Field Surveys and Evaluation of Native Predators of the Hemlock Woolly Adelgid (Homoptera: Adelgidae) in the Southeastern United States

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Abstract

There has been little research conducted on native enemy effects on the hemlock woolly adelgid, *Adelges tsugae* Annand. This two-year study examined the relationship between native predators and *A. tsugae* in the southeastern United States utilizing field surveys and cage exclusion experiments. Predators were collected in very low densities in 1997 and 1998. *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae), lacewings (Neuroptera: Chrysopidae and Hemerobiidae), and gall gnats (Diptera: Cecidomyiidae) represented 81% of the total predators collected in 1998. Cage exclusion experiments revealed no significant predator effects at all three sites in 1997 and 1998. It is unlikely native predators are exhibiting any significant control on adelgid populations due to the low densities of predators collected at a time when adelgids were abundant. Therefore, controlled releases of exotic predators into these sites should be considered. It is important for scientists and resource managers to continue to recognize the importance for pre-release surveys of native natural enemies prior to mass releases of foreign predators.

Introduction

The hemlock woolly adelgid, *Adelges tsugae* Annand, is an exotic pest of eastern hemlock, *Tsuga canadensis* (L.) Carriere, and Carolina hemlock, *Tsuga caroliniana* Engelm., in the eastern United States from north-central North Carolina to northern Massachusetts. This destructive homopteran was accidentally imported from Japan and was first discovered in the eastern United States near Richmond, Virginia in 1951 and in the western U.S. in the early 1920's (McClure 1989 and 1991). *Adelges tsugae* exploits the valuable hemlock tree by depleting storage cells, or parenchyma cells, located in the xylem tissue (Shields et al. 1996). Heavy infestations of the adelgid can result in the premature drop of foliage, bud abortion, and in extreme cases, mortality within 4 years of infestation (McClure 1991). *A. tsugae* undergoes a polymorphic life cycle where a certain portion of the winter generation (sistens) progeny become wingless progrediens that remain on hemlock while the remaining portion become winged sexuparae which migrate to spruce and subsequently die. Both the sexuparae and progrediens mature in the spring (McClure 1989).

Due to the ineffectiveness of insecticides and the lack of natural enemies of *A. tsugae* in the eastern United States, classical biological control, or the importation of natural enemies from an exotic pest's original location, has become the most researched and promising control option. Classical biological control is the most feasible control method because *A. tsugae* is kept at innocuous densities in Japan by a combination of natural enemies and host resistance. Recently, a small coccinellid beetle, *Pseudoscymnus tsugae* sp. nov., was described as an important predator of *A. tsugae* in Japan (Sasaji and McClure 1997). Experiments in the northeastern United States have shown that this beetle is a very promising biological control agent for *A. tsugae* (Cheah and McClure 1996).

One of the most important first steps in biological control is to survey for and evaluate the effect of native enemies on pest populations before any type of release of exotic enemies is implemented. Evaluation is important because it scientifically examines the values and weaknesses of native natural enemies. It also allows for more educated decisions on the introductions of exotic enemies and the necessity or lack thereof to modify the environment to assist incumbent enemies (DeBach et al. 1976). If an exotic predator is to be considered for release into the southeast in the future, an intensive survey of natural enemies and their effects on adelgid survivorship is needed. The primary objective of this two-year study was to identify natural enemies of *A. tsugae* in North Carolina and Virginia and their degree of synchronization with *A. tsugae* in the field. The second objective was to determine the effects of predation on adelgid survivorship using predator exclusion cages.

Materials and Methods

Field Surveys

All research was conducted at three field sites: Hanging Rock State Park (HR), Stokes County, North Carolina; North Creek (NCR), Jefferson National Forest, Botetourt County, Virginia; and Cave Mountain Lake (CML), Jefferson National Forest, Rockbridge County, Virginia. All trees in all sites were selected for study based on high degrees of adelgid infestation. Arthropod collections were performed in two ways: shaking hemlock branches in the lower canopy of hemlock trees into a 0.45 square meter beat net (Montgomery and Lyon 1996) and probing for arthropods in infested twig samples with the aid of a light microscope. The distal 0.5 meter of 5 infested branches was sampled on every tree and one sample consisted of 5 branches per tree. Twig sampling was conducted only in 1998 and began in late March. It was added to the sampling scheme in order to learn more about microscopic immature predators. Three twigs per tree were clipped with twig cutters from selected trees at every site. Sampling during both years of the study was conducted in the spring and summer months at all three sites.

Most predatory taxa were identified by comparing recently collected individuals with specimens that had been determined by taxonomy specialists. Predators identified in table 1 have either been observed feeding on adelgids given

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to them in the laboratory or been observed feeding on adelgids from infested twigs collected in the field. Voucher specimens have been deposited in the North Carolina State University Insect Collection, Raleigh, NC, and the National Museum of Natural History, Washington D.C.

Cage exclusion experiments

Each tree at each site was randomly assigned three caged treatments (closed-cage, open-cage, no-cage) in the lower canopy. The closed-cage treatment monitored cage and other effects on adelgid survivorship; the open-cage monitored cage effects, predator effects, and other effects; and the no-cage treatment monitored predation effects and other effects on adelgid survivorship. During both study years, experiments were conducted in late-May and June. The spring generation of *A. tsugae* (progrediens) was chosen as the most appropriate life stage to evaluate. We believed that predators would be most abundant during this spring period due to the large number of adult adelgids. This was considered a critical period for predator evaluation because if predators were most abundant at this time, they could hypothetically have the most profound effect on adelgid survivorship by feeding on adults and preventing their entire clutch from being laid. At all sites, appropriate twigs were selected from cage treatments for before and after counts of the number of live progrediens per 10 cm of infested twig. The difference between the number of live progrediens between the before and after counts was then analyzed in all treatments. If there was a significant before/after effect in the no-cage treatment or open-cage treatment compared to the closed-cage treatment, then predation was considered as the cause.

Table 1.—Percentage of total predators collected from twig samples and beat samples combined in all three sites, 1998.

Taxon	HR	NCR	CML
Coleoptera: Coccinellidae (*H. axyridis*)	28.92	38.00	40.50
Coleoptera: Derodontidae (*L. rubidus*)	2.41	2.00	3.31
Diptera: Cecidomyiidae (*Aphidoletes* sp., *Lestodiplosis* sp.)	0.00	20.00	30.58
Diptera: Chamaemyiidae) (*Leucopis* sp.)	0.00	2.00	6.61
Diptera: Syrphidae	25.30	8.00	5.79
Neuroptera: Chrysopidae and Hemerobiidae	43.37	30.00	13.22

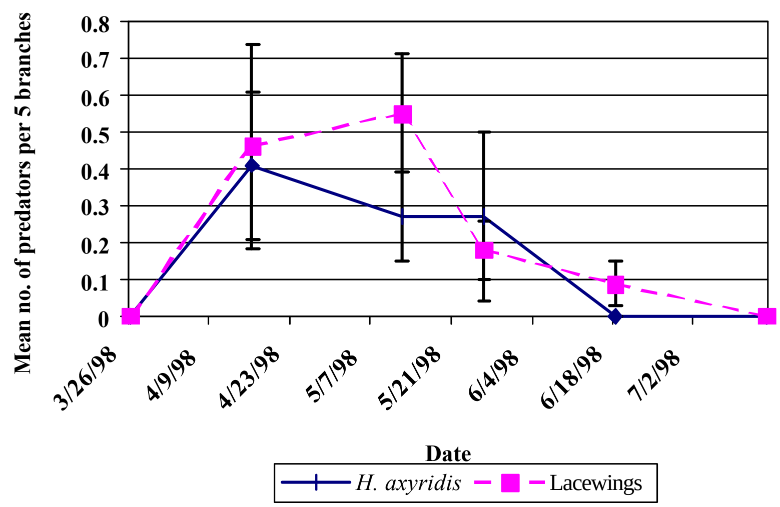

Figure 1.—Densities (mean ± SE) of the most abundant predators in beat samples at Hanging Rock State Park, NC, in 1998.

Results

Field Surveys

Overall in 1997, 22 predators were collected from the beat samples at all three sites combined. The 3 species collected were Asian-multicolored lady beetles, *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae); green lacewings, most likely *Chrysoperla harrisii* (Fitch) (Neuroptera: Chrysopidae); and brown lacewings, most likely *Hemerobius humulinus* L. (Neuroptera: Hemerobiidae). Densities in 1997 were so low and sampling dates were conducted so late in the field season that it was difficult to make any definite conclusions about predator phenology. Sixty-eight immature predators from the family Cecidomyiidae were collected on 24 June 1997 from the no-cage twig samples during the cage exclusion experiments at the Virginia sites. Four of the 68 were identified as *Aphidoletes abietis* Kieffer.

A total of 254 predators was collected from 1998 beat samples and twig samples combined at all three sites. In the 1998 twig samples and beat samples combined, *H. axyridis,* lacewings (Neuroptera: Chrysopidae and Hemerobiidae), and gall gnats (Diptera: Cecidomyiidae) comprised 81% of all individuals collected in all three sites. Table 1 gives a complete listing of the predators collected in 1998. At all sites, overall predator densities in both beat and twig samples were very low in 1998. Predators collected in the beat samples were most abundant in April and May while the greatest abundance of predators collected in the twig samples was observed in late-March and late-June. Figures 1-5 illustrate predator densities over time at all sites.

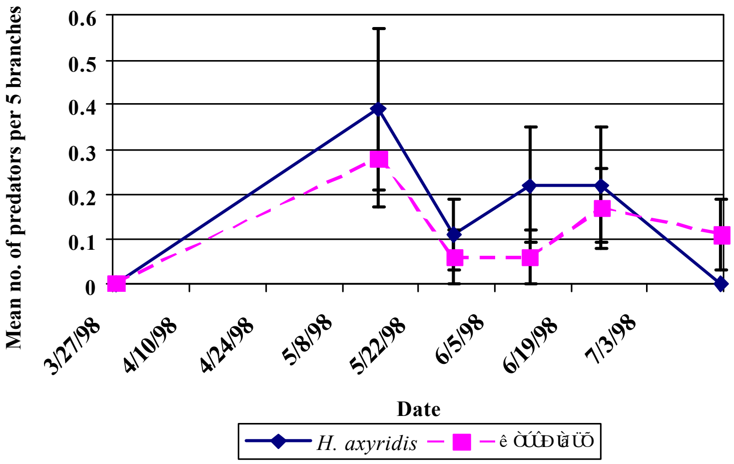

Figure 2.—Densities (mean + SE) of the most abundant predators in beat samples at North Creek, VA, in 1998.

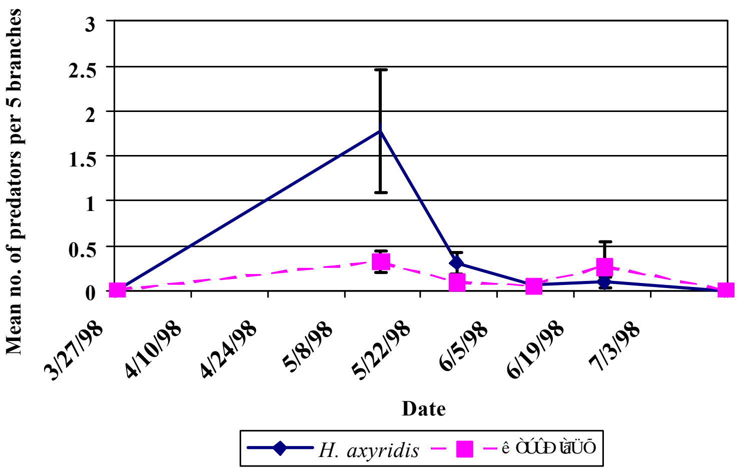

Figure 3.—Densities (mean ± SE) of the most abundant predators in beat samples at Cave Mountain Lake, VA, in 1998.

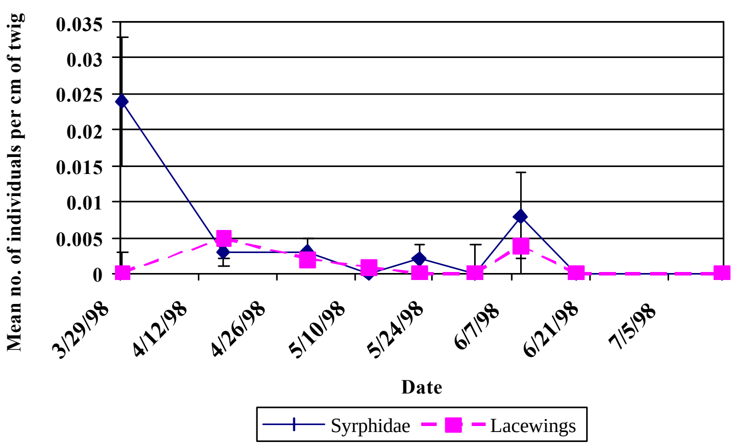

Figure 4.—Densities (mean ± SE) of the most abundant predators in twig samples at Hanging Rock State Park, NC, in 1998.

Cage exclusion experiments

Figures 6 and 7 show the results of the 1997 and 1998 cage exclusion experiments respectively. Results from the statistical analysis revealed significant before/after effects in every treatment at every site in 1997. However, there were no significant differences between the no-cage treatment and other treatments in the change from the before to after count at any site. These results show that there was no difference between treatments in adelgid survivorship in 1997 at any site and no evidence of predator effects.

Results from 1998 revealed no before/after effects in any treatment at either Cave Mountain Lake or North Creek.

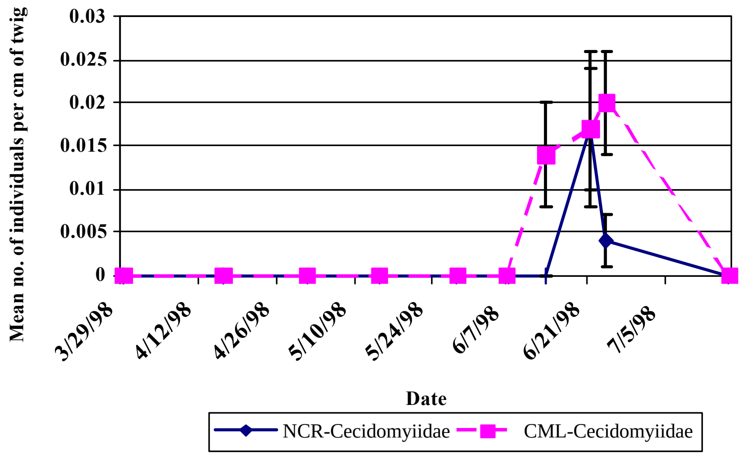

Figure 5.—Densities (mean ± SE) of the most abundant predators in twig samples at the Virginia sites, 1998; NCR, North Creek; CML, Cave Mountain Lake.

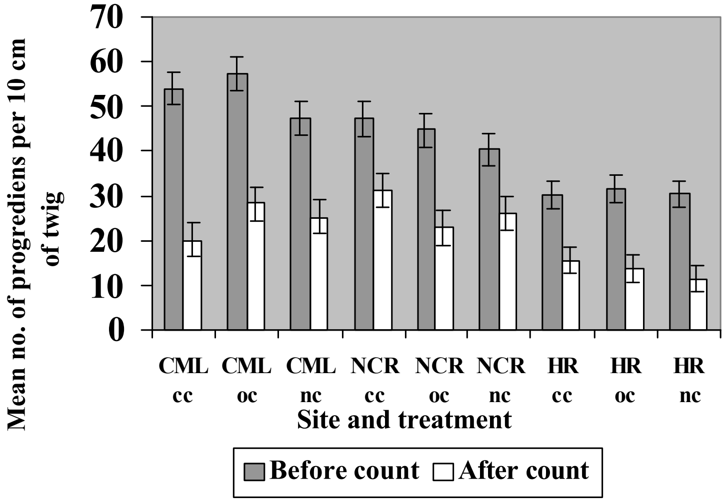

Figure 6.—Mean number of progrediens per 10 centimeters of infested twig ± SE in before and after counts of three caged treatments at all three sites in 1997. CML, Cave Mountain Lake; NCR, North Creek; HR, Hanging Rock; CC, closed-cage; OC, open-cage; NC, no-cage.

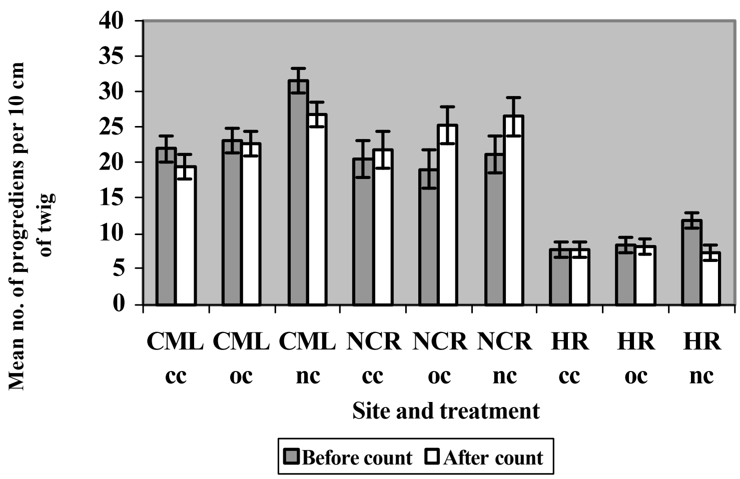

Figure 7.—Mean number of progrediens per 10 centimeters of infested twig in before and after counts of three caged treatments at all three sites in 1998. CML, Cave Mountain Lake; NCR, North Creek; HR, Hanging Rock; CC, closed-cage; OC, open-cage; NC, no-cage.

There were also no significant differences between the no-cage treatment and other treatments in the difference from the before to after count. Therefore, there was no difference in adelgid survivorship between treatments over time and no suggestion of predator effects. At Hanging Rock, results showed a significant before/after effect in the no-cage treatment only. This change from the before to after count was significantly different than the changes from the before to after count in the closed-cage and open-cage treatments. However, this effect probably doesn't have any biological significance due to the lack of predators sampled at the time of the after counts.

Discussion

Results from the 1997 and 1998 field surveys indicate the existence of a small native predator complex associated with *Adelges tsugae* in the southeastern United States. Many of the predators collected in this survey have been found before to be associated with *A. tsugae*. In surveys of predators of *A. tsugae* in Connecticut, representatives from the families Cecidomyiidae, Syrphidae, and Chrysopidae were collected (McClure 1987). *Laricobius rubidus* was also found in surveys of hemlock in Connecticut (Montgomery and Lyon 1996). The most important predators found in this study in terms of abundance were *Harmonia axyridis*, cecidomyids, and lacewings in the families Chrysopidae and Hemerobiidae. Representatives of these groups and many of the individuals collected in this study are known predators of the family Adelgidae (Wilson 1938, Smith and Coppel 1957, Amman 1966, Harris 1973, Tedders and Schaefer 1994).

Even though predators of *A. tsugae* have been documented in this study, results from the cage exclusion studies and field surveys strongly suggest that they are not abundant enough to effectively control *A. tsugae* or prevent tree mortality. Other surveys have found similar predatory taxa associated with *A. tsugae* that were in densities too low to impact adelgid populations (McClure 1987). Predators were collected in very low densities during both years of the study but they were moderately well synchronized with the adelgid life cycle. Figures 1-3 show that the highest abundance of predators in the beat samples (mid-April to mid-May) was observed at a time when sistens adults were beginning to die off but progrediens eggs and nymphs were abundant. This suggests that these predators likely have preferred sources of prey since their populations did not respond with any numerical increase to the abundant numbers of adelgids available to them.

The high densities of cecidomyids observed in late June of 1997 and 1998 (Figure 5) had little impact on adelgid survivorship because they were feeding at a time when adelgids had already laid most of their eggs and adults were dying off. If they and other adelgid specific predators such as *Leucopis* sp. were in high densities from mid-April to early-June when adelgid eggs, nymphs, or adults were most abundant, they may have had more of an effect on adelgid survivorship.

Due to the low densities of predators and their lack of ability to control adelgid populations in these three sites, the release of a foreign specific predator such as *Pseudoscymnus tsugae* should be considered. Such a release should not proceed without caution however. Native predator densities were low in these sites but it is difficult to make an accurate statement of the predator/prey relationship in a two-year study. Low predator numbers could easily be attributed to normal yearly population fluctuations. It should also be noted that *Harmonia axyridis* was one of the more common predators. This generalist predator, which will feed on a large number of organisms and may feed on other predators, could pose a problem for the establishment of an exotic predator.

Even though predators were collected in low densities in this study, it is still important for scientists and resource managers to understand the importance of conducting native enemy evaluations prior to mass releases of an exotic natural enemy. The baseline information gathered in these studies lays the groundwork for future studies with exotic enemies and in some cases may show that incumbent natural enemies serve an important role in pest control. Future research should more closely examine the relationships between exotic predators such as *Pseudoscymnus tsugae* and incumbent predators of these sites.

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