Summary of Native and Established Predators of the Hemlock Woolly Adelgid and the Balsam Woolly Adelgid (Homoptera: Adelgidae) in the Southeastern United States

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Abstract

There has been little research conducted on the effects of native or established predators on populations of the hemlock woolly adelgid, *Adelges tsugae* Annand, or the balsam woolly adelid, *A. piceae* Ratz. This paper reviews what is known about the native and established predators of both species in the southeast. Field surveys and cage exclusion experiments were used to examine the relationship between established predators and *A. tsugae*. Predators were collected in very low densities. *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 in all study sites. It is unlikely that established predators are exhibiting any significant control on hemlock woolly adelgid populations because of the low densities of predators that were encountered at a time when adelgids were abundant. While similar studies of the predators of balsam woolly adelgid have not been conducted, it is clear that predators have had little impact on this adelgid.

Keywords:

Adelges tsugae, *Adelges piceae*, *Harmonia axyridis*, cage exclusion.

Introduction

Both the hemlock woolly adelgid, *Adelges tsugae* Annand, and the balsam woolly adelgid, *A. piceae* Ratz., are exotic pests of hemlock and fir, respectively. Hemlock woolly adelgid (HWA) was first discovered in the eastern United States near Richmond, Virginia, in 1951 (Annand 1924, 1928; McClure 1989, 1991). HWA became a pest of concern in the 1980s when it began to spread in natural stands and cause widespread mortality. Prior to that HWA was considered an ornamental pest that could be controlled with pesticides. Balsam woolly adelgid (BWA) was first found in natural stands of balsam fir in 1908, and in Fraser fir of the southern Appalachians in 1955. Severe mortality was immediately apparent. Neither adelgid is considered a pest in its native range.

The early research on BWA focused on classical biological control by introducing a number of predators of European origin. While some of these predators appear to have been successfully established (see Zilahi-Balogh, this volume), none have had an impact on BWA populations. The extensive 35-year classical biological control program for BWA in Canada and the southeastern United States has been well documented (Smith 1958, Amman 1966, Amman and Speers 1971, Harris and Dawson 1979, Schooley et al. 1984). The more recent research on BWA has emphasized host resistance (Fowler et al. 2001).

The use of insecticides to control *A. tsugae* has proven impractical because of the high costs involved with treating trees in forest settings. Because of the apparent lack of natural enemies of HWA in the United States, classical biological control has become the most researched control option. However, little research had been conducted with the biological control of HWA until the early 1990s. Since then a number of individual studies have demonstrated the potential for biological control. Promising biological control agents are currently available or may become available soon. (McClure 1995; Cheah and McClure 1996, 1998; Sasaji and McClure 1997; Montgomery 1998; Salom 1998).

An important first step in biological control is to survey and evaluate the effect of native enemies before releasing imported natural enemies (DeBach and Bartlett 1964). Evaluation is important because it examines the values and weaknesses of natural enemies. It also allows for more educated decisions on the introductions of non-native enemies and the necessity or lack thereof to modify the environment to assist established enemies (DeBach et al. 1976). Additionally, as biological diversity becomes more of an important issue, there will be an increasing need to determine if introduced natural enemies will negatively affect resident enemies.

There have been relatively few natural enemy evaluation studies for HWA in the eastern United States (Montgomery and Lyon 1996). The primary objective of a 2-year (1997 and 1998) study in North Carolina and Virginia was to identify natural enemies of HWA and their degree of synchronization with HWA in the field. The second objective was to determine the effects of predation on adelgid survivorship using predator exclusion cages.

Materials and Methods

Geographical Area and Study Sites. Research was conducted at three field sites: Hanging Rock State Park, Stokes County, North Carolina; North Creek, Jefferson National Forest, Botetourt County, Virginia; and Cave Mountain Lake, Jefferson National Forest, Rockbridge County, Virginia. Hemlock trees with high infestations were selected for study at each site. See Wallace and Hain (2000) for a detailed description of the study sites, the field surveys using beat nets and twig samples, and the cage exclusion experiments.

Arthropods collected in beat and twig samples known to prey on soft-bodied arthropods were fed adelgids in the laboratory to determine if they were adelgid predators. Immature insects found feeding on adelgids in twig samples were reared on adelgids to the adult stage to make species determinations. Several groups only were identified to the family or generic level because of rearing difficulties. Most taxa were identified by comparing recently collected individuals with specimens that had been determined by taxonomy specialists. Predators identified in the tables had either been observed feeding on adelgids given to them in the laboratory or been observed feeding on adelgids from infested twigs collected in the field. Spiders and harvestmen are not known to feed on adelgids and were never seen feeding on adelgids, but they were collected so their densities could be compared with known predator densities. Voucher specimens have been deposited in the North Carolina State University Insect Collection, Raleigh, North Carolina, and the National Museum of Natural History, Washington, DC.

Statistical Analyses. Data from the cage exclusion experiments were analyzed using statistical analysis software (SAS Institute 1992). Means and standard errors were calculated using PROC LSMEANS. Before/after effects for individual treatments and the comparison between all three treatments in their effect on adelgid survivorship were analyzed using PROC GLM. Treatment effects, tree effects, before/after effects, no-cage after effects, and the before and after/treatment interaction were analyzed in the comparison between treatments. A significant no-cage after effect demonstrated a difference between the no-cage treatments and the remaining treatments in the change in the number of live adelgids from the before to after count. Data from field survey results were analyzed using descriptive statistics.

Results

Field Surveys. In 1997 a total of 22 predators representing at least three species, three genera, three families, and two orders of insects was collected from beat samples at all three sites combined over four sampling dates at Hanging Rock and five sampling dates at both Virginia sites. The three insect groups collected were multicolored Asian lady beetles, *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae); green lacewings (Neuroptera: Chrysopidae); and brown lacewings (Neuroptera: Hemerobiidae). (Lacewings were identified as *Chrysoperla harrisii* (Fitch)), *Hemerobius humulinus* L., and *Hemerobius* sp.).

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. On an earlier date (12 June), three specimens of *Aphidoletes aphidimyza* Rondani were collected from the no-cage twig samples at the Virginia sites. Other predaceous cecidomyiids collected in 1997 included individuals from the genera *Aphidoletes*, *Lestodiplosis*, and *Trisopsis*.

A total of 147 predators representing at least four species, four genera, four families, and two orders of insects was collected from 1998 beat samples over six sampling dates at all sites (Wallace and Hain 2000). In the 1998 twig samples a total of 107 predators representing at least eight species, eight genera, seven families, and three orders of insects were collected over nine dates at Hanging Rock and 11 dates at the Virginia sites. A total of 16,939.48 cm of infested twig was sampled in the twig studies from all three sites. In the 1998 combined twig samples and beat samples, *H. axyridis*, lacewings (Neuroptera: Chrysopidae and Hemerobiidae), and gall gnats (Diptera: Cecidomyiidae) comprised 81% of all individuals collected in all three sites (Wallace and Hain 2000). Predators were only observed feeding on immature or adult adelgids, never directly on eggs. It was assumed they also fed on eggs, perhaps secondarily, because many were found inside of woolly masses and many of the predators are documented as predators of adelgid eggs (Wilson 1938; Smith and Coppel 1957; Amman 1966).

At Hanging Rock, overall predator densities in both beat and twig samples were very low in 1998 (Wallace and Hain 2000). The most abundant predators at this site in 1998 combined beat and twig samples were brown and green lacewings (Neuroptera: Chrysopidae and Hemerobiidae); followed by *H. axyridis*, flower or hover fly larvae (Diptera: Syrphidae); and tooth-necked fungus beetles, *Laricobius rubidus* Lec. (Coleoptera: Derodontidae) (Wallace and Hain 2000). The highest densities overall in twig samples were seen in early March with the syrphid larvae predators. In the beat samples, predators were most abundant from mid-April to mid-May. During this time, *H. axyridis* and lacewings were at their highest densities of the year.

At North Creek in 1998, predators also were found in very low densities in both beat and twig samples (Wallace and Hain 2000). The most abundant predators found in 1998 combined twig and beat samples were *H. axyridis*; followed by lacewings; cecidomyids; syrphids; aphid flies, *Leucopis* spp. (Diptera: Chamaemyiidae); and *L. rubidus* (Wallace and Hain 2000). The highest predator/twig densities were in late June when cecidomyid larvae were sampled. Predators peaked in density in mid-May in the beat samples when *H. axyridis* and lacewings were most abundant.

Cave Mountain Lake had very low densities of predators in 1998 (Wallace and Hain 2000). The most abundant predators found in combined twig and beat samples were *H. axyridis* followed by cecidomyids, lacewings, *Leucopis* spp., syrphids, and *L. rubidus* (Wallace and Hain 2000). The highest densities in the twig samples, similar to North Creek, were seen with the cecidomyid bloom in late June. The beat samples were very similar to the North Creek beat samples in that predators peaked in density during mid-May when *H. axyridis* and lacewings were at their highest densities.

***Cage Exclusion Experiments**.* In 1998 there were no significant before/after effects in any treatment at either Cave Mountain Lake or North Creek (Wallace and Hain 2000). Similar to 1997, there were also no significant differences between the no-cage treatment and other treatments in the number of live adelgids in the before- and after-counts. Therefore, there was no difference in adelgid survivorship between treatments over time and no suggestion of predator effects. A significant before/after effect (Wallace and Hain 2000) occurred at Hanging Rock in the no-cage treatment only and this change in the number of live adelgids was significantly different than the changes in the open- and closed-cage treatments. Thus, the closed- and open-cage treatments protected the adelgids from some type of mortality agent.

Discussion

Results from the 1997 and 1998 field surveys indicate a small established predator complex of HWA in the southeastern United States. Predators were either found feeding on adult and immature adelgids on twigs from the field or were observed feeding on adelgids in the laboratory. Many of the predators collected in this survey have been found before to be associated with HWA. In surveys of predators of HWA in Connecticut, representatives from the families Cecidomyiidae, Syrphidae, and Chrysopidae were collected (McClure 1987). *L. rubidus* also was 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. Together, these three groups of insects comprised 81% of all individuals collected in all three sites in both twig and beat samples. 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 HWA 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 HWA or prevent tree mortality. Other surveys have found similar predatory taxa associated with HWA that were in densities too low to impact adelgid populations (McClure 1987). The fact that there was no significant difference in the change in adelgid density from the before to after count in any treatment or site (with the exception of Hanging Rock in 1998) was evidence for no predation effects in 1997 and 1998. It is unlikely that the effect seen at Hanging Rock in 1998 is significant enough to reduce adelgid populations. Predators were present at the time of the before and after counts (lacewings and syrphids), but they were collected in very low densities.

Even though predators were collected in very low densities during both years of the study, predators were moderately well synchronized with the adelgid life cycle. That the highest abundance of predators in the beat samples (mid-April to mid-May) ocurred when sistens adults were beginning to die off but progrediens eggs and nymphs were abundant suggests that these predators likely have other preferred sources of prey. Their populations did not respond with any numerical increase to the abundant numbers of adelgids available to them.

The high densities of cecidomyiids in late June of 1997 and 1998 (Wallace and Hain 2000) had no 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* spp. 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. Certain predators of *A. piceae* also have been found to be poorly synchronized with the adelgid life cycle (Brown and Clark 1957; Amman 1966). *L. erichsonii*, on the contrary, showed potential for controlling BWA in Canada because larvae fed earlier in the season when prey were most numerous (Clark and Brown 1958).

Because of the low densities of predators and their lack of ability to control adelgid populations in these three sites, the release of a specific non-native predator should be considered. However, such a release should not proceed without caution. Native predator densities were low in our sites and it is difficult to make an accurate statement of the predator/prey relationship in a 2-year study. Low predator numbers could easily be attributed to normal yearly population fluctuations. Additionally, it also is preliminary to conclude that what is happening in these sites is happening in every adelgid-infested site.

Although classical biological control has not proven successful for BWA (Amman 1966; Schooley et al. 1984), the potential for biological control of the hemlock woolly adelgid may be greater because of the milder climates where hemlock is found. Consequently, these milder areas may prove to be more conducive for the establishment of predator populations. Recently, a small coccinellid beetle, *Pseudoscymnus tsugae* Sasaji and McClure 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, 1998). Future research should examine more closely the relationships between non-native predators and established predators in these sites.

It is important, however, to recognize the value of host resistance in any biological control effort. The host's ability to resist attack and survive provides time for the biological control organisms to have an impact. A general rule of thumb is that six to 10 generations of the prey are required before a release of natural enemies will have an impact on their prey. For HWA this means a minimum of 3 years will pass before a predator release will show results. Just as there are fir species that show resistance to BWA (Fowler et al. 2001), there are hemlock species that show resistance to HWA. It is imperative that we understand the mechanism of that resistance. If it is related to site conditions, sites could be identified where infested trees would survive the longest, and, consequently, where biological controls would be most likely to succeed. If the host resistance is physiological and/or genetic, then species or subspecies could be identified and utilized in restoration projects as well as biological control projects.

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