An Overview of Lady Beetles in Relation to their Potential as Biological Controls for Hemlock Woolly Adelgid

Guoyue Yu[1] and Michael E. Montgomery[2]

[1]Institute of Plant & Environmental Protection
Beijing Academy of Agricultural & Forestry Science
Beijing 100097, Poeples Republic of China
yu_guoyue@yahoo.com.cn

[2]USDA Forest Service, Northern Research Station
51 Millpond Road, Hamden, CT 06514 USA

ABSTRACT

More than 63 species of lady beetles (Coleoptera: Coccinellidae) have been collected in China from hemlock infested with hemlock woolly adelgid, *Adelges tsugae*. The lady beetle species that seem most useful for biological control are in the genus/subgenus *Scymnus* (*Neopullus*), namely *S. camptodromus*, *S. sinuanodulus*, and *S. ningshanensis*. The geographic range of these lady beetles is limited to one or two provinces. Only five lady beetles were found in Japan; however, it has been surveyed there less intensively. Review of the life history of lady beetles and their prey indicates that lady beetles have been less effective for biological control of aphids than of scales. Because the generational period for adelgids is closer to that of scales than aphids, it is hypothesized that lady beetles that prey on adelgids will be more effective than those that prey on aphids. Introducing biological controls faces problems of climate-matching and often, time is required for agents to become adapted to the new environment.

KEYWORDS

Coccinellidae, biological control, China, Japan, climate

INTRODUCTION

The search in Asia for natural enemies suitable for biological control of the hemlock woolly adelgid (HWA), *Adelges tsugae* Annand, began in 1992 and continues today. The first overseas explorer, Mark McClure, found five natural enemies in Japan during a six-week visit and imported two species, an orbatic mite and a previously unknown species of lady beetle (McClure 1995). In 1994, Sean Murphy of CABI in London went to Taiwan and China at the request of the USDA Forest Service to search for natural enemies. He found five families of predators: Cedidomyiidae, Coccinellidae, Derodontidae, Salpingidae, and Syrphidae (Murphy 1995). The most abundant predator in Taiwan was a derodontid beetle subsequently named *Laricobius taiwanensis* (Yu and Montgomery, in press). These pioneering efforts demonstrated that natural enemies of HWA in Asia are numerous and many are species not previously known to science.

This paper summarizes the surveys we and our colleagues made for natural enemies of hemlock woolly adelgids from 1995-2004. It quickly became apparent that lady beetles (Coleoptera: Coccinellidae) are both diverse and important predators of the hemlock woolly adelgid in China. Our report focuses on that family, although other families of natural enemies also play a major role in the region. We first provide an account of the species collected, then discuss the use of lady beetles to control other adelgids, and finally, comment on factors influencing successful use of lady beetles for biological control.

LADY BEETLES COLLECTED FROM HEMLOCKS IN CHINA AND JAPAN

Surveys were not done every year or systematically, and time spent actually collecting in the field was limited—usually only a few hours for each field site and only one to four days in each province. We investigated sites in Yunnan (1995-1998, 2002, and 2004), Sichuan (1995-1998 and 2003), Shaanxi (1998 and 2002), Guangxi (2003), and Hubei (2004).

Yu et al. (1997, 2000) recorded a total of 54 species of Coccinellidae collected from hemlocks in China. From 2002, we continued to search for natural enemies of the hemlock woolly adelgid in Shaanxi, Sichuan, Yunnan, Guangxi, and Hubei. In Hubei and Guangxi, we found hemlock but no adelgids. In these years, 27 species of lady beetles were found on Chinese hemlocks; three of these are new species (Yu and Montgomery, in press). As of 2005, the total number of species of ladybugs we have found on Chinese hemlocks is 63, with 28 species new to science and one new to China (Table 1). Of the 63 species, 48 are found in Yunnan, 13 in Sichuan, and 16 in Shaanxi. Six species are common to Yunnan and Shaanxi, four to Yunnan and Sichuan, and two to Sichuan and Shaanxi. There are no species common to all three provinces. Sichuan is probably under-represented because the first author (Yu) did not personally collect natural enemies in the province, and local partners targeted *Scymnus camptodromus* and paid little attention to other Scymninae or big-sized lady beetles.

Presently only 10 of the ladybug species in China are known to be predators of HWA. They are *Oenopia billieti* (Mulsant), *Adalia conglomerata* (L.), *Calvia championorum* Booth, *Sasajiscymnus* (=*Pseudoscymnus*) *ocellatus* (Yu), *S. camptodromus* Yu et Liu, *S. sinuanodulus* Yu et Yao, *S. ningshanensis*, *S. paralleus* Yu and Pang, *S. yunshanpingensis* Yu, and *S. geminus* Yu and Montgomery. The first three are in the subfamily Coccinellinae and are large species known to prey on aphids and other Homoptera. Because of their more general host range, they were not considered for importation. The remaining seven species are in the subfamily Scymninae, a subfamily of small (less than 3 mm long) pubescent lady beetles that are usually prey-specific (Hagen et al. 1999). Although seven of these species were imported, colonization was attempted for only the three species that were most abundant: *S. camptodromus*, *S. sinuanodulus*, and *S. ningshanensis*.

From 2002 to 2004, we also surveyed natural enemies of HWA in Japan. Previously, only one species, *Sasajiscymnus tsugae* (Sasaji and McClure 1997), was recorded from Japanese hemlocks. However, we found other ladybugs as well: *Scymnus* (*Pullus*) *posticalis* Sicard, *Adalia conglomerata* (Linneaus); *Harmonia axyridis* (Pallas), and *Scymnus* (*Pullus*) *giganteus* Kamiya. Of the five species, *S. tsugae*, *A. conglomerata*, and *H. axyridis* were collected as larvae in June 2004. The first two were reared into adults. Kamiya (1965) recorded *A. conglomerata* as a predator of *Adelges japonicus* Monzen. We observed that both its larvae and adults preyed on HWA. Other natural enemies (*Laricobius* spp., lacewings, Miridae etc.) were also found on hemlocks in China in addition to other ladybugs identified only to genus.

WORLD COCCINELLIDS PREDACEOUS ON ADELGIDS

Yu (2001) lists 48 species of lady beetles that prey on adelgids recorded from all over the world. Most of them were introduced into North America for biocontrol of the balsam woolly adelgid, *Adelges piceae* (Ratzenburg), in 1934-1969. Of these, five are Chilocorinae, 10 Scymninae, and 21 Coccinellinae. All but two of 16 lady beetles introduced into North America for control of *A. piceae* prey on other adelgids in their native region. Several of these species are known to be general predators on Aphididae, and one, *Chilocorus kuwanae* Silvestri, is well known as a predator of diaspine scale. The two species established in North America, *Aphidecta obliterata* (L.) and *Scymnus* (*Pullus*) *impexus* Mulsant, prey not only on *A. piceae* but on other adelgids and aphids as well. Another *Pullus* species, *Scymnus* (*Pullus*) *suturalis* Thunberg, a predator of adelgids on pines that was introduced from Europe to North America, also was found to attack HWA (Montgomery and Lyon 1996).

Successful biological control of balsam woolly adelgid was not achieved despite a 35-year effort that included 11 species of Coccinellidae (Schooley et al. 1984). What can we learn from this failure? Yu (2001) mentioned the following: 1) predators selected for introduction should prey and reproduce mainly or only on HWA in their native country; 2) higher latitude or colder areas of predator collection in China, such as Shaanxi Province, need to be explored for predators; 3) monophagous predators are to be preferred, their life cycle should be well synchronized with that of HWA, and they should be able to survive the summer aestivation period of HWA; and 4) introduction of multiple species may be necessary for effective predation.

COMMENTS ON BIOLOGICAL CONTROL OF HWA

Theoretically, can lady beetles control adelgids?

Although there have been hundreds of introductions of lady beetles for biological control, few have been successful. Generally, lady beetles are ineffective in the biological control of aphids (Dixon et al. 1995), although there are many examples of outstanding control of coccids by lady beetles (Clausen 1978; Dixon 2000). For a predator to effectively control a prey species, the "generation time ratio" of predator to prey should be less than 1.0 (Dixon et al. 1995 and 1997). Aphids with parthenogenetic, viviparous reproduction can have generation times of 1-2 weeks and their abundance is strongly responsive to host quality. On average, aphidophagous lady beetles develop slower than their prey aphids, with generation times often of more than a month, whereas the lady beetles that feed on coccids have generation times similar to their prey. Another hypothesis is that lady beetles feeding on coccids are more efficient, killing more prey because the coccids are immobile and the lady beetles feed selectively, consuming only the most nutritious parts of the prey (Dixon 2000). Surprisingly, the lady beetles that feed on coccids have lower fecundity than those that feed primarily on aphids, seem to eat prey at a slower rate, and grow more slowly (Dixon 2000). In sum, it seems that the greater prey

Table 1. Species collected in China from *Tsuga* spp. (1995 - 2004).

SPECIES	COLLECTION PROVINCES[1]	RELATIVE ABUNDANCE[2]
Subfamily Coccidulinae		
Sumnius nigrofuseus Jing	Yun	2
Rodolia limbota	Sha	3
Subfamily Scymninae		
Stethorus (*Allostethorus*) descrip. pending	Yun	15
Clitostethus wenbishanus Yu	Yun	1
Scymnus (*Neopullus*) *camptodromus* Yu and Liu	Yun, Sic	119
Scymnus (*Neopullus*) *sinuanodulus* Yu and Yao	Yun	93
Scymnus (*Neopullus*) *ningshanensis* Yu and Yao	Sic, Sha	38
Scymnus (*Neopullus*) *lijiangensis* Yu	Yun	4
Scymnus (*Neopullus*) *thecacontus* Ren and Pang	Yun	1
Scymnus (*Neopullus*) *lycotropus* Yu	Yun	4
Scymnus (*Neopullus*) *nigromarginalis* Yu	Yun	1
Scymnus (*Neopullus*) *paralleus* Yu and Pang	Sha	3
Scymnus (*Parapullus*) *tsugae* Yu and Yao	Yun	2
Scymnus (*Parapullus*) descrip. pending	Sha	80
Scymnus (*Scymnus*) *najaformis* Yu	Yun	9
Scymnus (*Scymnus*) *unciformis* Yu	Yun	1
Scymnus (*Scymnus*) *paracrinitus* Yu	Yun	4
Scymnus (*Pullus*) sp. 1	Yun	1
Scymnus (*Pullus*) *nigrobasalis* Yu	Yun	2
Scymnus (*Pullus*) *baoxingensis* Yu	Sic	2
Scymnus (*Pullus*) *gucheng* Yu	Yun	2
Scymnus (*Pullus*) *yunshanpingensis* Yu	Yun	34
Scymnus (*Pullus*) *geminus* Yu and Montgomery	Yun	15
Scymnus (*Pullus*) *heyuanus* Yu	Yun	3
Scymnus (*Pullus*) *japonicus* Weise	Yun, Sha	4
Scymnus (*Pullus*) *ancontophyllus* Ren and Pang	Yun, Sic	5
Scymnus (*Pullus*) *robustibasalis* Yu	Yun	2
Scymnus (*Pullus*) *jaculatorius* Yu	Yun	1
Scymnus (*Pullus*) *toxosiphonius* Pang and Huang	Yun	7
Scymnus (*Pullus*) sp. 3	Yun	3
Pseudoscymnus heijia Yu and Montgomery	Yun, Sic	10
Pseudoscymnus ocellatus Yu	Sic, Sha	3
Pseudoscymnus truncatulus Yu	Yun	2
Pseudoscymnus sp. 1	Yun	1
Pseudoscymnus sp. 2	Yun	1
Cryptogonus *lijiangensis* Pang and Mao	Yun	1
Cryptogonus ocoguttatus Mader	Yun, Sic	3

Subfamily Chilocorinae		
Telsimia sp.	Yun	2
Subfamily Sticholotidinae		
Shirozuella quadrimacularis Yu	Yun	1
Shirozuella nibagou Yu	Sic	3
Subfamily Coccinellinae		
Hippodamia variegata (Goeze)	Yun	3
Propylea quatuordecimpunctata (L.)	Sic	1
Adalia bipunctata (L.)	Yun	11
Adalia conglomerata (L.)	Yun, Sha	6
Oenopia billieti (Mulsant)	Yun, Sha	4
Oenopia deqenensis Jing	Yun, Sic	21
Oenopia emmerichi Mader	Yun	3
Oenopia sexmaculata Jing	Sha	1
Oenopia signatella (Mulsant)	Sha	16
Oenopia zonatus Yu	Sic	3
Xanthadalia hiekei Iablokoff-Khnzorian	Yun	27
Coccinella septempunctata L.	Yun, Sha	3
Harmonia axyridis (Pallas)	Yun, Sha	9
Harmonia eucharis (Mulsant)	Yun	5
Harmonia quadripunctata (Pontoppidian)	Yun	1
Harmonia descrip. pending	Sic	1
Calvia quatuordecimguttata (L.)	Sha	20
Calvia championorum Booth	Sha	8
Calvia sp.	Yun, Sha	2
Halyzia sedecimguttata (L.)	Sic	1
Halyzia straminea (Hope)	Yun	1
Halyzia sanscrita Mulsant	Yun, Sha	2
Vibidia duodecimguttata (Poda)	Yun	4

[1] Yun = Yunnan, Sic = Sichuan, Sha = Shaanxi.
[2] Total numbers collected by the authors, Yao Defu, Nathan Havill or Tom McAvoy; does not include collections of mass numbers of *S. camptodromus* and *S. sinuanodulus* by others.

specificity of the coccidophagous lady beetles and the longer generation time of the coccids accounts for the success of these lady beetles as biological control agents.

When we consider the generational times of aphids and scales, adelgids seem closer to scales than to aphids. Both adelgids and scales have a mobile crawler stage but thereafter are sessile. Adelgids and most scales are oviparous. On the other hand, adelgids and aphids both have parthenogenic generations on secondary hosts. Cheah and McClure (2000) considered *A. tsugae* to be more similar to coccids than to aphids. They pointed out that it takes a couple of years for the adelgid to begin to cause decline in the host plant; thus, the adelgids would be less ephemeral than aphids. They also pointed out that the lady beetle *S. tsugae* has a generation time of five weeks, which is shorter than either the spring or overwintering generation of the adelgid. However, they mentioned that the aestivation of the adelgid, while the lady beetle is active, may be a 'bottleneck'. The development of *A. tsugae* during the winter months and initiation of egg laying in late winter may also make it difficult for lady beetles to control this prey.

Other families of predators have been used successfully for biological control of adelgids in the genus *Pineus* (Zilahi-Balogh et al. 2002). Chamaemyiid species (genus *Leucopis*) were successfully established in Chile, New Zealand, and Hawaii for biological control of *P. pini* (Macquart) (= laevis Maskill). An anthocorid predator introduced into Kenya, *Tetraphleps raoi*, has also been successful in reducing populations of *P. pini*. However, there are no examples of successful biological control of species in the genus *Adelges*.

Can better climate matching yield more successful predators?

An example of insufficient consideration of climate is the collection of predators from India and Pakistan for biological control of the balsam woolly adelgid in North America. In this case, none of the predators were recovered in the field in North Carolina (Amman and Speers, 1971) or in eastern Canada. The lady beetles imported for biological control of HWA generally come from latitudes further south than those where the adelgid occurs in the eastern U.S. *Sasajiscymnus tsugae* (Sasaji and McClure, 1997) was collected in the Osaka area on *Tsuga sieboldii*, and the holotype tree is located near Takatsuki City, Osaka Perfecture, Japan (N 34º 57', altitude 374 meters). The weather there is a little warmer and more rainy, but is a reasonable match with the climate where HWA now occurs in the eastern United States. The Chinese lady beetles *S. sinuanodulus* and *S. ningshanensis* were collected at more southern latitudes but higher altitudes, N 31.6º, 2,700 meters, and N 33.3º, 1,800 meters, respectively. The combination of low latitude and high altitude results in seasonal temperature averages that are similar to the high mountains of the southern Appalachians in the U. S. The main difference in where HWA occurs in east Asia and the eastern United States is the pattern of rainfall; dry winters and wet summers occur in Asia, whereas monthly rainfall is fairly even in eastern United States throughout the year (Wang et al. 1998; Montgomery et al. 2002).

Adaptation of natural enemies to new habits may take years or decades. For example, the mealybug destructor, *Cryptolaemus montrouzieri* Mulsant, was introduced to China from the Soviet Union in 1955 and was mass-reared and released in quantity in South China (Guangdong and Fujian Provinces) several times. Average maximum July temperature in Guanzhou, Guangdong, is 32.6°C. Establishment was not confirmed until 1978, more than 20 years later (Pang and Li, 1979). Comparison of survival at different temperatures shows that, after 30 years, the mealybug destructor adapted to the higher temperature in Guangdong (Table 2). Currently, home areas for the beetles introduced for biological control of HWA are warmer than the target's home areas and differ as well in varying degrees in rainfall patterns; thus, successful control of the hemlock woolly adelgid may be delayed while the beetles adapt to a new temperature regime.

Table 2. Percent hatch and survival at different temperatures of *Cryptolaemus montrouzieri* in 1962 prior to release in Guangdong Province, and three decades after release (1996).

	Year	Temperature (ºC)		
		32	34	36
Egg hatch	1962	4	0	0
	1996	51.3	36.2	7
Larval-pupal survival	1962	0	0	0
	1996	41.6	9.3	--

(Data from Li 1993, Chen et al. 2000)

What are the opportunities to introduce more lady beetles?

Considerable data on hemlocks, the adelgid, and natural enemies have been accumulated in the past decade. When considering the biological control of the adelgid, there still are many questions to ask: Where should we look? What should we look for? What may we find? In answering these questions, there is an inherent dilemma. For the safety of native species, natural enemies should be host-specific and narrow in distribution; unfortunately, the lady beetles meeting these requirements would, theoretically, be less successful in establishment in a new environment.

China has more potential as a source for biological control as it has a greater diversity of lady beetles on hemlock trees than Japan. However, the localized distribution of many of these beetles suggests limitations. Three provinces in China (Yunnan, Sichuan, and Shaanxi) have quite different lady beetle communities, and Scymnini species especially are different (Wang et al. 1998; Yu et al. 2000; Montgomery et al. 1996). The limited geographic range of the lady beetles in China, which are adelgid specialists, suggests that they may not adapt rapidly to a new environment. Although Japan appears to have a low diversity of specialist predators, a systematic survey needs to be done for both *Tsuga sieboldii* and *T. diversifolia*, which are associated with warmer and cooler climates, respectively.

Lady beetles considered to be less host-specific have not been evaluated for biological control of HWA, even though they may be important regulators of the adelgid in its native habitats. Examples of presumed generalists which may need further study are: *Adalia conglomerata* L., recorded previously to prey on *Adelges japonicus* (Kamiya 1965), *A. piceae* (Clausen 1978; Schooley et al. 1984), and the hemlock woolly adelgid (Yu et al. 2000); and *C. championorum*, distributed in many parts of China (Gansu, Shaanxi, Sichuan, and Yunnan provinces, and in Taiwan) (Yu and Wang 1999) from elevations of 1,580 m to 2,600 m and in northern India (Booth 1997). *Calvia quatuordecimguttata* (L.) is a species widely distributed in Asia and North America (Gordon 1985), and though there are no reports of its hosts in North America, a total of 20 specimens were collected from hemlock in fall of 2002 in Shaanxi Province, China (Yu and Montgomery, in press).

What use can be made of local natural enemies?

According to biological control theory, natural enemies should come from the native country or endemic area of the pest. However, there is increasing evidence that natural enemies present in the area where the pest has invaded could contribute to control by making a host shift to use the new resource. For example, the parasite *Chouioia cunea* Yang is used in China for control of the fall webworm, *Hyphantria cunea* (Drury), which is native to North America. It is easy to mass-rear, and five years after releasing the parasite, the parasitism rate is as high as 92% (Yang 2004).

For control of HWA in the eastern United States, several North American natural enemies have potential. *Laricobius rubidus* LeConte, native to the eastern U. S., has already been observed to feed and reproduce on HWA (Montgomery and Lyon 1996). *Laricobius nigrinus* Fender, which is native to western North America, has been successfully introduced to the other side of the continent and is a very promising potential control agent (Lamb et al. 2002). The role of native American lady beetles (such as *Mulsantina hudsonica* (Casey)) and established exotic species (such as *H. axyridis*) should not be overlooked.

ACKNOWLEDGEMENTS

Thanks are given to the following colleagues for collecting natural enemies or providing valuable assistance: Yao Defu, Li Guangwu, Wang Hongbin, and Wei Jiangrong (Chinese Academy of Forestry, Beijing); Lu Wenhua (University of Rhode Island); Nathan Havill (Northeastern Research Station, USDA Forest Service, Hamden, Connecticut); Shigehiko Shiyake (Osaka Natural History Museum, Osaka); Zhang Shize (Northwest Agricultural and Forestry Sci-Technology University, Yangling); Yang Jingquan (Yunnan Alpine Botanic Research Institute, Lijiang); Gen Xiaoli and Jia Chunghong (Beijing Academy of Agricultural and Forestry Science, Beijing); Zhang Ming (Sichuan Agricultural University, Ya'an); and Xu Xueqin and Gao Hengxiao (Sichuan Forestry Bureau, Chengdu). The study was supported by cooperative agreement from the USDA, Forest Service, Northeastern Research Station.

REFERENCES

Amman, G.D., and C.F. Speers. 1971. Introduction and evaluation of predators from India and Pakistan for control of the balsam woolly aphid (Homoptera: Adelgidae) in North Carolina. *Canadian Entomologist* 103:528-533.

Booth, R.G. 1997. A review of the species of *Calvia* (Coleoptera: Coccinellidae) from the Indian subcontinent, with descriptions of two new species. *Journal of Natural History* 31:917-934.

Cheah, C.A.S.-J., and M.S. McClure. 2000. Seasonal synchrony of life cycles between the exotic predator, *Pseudoscymnus tsugae* (Coleoptera: Coccinelldidae) and its prey, the hemlock woolly adelgid *Adelges tsugae* (Homoptera: Adelgidae). *Agricultural and Forest Entomology* 2:241-251.

Chen, X.F., S.X. Ren, X.L. Ying, and H. Pang. 2000. The effects of temperature on laboratory populations of *Cryptolaemus montrouzieri* Mulsant. *Acta Ecologica Sinica* 20(1):129-133. In Chinese with summary in English.

Clausen, C.P. (ed.). 1978. Introduced parasites and predators of arthropod pests and weeds: A world review. USDA Agriculture Handbook No. 480. 545 p.

Dixon, A.F.G. 2000. Insect predator-prey dynamics: Ladybird beetles and biological control. Cambridge University Press, Cambridge.

Dixon, A.F.G., J.L. Hemptinne, and P. Kindlmann. 1995. The ladybird fantasy–prospects and limits to their use in the biocontrol of aphids. *Züchtungsforschung* 1(2):395-397.

Dixon, A.F.G., J.L. Hemptinne, and P. Kindlmann. 1997. Effectiveness of ladybirds as biological control agents: Patterns and processes. *Entomophaga* 42(1/2):71-83.

Gordon, R.D. 1985. The Coccinellidae (Coleoptera) of America North of Mexico. *Journal of the New York Entomological Society* 93(1):912.

Hagen, K. S., N.J. Mills, G. Gordh, and J.A. McMurtry. 1999. Terrestrial arthropod predators of insect and mite pests. Pp. 383-503 *in* Bellows, T.S., and T.W. Fisher (eds.), Handbook of Biological Control. Academic Press, New York.

Kamiya, H. 1965. On the Coccinellidae attacking the aphids in Japan and the Ryukyus. *Mushi* 40(12):147-175.

Lamb, A.B., S.M. Salom, and L.T. Kok. 2002. Field evaluation and improvement of rearing procedures for *Laricobius nigrinus* (Fender) (Coleoptera: Derodontidae), a predator of hemlock woolly adelgid. Pp. 189-196 *in* Onken, B., R. Reardon, and J. Lashomb (eds.), Proceedings, Symposium on Hemlock Woolly Adelgid in the Eastern United States, February 5-7, 2002, East Brunswick, NJ. New Brunswick, NJ: Rutgers University.

Li, L.Y. 1993. Studies and application respective of *Cryptolaemus montrouzieri* Mulsant in China. *Natural Enemies of Insects* 15(3):142-150.

McClure, M.S. 1995. Natural enemies to control woolly adelgid. *Frontiers of Plant Science* 47(2): 5-7.

Montgomery, M. E., and S.M. Lyon. 1996. Natural enemies of adelgids in North America: Their prospect for biological control of *Adelges tsugae* (Homoptera: Adelgidae). Pp. 89-102 *in* Onken, B., R. Reardon, and J. Lashomb (eds.), Proceedings, Symposium on Hemlock Woolly Adelgid in the Eastern United States, February 5-7, 2002, East Brunswick, NJ. New Brunswick, NJ: Rutgers University.

Montgomery, M.E., H.B. Wang, D.F. Yao, W.H. Lu, N. Havill, and G.W. Li. 2002. Biology of *Scymnus ningshanensis* (Coleoptera: Coccinellidae): A predator of *Adelges tsugae* (Homoptera: Adelgidae). Pp. 181-188 *in* Onken, B., R. Reardon, and J. Lashomb (eds.), Proceedings, Symposium on Hemlock Woolly Adelgid in the Eastern United States, February 5-7, 2002, East Brunswick, NJ. New Brunswick, NJ: Rutgers University.

Murphy, S.T. 1995. Insect natrual enemy complexes of hemlock dwelling *Adelges* spp. in Asia and the identification of potential agents for the biological control of *A. tsugae* in the northeastern USA. P. 34 *in* International Institute of Biological Control (CABI), Silwood Park, Ascot, Berkshire, United Kingdom.

Pang, X.F., and L. Li. 1979. *Cryptolaemus montrouzieri* Mulsant settled in Guangdong, controlling *Pseudococcus* sp. on *Aleurites moluccuna* (L.). *Natural Enemies of Insects* 1979(3):50. In Chinese.

Sasaji, H., and M.S. McClure. 1997. Description and distribution of *Pseudoscymnus tsugae* sp. nov. (Coleoptera: Coccinellidae), an important predator of hemlock woolly adelgid in Japan. *Annals of the Entomological Society of America* 90(5):563-568.

Schooley, H.O., J.W.E. Harris, and B. Pendrel. 1984. *Adelges piceae* (Ratz.), balsam woolly adelgid (Homoptera: Adelgidae). Pp. 229-234 *in* Kelleher, J.S., and M.A. Hulme (eds.), Biological Control Programmes Against Insects and Weeds in Canada, 1969-1980. Commonwealth Agricultural Bureau, London.

Wang, H.B., D.F. Yao, G.W. Li, C.H. Zhang, L. Li, H.X. Guo, and D.Q. Zhao. 1998. Investigation on hemlock woolly adelgids and its natural enemies in China. Pp. 41-46 *in* Resource Technology 1997: Beijing international symposium proceedings. Chinese Academy of Forestry, China Forestry Publishing House, Beijing.

Yang, Z.Q. 2004. Advance in bio-control researches of the important forest insect pests with natural enemies in China. *Chinese Journal of Biological Control* 20(4):221-227. In Chinese with summary in English.

Yu, G.Y. 2001. The Coccinellids (Coleoptera) predacious on adelgids, with notes on the biocontrol of the hemlock woolly adelgid (Homoptera: Adelgidae). Special Publication of Japan Coleopterist Society, Osaka 1:297-304.

Yu, G., and M.E. Montgomery. In press. A new species of *Laricobius* (Coleoptera: Derodontidae) from Taiwan. *Formosan Entomologist*.

Yu, G.Y., M.E. Montgomery, and D.F. Yao. 2000. Lady beetles (Coleoptera: Coccinellidae) from Chinese hemlocks infested with the hemlock woolly adelgid, *Adelges tsugae* Annand (Homoptera: Adelgidae). *Coleopterists Bulletin* 54 (2):154-199.

Yu, G.Y., and X.F. Pang. 1994. Descriptions of two new species of *Scymnus* Kugelann from China (Coleoptera: Coccinellidae). *Acta Entomologica Sinica* 37(2):209-212. In Chinese with summary in English.

Yu, G.Y., and H.Y. Wang. 1999. Guidebook to lady beetles of Taiwan. Shih Pui Ni, Taipei. In English and Chinese.

Yu, G.Y., D.F. Yao, and H.P. Liu. 1997. The Coccinellidae collected from *Tsuga* with *Adelges tsugae* Annand (Homoptera: Adelgidae). *Scientia Silvae Sinicae* 33:432-440. In English and Chinese.

Zilahi-Balogh, G., L.T. Kok, and S.M. Salom. 2002. A review of world-wide biological control efforts for the family Adelgidae. Pp. 129-140 *in* Onken, B., R. Reardon, and J. Lashomb (eds.), Proceedings, Symposium on Hemlock Woolly Adelgid in the Eastern United States, February 5-7, 2002, East Brunswick, NJ. New Brunswick, NJ: Rutgers University.

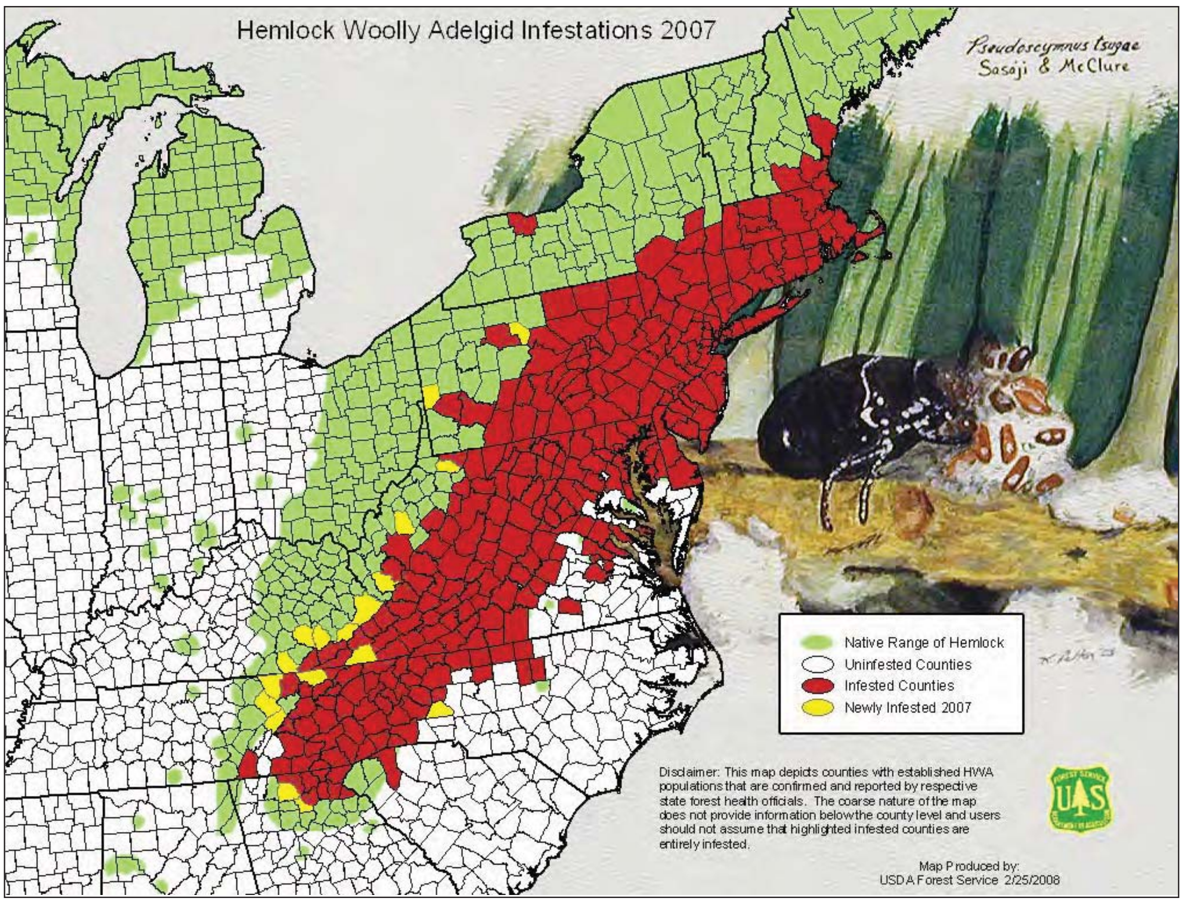
Forest Health Technology
Enterprise Team

TECHNOLOGY
TRANSFER

Hemlock Woolly Adelgid

Fourth Symposium on Hemlock Woolly Adelgid in the Eastern United States

Hartford, Connecticut
February 12-14, 2008



Brad Onken and Richard Reardon, Compilers

Forest Health Technology Enterprise Team—Morgantown, West Virginia

U.S. Department of Agriculture

Forest Service

FHTET-2008-01
June 2008