

CHAPTER 10: OTHER SPECIES CONSIDERED

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INTRODUCTION

This chapter reports on predators which have only preliminary information or were found to have a host range that was too broad to be considered as safe biological control agents. The predators reviewed here include predaceous anthocorid bugs from China and western North America, a *Laricobius* beetle from China, and a lady beetle native to western North America. For each of the species, information on their taxonomy, biology, and host range is provided and their potential as a biological control agent for *Adelges tsugae* Annand, the hemlock woolly adelgid (HWA), is evaluated. Key questions for the reader to ponder are how host specific should HWA predators be and can successful biological control be achieved using only predators that are specific only to HWA.

SPECIES CONSIDERED

Tetraphleps galchanoides Ghauri (Hemiptera: Anthocoridae)

The Anthocoridae is a family of 500-600 worldwide species that are mostly predaceous, a few of which have been deliberately introduced as biological control agents (Lattin 1999). Within the Anthocoridae, the genus *Tetraphleps* has about 14 described species worldwide which feed primarily on aphids and adelgids (Lattin 2000). There are five species of *Tetraphleps* native to North America and four of these have been observed to prey on the balsam woolly adelgid (Kelton 1978). *Tetraphleps raoi* Ghauri and *T. Abdulghani* Ghauri, both native to Pakistan and India, were introduced to North America for biological control of the balsam woolly

adelgid, but apparently did not establish. Bu and Zheng (2001) attributed the failure to establish to a lack of climatic suitability. While *T. raoi* was not successfully introduced into North America, it was established in Kenya for control of *Pineus pini* (Macquart), where it is believed to be responsible for a decline in the density of the adelgid (Lattin 2000).

Tetraphleps galchanoides (Fig. 1) is known from India and China (Bu and Zheng 2001). The first report in China was a specimen collected from *Tsuga chinensis* in Baoxing County, Sichuan Province (Yao and Wang 1998). They reported that an adult could eat 2.7 nymphs and 5.6 eggs of HWA per day. In the spring of 2007, a very dense population of HWA was observed in Yunnan Province that was preyed on heavily by both adults and nymphs of *T. galchanoides* (McAvoy et al. 2008). Laboratory experiments showed that *T. galchanoides* preying on HWA was a Type II Holling functional response—predation rate increased as prey densities increased (Li et al. 2008).



Figure 1. Adult *Tetraphleps galchanoides*.

From 2002-2008, basic biology and host feeding studies were conducted in quarantine to determine the potential of *T. galchanoides* as a biological control agent of HWA (McAvoy et al. 2007, McAvoy et al. 2008). In 2002, eggs and nymphs were recovered from hemlock foliage collected in the fall in Sichuan, China that were shipped to the quarantine facility at Virginia Tech. When newly hatched nymphs were fed only the balsam woolly adelgid, *Adelges piceae* Ratz., none developed to the next nymphal stage; but when fed exclusively pine bark adelgid, *Pineus strobi* (Hartig), or woolly alder aphid, *Paraprociphilus tessellatus* (Fitch), they successfully developed to the adult stage. Research (unpublished) in China indicated that *T. galchanoides* preyed on the bean aphid placed in Petri dishes.

Tetrableps galchanoides females normally oviposit their eggs into the lower side of the hemlock needle tissue. When offered a choice of foliage of white pine (*Pinus strobus*), red spruce (*Picea rubens*), and Fraser fir (*Abies fraseri*), *T. galchanoides* oviposited in white pine and fir but not spruce needles. However, in a no-choice test with spruce only, *T. galchanoides* did lay eggs in spruce needles. In a choice test with all four conifer species, *T. galchanoides* oviposited only in hemlock needles, indicating that hemlock is the preferred host, but will lay eggs in the other three non-target species, spruce being the least preferred species. Eggs were also oviposited in leaves of smooth alder (*Alnus serrulata*) in a no-choice test. Unlike the eggs inserted into the conifer needle tissue, eggs in the alder test were laid on the surface of the leaf and not inserted into the leaf tissue. Several of these eggs hatched.

Tetrableps galchanoides fed and oviposited on non-target adelgids and aphids. Additional feeding tests found that *T. galchanoides* adults will feed on *Laricobius osakensis* Montgomery and Shiyake (Coleoptera: Derodontidae) larvae. Due to the suitability of several non-target homopteran species as hosts and its feeding on the larvae of a potential biological control agent, this species is not considered at this time to be a suitable candidate for release as a biological control agent.

***Anthocoris nemoralis* Fabricius and *A. antevolens* White**

The genus *Anthocoris* occurs primarily in the Northern Hemisphere and consists of about 70 species. The Palearctic has 47 species, and 12 species occur in Canada and the United States (Lattin 2000). Only one species that is native to North America, *Anthocoris antevolens* White, is known to use adelgids as prey and this is considered incidental (Lattin and Stanton 1992). In North America, the hemipterans *Daecocororis pinicola*, *D. piceicola*, and *D. nubilus* in the family Miridae prey on adelgids on pine and spruce (Wheeler 2001).

Several species of Anthocoridae were collected by R. McDonald from October to February, 2008-2011, in Seattle, WA while he was collecting *L. nigrinus* for release in the eastern United States. The most abundant species was *Anthocoris nemoralis* (Fab.) with 55 adults collected or 89% of the total *Anthocoris* collected. This species was intentionally introduced from Europe as a biological control agent in orchards against aphids, psyllids, thrips, and moth eggs and larvae (Kelton 1978). It became established in the 1950s and is found in British Columbia, Ontario, Washington, Oregon, and California (Lewis et al. 2005). The second most common species was *A. antevolens* White, with seven adults found (11%). This species is native to North America and is found across Canada and western United States. This is the first report of finding *Anthocoris* species on *Tsuga*.

Adults shipped to the Virginia Tech quarantine facility were reared on *Tsuga canadensis* foliage infested with HWA at 15 °C. The mean length of time that the adults lived was 36 days. The number of females collected was low with only 1 female for every 6 males, and no oviposition was observed on hemlock. No nymphs were found during beat-sheet sampling of hemlock. It appears that the adults of these two species of *Anthocoris* may only use HWA as an occasional food source, but not for oviposition.

***Laricobius kandingensis* Zilahi-Balogh and Jelínek**

The genus *Laricobius* (Coleoptera: Derodontidae) has 21 described species, all of which prey only on adelgids (Leschen 2011). Two of these species were discovered as a result of an expedition to China that specifically targeted this genus. In April 2002, an expedition to Sichuan Province, China found a new species in Baoxing County and another new species in Kangding County. These were described, and named according to where they were found: *L. baoxingensis* Zilahi-Balogh and Jelínek, and *L. kangdingensis* Zilahi-Balogh and Jelínek (Zilahi-Balogh et al. 2007). Both species were found on adelgid infested hemlock (*T. chinensis* (Franchet) Pritzl) in April 2002. Only female adults (n=5) of *L. baoxingensis* were collected and these died without reproducing after being shipped to the quarantine laboratory at Virginia Tech in Blacksburg, Virginia. Only larvae (n=23) of *L. kangdingensis* were collected and these completed development on *T. canadensis* infested with HWA in the quarantine.

Quarantine studies of *L. kangdingensis* at Virginia Tech (Gatton et al. 2009) found it to be univoltine, have 4 larval instars, a low temperature development threshold for eggs (0 °C), larvae (1.6 °C), and pre-pupae (5.8 °C), yet completed development only at temperatures between 12-15 °C. Host-range studies showed it preferred HWA over all other species tested.

This species has not been pursued as a biological control agent due to problems with rearing the beetles in quarantine. The largest challenge was the result of the small size of the founding colony and ultimately the colony could not be maintained. Efforts to start new colonies were not successful because only small numbers could be collected in China, and collected beetles did not survive shipment to the quarantine in the United States. In the meantime, another species, *Laricobius osakensis* Montgomery and Shiyake, was discovered in Japan and it was much more abundant and widespread in its native habitat; thus, work with the Chinese *Laricobius* was discontinued.

***Scymnus (Pullus) coniferarum* (Crotch)**

Scymnus is the largest genus of lady beetles (Coccinellidae) with over 600 species worldwide. This large genus is divided into six subfamilies of which the subgenus *Pullus* is the largest with more than 300 described species. Although a large subgenus, *Scymnus (Pullus)* has only three species that are known to be specialists on adelgids (Whitehead 1967). Two of these species, *S. (P.) impexus* (Mulsant) and *S. (P.) suturalis* (Thunberg), are native to Eurasia and have been introduced to North America, and one species, discussed here, is native to the western North America.

Scymnus (Pullus) coniferarum Crotch (Coleoptera: Coccinellidae) was described in 1874 from specimens collected from pine in California. It is a small lady beetle, about 2 mm in length, that is clothed in fine, short pubescence with a black head and pronotum and reddish-yellow brown elytra that is piceous along the suture and at the base (Fig. 2a). Its larvae are covered in a white woolly wax (Fig. 2b). Whitehead (1967) and Gordon (1976) provide full descriptions with figures.

The known native geographical range of *S. (P.) coniferarum* is western North America (Gordon 1985). Specimens have been collected from various species of pines in British Columbia, Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, South Dakota, Utah, and Wyoming (Gordon 1976). Recently several hundred specimens have been collected from western hemlock in Washington State (Montgomery et al. 2009, McDonald 2010). It has recently been recovered from Monterey pine in Chile and Peru (Gonzalez 2006), probably an accidental introduction since pine and adelgids are not native to South America. There is a report of it in the eastern United States (Malkin 1945), but this may be a misidentification. Gordon (1976) recorded it in Pennsylvania, but later clarified that these were *S. (P.) suturalis* (Gordon 1985). Considering that the species has spread intercontinentally, has been found as far east as the Black Hills of South Dakota, and occurs in a variety of habitats

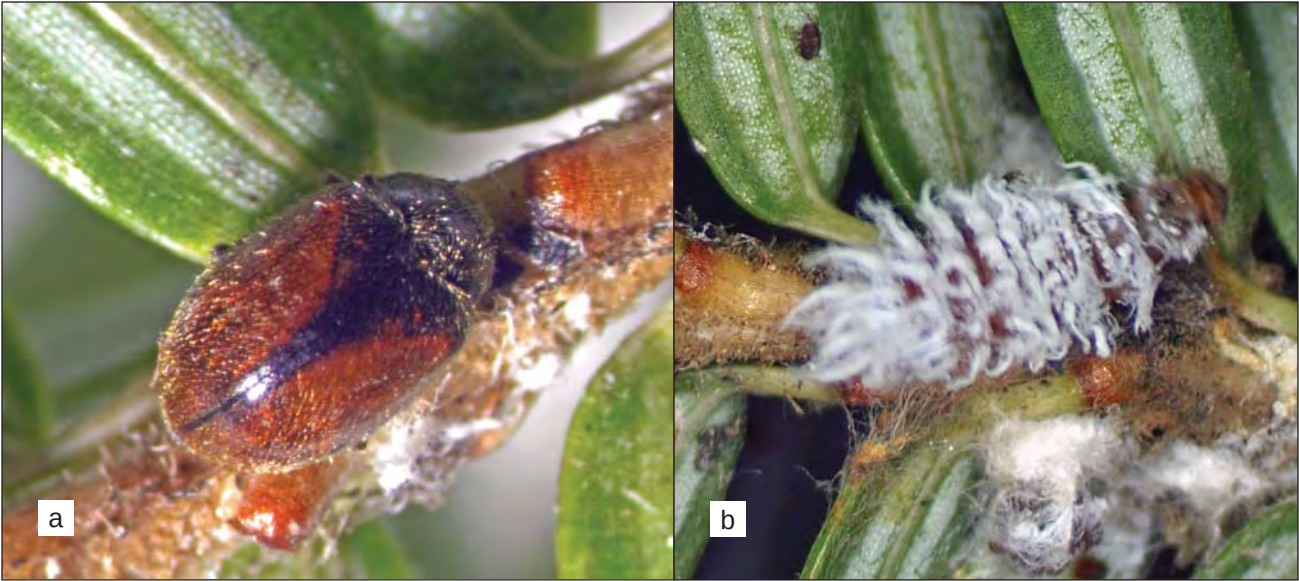


Figure 2. Adult (a) and larva (b) of *Scymnus (Pullus) coniferarum*.

in western North America, it is possible that it is already established in eastern North America.

The seasonal occurrence of *S. (P.) coniferarum* and another predator, *L. nigrinus*, as well as their prey, HWA, in the Seattle, WA area is shown in Table 1. Other information indicates that the production of progrediens eggs continues during July in western Washington (Kohler et al. 2008). The adults of both predators are present and presumably feed on HWA during the late fall and winter months. Larvae of *L. nigrinus* appear in March and complete development by mid-May. The larvae of *S. coniferarum* appear near the end of May and

continue to feed on the progrediens and their sistens eggs into July. In severe winter weather, adults seek shelter in bark crevices on the bole of the tree.

The only hosts of *S. (P.) coniferarum* reported in the literature are adelgids that feed on pine (*Pineus* spp.) (Whitehead 1967, Gordon 1976). Recent observations in the Seattle area have found it abundant on hemlocks infested with HWA, and to a lesser extent on western white pine, but it was not found on several species of hard pines and spruce trees (Montgomery et al. 2009, Montgomery and McDonald 2010).

Table 1. Seasonal occurrence of HWA progrediens stages (blue shading) and HWA sistens stages (yellow shading) and their predators *Laricobius nigrinus* (Ln) and *Scymnus coniferarum* (Sc) in the Seattle, WA area (light pink = relatively few, dark pink = peak abundance). Observations not made July-Sept.

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
HWA adults									
HWA eggs									
HWA nymphs									
Ln adults									
Ln larvae									
Sc adults									
Sc larvae									

Laboratory studies indicate that *S. (P.) coniferarum* feeds specifically on adelgids and does not attack other Homoptera to a significant extent. In the laboratory, the beetle completed development from egg to adult on HWA and the pine bark adelgid, but mortality was greater on the latter host. In no-choice tests *S. (P.) coniferarum* adults did not feed on the native woolly alder aphid, *Prociphilus tessellatus* (Fitch) or the lime aphid, *Eucallipterus tiliae* (L.). In the laboratory, *S. (P.) coniferarum* has been reared for several successive generations on HWA growing on eastern hemlock, and studies on its potential to feed on non-target species are ongoing.

IMPLICATIONS FOR BIOLOGICAL CONTROL

Tetrableps galchanoides is an example of an opportunistic predator. These bugs migrate to high prey densities where they can capture prey efficiently. Because of their feeding efficiency at high prey densities and relatively large size, these opportunistic predators are very effective in reducing outbreak populations in the adelgids' native environment. After the food supply is depleted, they disperse in search of another abundant source of suitable prey. In Japan, several opportunistic predators in the beetle families Elateridae, Cantharidae, Melyridae, and Coccinellidae also attack the progrediens/sexupara generations during May (Shiyake et al. 2008). Thus, we see in Asia that late spring predation by opportunistic generalists may play a critical role in reducing high outbreak densities of HWA to below damaging thresholds. Why similar predation on HWA by opportunistic generalist predators does not occur in the eastern United States is unclear. There are several species of native predators in the families Anthocoridae, Miridae, Elateridae, Cantharidae, and Melyridae that potentially could prey on HWA.

Scymnus (P.) coniferarum merits further study to better assess its potential as a biological control of HWA. Its larvae appear after *L. nigrinus* larvae have stopped feeding and have migrated to the soil. The late spring feeding of *S. (P.) coniferarum*

indicates its impact on HWA population dynamics should complement that of *L. nigrinus*. Late spring predation of HWA may be critical in obtaining suppression of HWA below damaging levels (see Chapter 2). A question that remains to be addressed is the extent that *S. (P.) coniferarum* would feed on other adelgids, including native species present in the eastern United States. Except for *Pineus floccus* Patch, most of the adelgid species present in the eastern United States also occur in the western United States. Its feeding on alternative prey, particularly species such as *Pineus coloradensis* Fitch that are active during the summer, may allow it to sustain higher populations and thus be a more effective predator of HWA.

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IMPLEMENTATION AND STATUS OF BIOLOGICAL CONTROL OF THE HEMLOCK WOOLLY ADELGID

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