Competitive Interactions Among Two Biological Control Agents of Hemlock Woolly Adelgid and an Established Generalist Predator in Southwestern Virginia

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ABSTRACT

Classical biological control using prey-specific predators is currently underway to manage hemlock woolly adelgid (HWA) in the eastern United States. *Laricobius nigrinus* Fender and *Sasajiscymnus (=Pseudoscymnus) tsugae* Sasaji and McClure are prey-specific predators with good phenological synchrony with HWA. *Harmonia axyridis* Pallas, a highly polyphagous and voracious predator, previously introduced for biological control of various homopteran pests, is now commonly found in association with HWA in the southeastern United States. Competitive interactions among species utilizing the same resource at the same time can lead to reductions in predator diversity and decrease the efficacy of biological control. Therefore, we examined interactions among these three species in two hemlock stands in southwestern Virginia.

Adult female predators were enclosed in sleeve cages on infested hemlock branches for 6 weeks (April-May, 2003-04) at a high and low elevation hemlock stand in southwestern Virginia. Ten eastern hemlocks (20-40 year) were selected at each site that had densities of 3-4 HWA/cm. Predators were evaluated during the winter (sistens) generation of HWA, alone and in two- and three-predator conspecific or heterospecific groupings. Predator survival was assessed as the number of live predators at the end of each trial. Consumption of the HWA winter generation (sistens), impact on the spring generation (progrediens), and net reproduction for each predator was evaluated for 200 cm of branch clippings per enclosure. HWA densities on branches without predators were used as a control. Survival was analyzed using logistic regression. Predator feeding, impact, and net reproduction were analyzed using two-way ANOVA. Independent categorical variables for both models included species combination, site, and their interaction. Results were considered significant at the 5% probability level.

Survival by all predator species was not significantly affected by predator combination or site. Intra- and interspecific predation by *L. nigrinus* or *S. tsugae* was not observed and may be due to biological constraints (such as host specificity) or experimental conditions (such as high HWA densities). Intra- and interspecific predation by *H. axyridis* is well documented, but was not observed in our studies. Previous observations suggest it to be inversely related to prey density in this species. Its absence in our studies may be due to high HWA densities, avoidance behaviors, or temporal or spatial asynchrony among these species.

Predator feeding on the winter (sistens) generation of HWA and their impact on the following spring (progrediens) generation was significantly different by species combination and site. Among individual predators, *L. nigrinus* and *H. axyridis* had greater feeding overall than *S. tsugae*. This may due to *L. nigrinus* being adapted to lower temperatures and to the larger body size and voracity of *H. axyridis*. Feeding was significantly greater for all species in two- and three-predator conspecific and heterospecific combinations. This suggests that predator interactions did not significantly interfere with feeding activity. Feeding was greater at the low elevation site, and this may be related to the higher mean temperatures found at that site. Similarly, an individual predator, *L. nigrinus* had much greater impact than *H. axyridis* or *S. tsugae* on reducing the number of developing progrediens in the next generation. This may be attributed to the large number of larvae produced during the trial, which disturbed and consumed many HWA ovisacs. The other species fed mainly on sistens adults that had already laid their eggs. *L. nigrinus* and *H. axyridis* had significantly greater impact in conspecific groupings and with one another, while heterospecific grouping with *S. tsugae* did not increase their impact. However, further research is necessary to determine the density of predators, alone or in combination, that will maintain HWA densities below injury levels. Impact was greater at the high elevation site, and this may be attributed to increased HWA mortality at the lower temperatures found there. All predator treatments had greater feeding and impact than no-predator control branches.

Net reproduction by *L. nigrinus* and *H. axyridis* was significantly different by species combination and site. As an individual species, *L. nigrinus* had very high net reproduction when alone or with conspecifics in comparison to the other species. Immature stages were also further advanced, developmentally, than the other species. Since *L. nigrinus* has a much lower developmental threshold, they may have been able to continue reproduction at the low temperatures of early spring. Low reproductive output by *S. tsugae* and *H. axyridis* may be attributed to higher temperature requirements or prey quality. Competitive interference by conspecifics was observed for all species to varying degrees. For *L. nigrinus* and *S. tsugae*, this was detected by lower-than-expected results with conspecifics. Interference was the most pronounced for *H. axyridis*. Previous studies indicate that indirect interference, in the form of fecal cues or oviposition-deterring pheromones, as well as direct interference, such as through egg cannibalism, occur in this species. Similar mechanisms may be present in the two prey-specific species, but this requires further investigation. In contrast, no significant predator interference was detected in heterospecific groupings. This may be attributed to prey specificity by *L. nigrinus* and *S. tsugae*, the abundance of HWA provided, or the occurrence of different ovipositional strategies that may have served to reduce resource competition. Net reproduction was also greater at the low elevation site, and this may again be related to the higher mean temperatures found there.

The lack of strong seasonal synchrony for these species may limit competitive effects in field populations. For *L. nigrinus*, there may be limited overlap with other predators due to their earlier spring activity and development. However, *S. tsugae* may be at greater risk due to their later spring development, which overlaps with the presence of many generalist predators. Implications for management include applying low-density releases of the biological control agents to reduce the potential for conspecific interference and rapid dispersal. Further

studies are warranted to examine both direct and indirect mechanisms of competition, the existence of avoidance strategies, and the degree of natural dispersal (*i.e.* immigration and emigration) of these species in hemlock stands.

KEYWORDS

Laricobius nigrinus, *Sasajiscymnus (=Pseudoscymnus) tsugae*, *Harmonia axyridis*, biological control.