, G.D., SPEERS, C.F. 1964. Release of predators of the balsam woolly aphid in North Carolina. Research Note SE-32. U.S. Department of Agriculture, Forest Service. 4 p.

AMMAN, G.D., SPEERS, C.F. 1965. Balsam woolly aphid in the southern Appalachians. J. For. 63:18-20.

AMMAN, G.D., SPEERS, C.F. 1971. Introduction and evaluation of predators from India and Pakistan for control of the balsam woolly aphid (Homoptera: Adelgidae) in North Carolina. Can. Entomol. 103:528-533.

BALCH, R.E. 1952. Studies of the balsam woolly aphid, *Adelges piceae* (Ratz.) and its effects on balsam fir, *Abies balsamea* (L.) Mill. Publ. 867, Ottawa, Ontario: Canadian Department of Agriculture. 41 p.

BALCH, R.E., CLARK, R.C., BROWN, N.R. 1958. *Adelges piceae* (Ratz.) in Canada with reference to biological control. Proc. Tenth Int. Cong. Entomol. (1956) 4: 807-818.

BROWN, W.J. 1944. Some new and poorly known species of Coleoptera, II. Can. Entomol. 76: 4-10.

BROWN, N.R., CLARK, R.C. 1956. Studies of predators of the balsam woolly aphid, *Adelges piceae* (Ratz.) (Homoptera: Adelgidae) II. An annotated list of the predators associated with the balsam woolly aphid in eastern Canada. Can. Entomol. 88:678-683.

BROWN, N.R., CLARK, R.C. 1957. Studies of predators of the balsam woolly aphid, *Adelges piceae* (Ratz.) (Homoptera: Adelgidae). IV. *Neoleucopis obscura* (Hal.) (Diptera: Chamaemyiidae), an introduced predator in eastern Canada. Can. Entomol. 89:533-546.

BUFFAM, P.E. 1962. Observations of the effectiveness and biology of the European predator *Laricobius erichsonii* Rosen. (Coleoptera: Derodontidae) in Oregon and Washington. Can. Entomol. 94:461-472.

CHEAH, C.A.S-J., MCCLURE, M.S. 1996. Exotic natural enemies of *Adelges tsugae* and their prospect for biological control. Pp. 103-112 *In* these proceedings.

CLARK, R.C., BROWN, N.R. 1960. Studies of predators of the balsam woolly aphid, *Adelges piceae* (Ratz.) (Homoptera: Adelgidae). VII. *Laricobius rubidus* Lec. (Coleoptera: Derodontidae), a predator of *Pineus strobi* (Htg.) (Homoptera: Adelgidae). Can. Entomol. 92:237-240.

CLARK, R.C., BROWN, N.R. 1961. Studies of predators of the balsam woolly aphid, *Adelges piceae* (Ratz.) (Homoptera: Adelgidae). IX. *Pullus impexus* (Mils.) (Coleoptera: Coccinellidae), an introduced predator in eastern Canada. Can. Entomol. 93:1162-1168.

CLARK, R.C., BROWN, N.R. 1962. Studies of predators of the balsam woolly aphid, *Adelges piceae* (Ratz.) (Homoptera: Adelgidae). XI. *Cremifania nigrocellulata* Cz. (Diptera: Chamaemyiidae), an introduced predator in eastern Canada. Can. Entomol. 94:1171-1174.

CLAUSEN, C.P. 1978. Chermidae. Pp. 49-55 *In* Introduced parasites and predators of arthropod pests and weeds: A world review, ed. C.P. Clausen. Agric. Handb. 480. Washington, D.C.: U. S. Dept. of Agriculture.

CULLINEY, T.W., BEARDSLEY, J.W., DREA, J.J. 1988. Population regulation of the Eurasian pine adelgid (Homoptera: Adelgidae) in Hawaii. J. Econ. Entomol. 81: 142-147.

DELUCCHI, V. 1954. *Pullus impexus* (Muls.) (Coleoptera: Coccinelllidae), a predator of *Adelges piceae* (Ratz.) (Hemiptera: Adelgidae) with notes on its parasites. Bull. Entomol. Res. 45: 243-278.

DELUCCHI, V., PSCHORN-WALCHER, H. 1954. *Cremifania negrocellulata* Czerny (Diptera: Chamaemyiidae) ein rauber an *Drefusia* (*Adelges*) *piceae* Ratz. (Hemiptera: Adelgidae). Z. Angew. Entomol. 36: 84-107.

EHLER, L.E. 1990. Introduction strategies in biological control of insects. Pp. 111-134 *In* Critical issues in biological control, ed. ed. M. Mackauer, L.E. Ehler, and J. Roland. Andover, Harts., United Kingdom: Intercept, Ltd.

HARRIS, J.W.E., DAWSON, A.F. 1979. Predator release program for balsam woolly aphid, *Adelges piceae* (Homoptera: Adelgidae), in British Columbia, 1960-1969. J. Entomol. Soc. B.C. 16: 21-26.

HUMBLE, L.M. 1994. Recovery of additional exotic predators of balsam woolly adelgid, *Adelges piceae* (Ratzeburg) (Homoptera: Adelgidae), in British Columbia. Can. Entomol. 126: 1101-1103.

LYON, S.M., MONTGOMERY, M.E. 1995. *Scymnus (Pullus) suturalis* Thunberg (Coleoptera: Coccinellidae): New locality records, and a report of feeding on eastern hemlock woolly adelgid, *Adelges tsugae* Annand (Homoptera: Adelgidae). Coleopt. Bull. 49: 118.

MCCLURE, M.S. 1987. Biology and control of hemlock woolly adelgid. Bull. 851. New Haven: Connecticut Agriculture Experiment Station.

MCCLURE, M.S. 1992. Hemlock woolly adelgid. Am. Nurseryman 176: 82-89.

MITCHELL, R.G., WRIGHT, K.H. 1967. Foreign predator introductions for control of the balsam woolly aphid in the Pacific Northwest. J. Econ. Entomol. 60: 140-147.

RAWLINGS, G.B. 1958. Problems of forest entomology in exotic forests in New Zealand. Proc. Tenth Int. Cong. Entomol. (1956) 4: 241-246.

SCHOOLEY, H.O., HARRIS, J.W.E., PENDREL, B. 1984. *Adelges piceae* (Ratz.), balsam woolly adelgid (Homoptera: Adelgidae). Pp. 229-234 *In* Biological control programmes against insects and weeds in Canada 1969-1980, ed. J.S. Kelleher and M.A. Hulme. Farnham Royal, United Kingdom: Commonwealth Agricultural Bureau.

SMITH, B.C., COPPEL, H.C. 1957. Releases in North America and reviews of bionomics in Europe of insect predators of the balsam woolly aphid, *Adelges piceae* (Ratz.) (Homoptera: Adelgidae). Can. Entomol. 89: 419-420.

WYLIE, H.G. 1958. Observations on *Aphidecta obliterata* L. (Coleoptera: Coccinellidae), a predator of conifer infesting Aphidoidea. Can. Entomol. 90: 518-522.

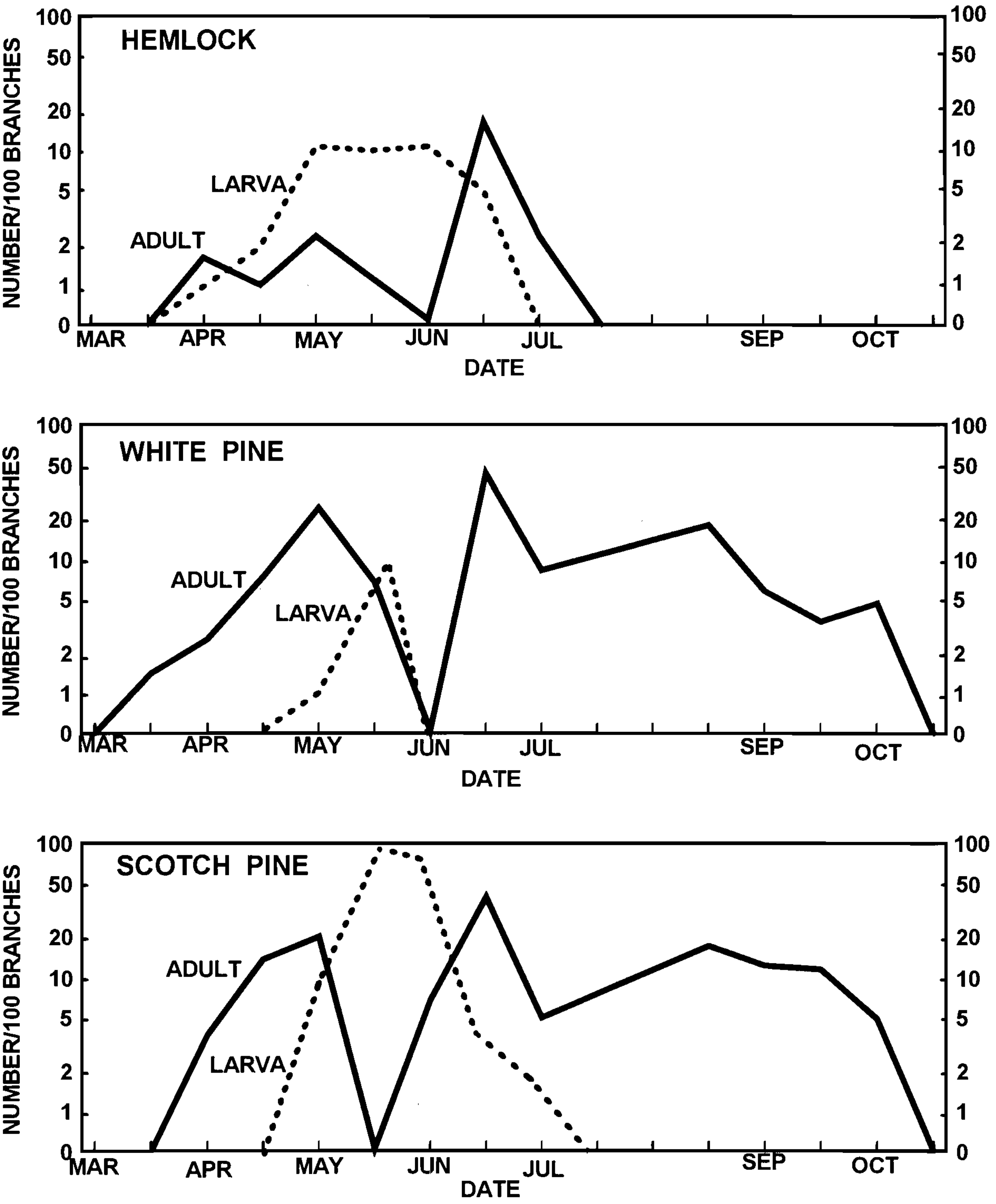

Figure 1. Relative seasonal distribution of *Scymnus suturalis* on foliage of three conifer species.

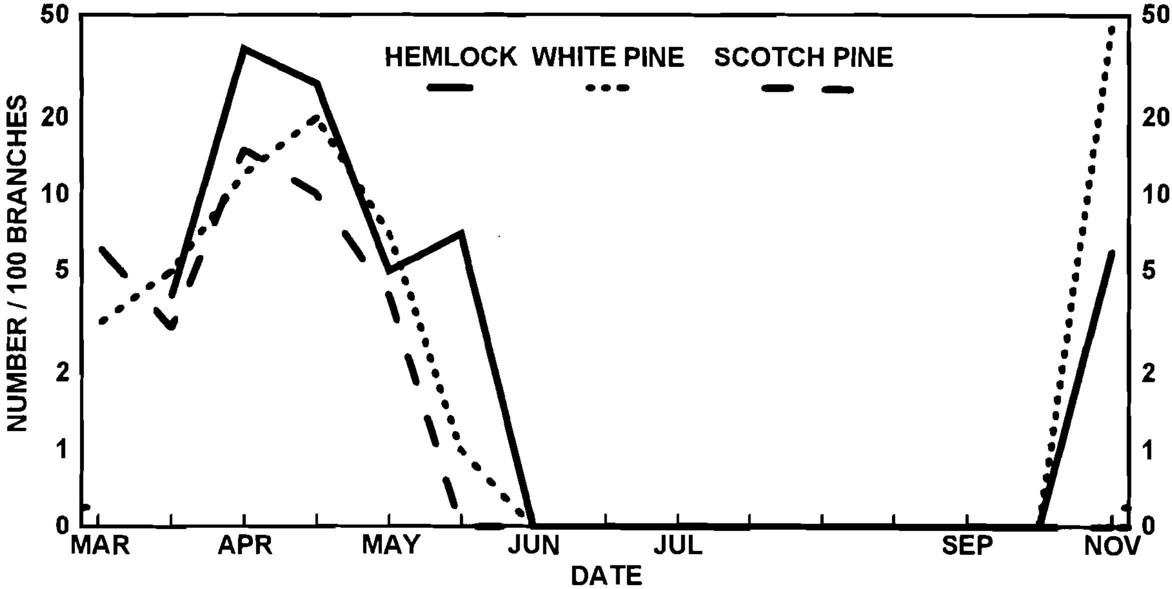

Figure 2. Relative seasonal abundance of *Laricobius rubidus* on foliage of three conifer species.