Biology of *Scymnus ningshanensis* (Coleoptera: Coccinellidae): A Predator of *Adelges tsugae* (Homoptera: Adelgidae)

Michael Montgomery,[1] Hongbin Wang,[2] Defu Yao,[2] Wenhau Lu,[1] Nathan Havill,[1] and Guangwu Li[2]

[1] USDA Forest Service, Northeastern Center for Forest Health Research,
51 Millpond Road, Hamden, CT 06514

[2] Chinese Academy of Forestry, Research Institute of Forest Environment and Protection
Beijing 100091, People's Republic of China

Abstract

Information is presented on the occurrence, development, and feeding of *Scymnus (Neopullus) ningshanensis* Yu et Yao. Information on its biology was collected in the field and laboratory in China and in quarantine in the United States. This lady beetle was found in China only on hemlock infested with *Adelges tsugae* Annand and did not occur on nearby pine infested with another adelgid. In the laboratory, newly hatched larvae survived only if they could feed on hemlock woolly adelgid eggs. Development of the immature stages was about 10% faster than *S. (N.) sinuanodulus* that occurs farther south in China. The climate in the native habitat of *S. ningshanensis* is similar to the climate of Connecticut in respect to temperature, but rainfall is lower in the winter and higher in the summer than in Connecticut. Eggs are laid in the spring for several weeks, both in the laboratory and field. Feeding on hemlock woolly adelgid eggs stimulates egg production. The species is univoltine and without a true diapause, although adults are inactive at temperatures below 7°C.

Keywords:

Lady beetles, biological control, bionomics, development.

Introduction

Scymnus (Neopullus) ningshanensis Yu et Yao is one of three Chinese lady beetles in the subgenus *Neopullus* imported into the USDA Forest Service Quarantine Laboratory, Ansonia, Connecticut, as a biological control agent for the hemlock woolly adelgid, *Adelges tsugae* Annand. Descriptions of these and other species of lady beetles found on hemlock in China are in Yu et al. (2000). The biology of another species, *S. (N.) sinuanodulus* Yu et Yao was examined in Lu and Montgomery (2001) and Lu et al. (in press). These lady beetles occur along the eastern edge of the Tibetan plateau (Figure 1). The hemlocks (*Tsuga chinensis* (Franch)) E. Dritz, *T. dumosa* (D. Don) Eich., and *T. forrestii* Downie) in this region grow between 1800 m and 3000 m in steep, rugged mountains which tend to be broken and isolated from each other (Montgomery et al. 2000). *Scymnus ningshanensis* was collected near Ningshan in Shaanxi Province from *T. chinensis*.

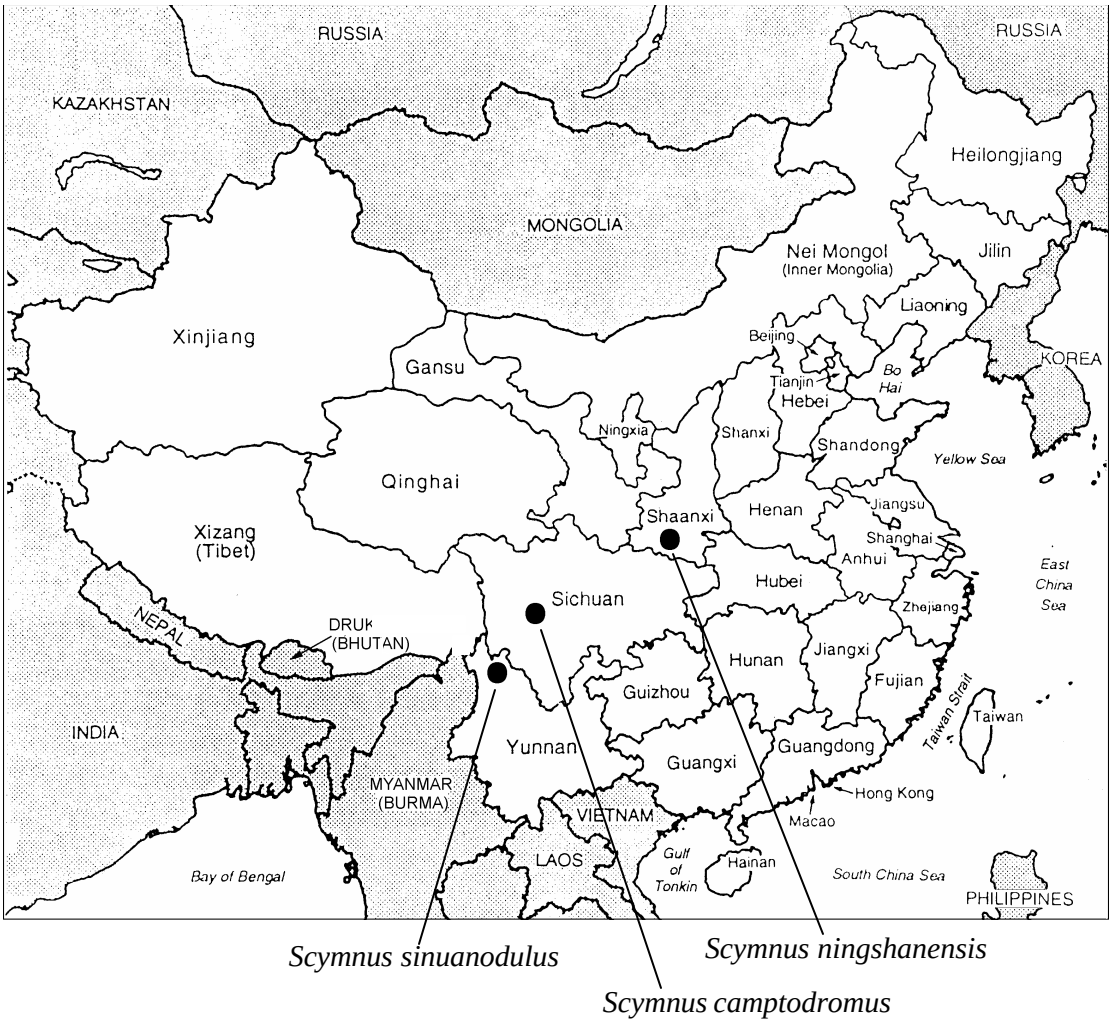

Figure 1. Map of China provinces showing where lady beetles were collected.

Scymnus is the largest genus of lady beetles with more than 600 species worldwide, many of which are used for biological control of Homoptera (Hagen et al. 1999). The subgenus *Neopullus* is one of six subgenera of *Scymnus*; the other subgenera are *Scymnus*, *Pullus*, *Didion*, *Mimiopullus,* and *Parapullus* (Pang and Yu 1993). *Neopullus* is known only from eastern Asia (Sasaji 1971). We previously reported on the biology of *S. (N.) sinuanodulus* (Lu and Montgomery 2001). The only other species in the subgenus with information on its developmental bionomics is *Scymnus (Neopullus) hoffmanni* Weise (Yang and Zheng 1991).

We present here a summary of the occurrence, development, and feeding of *S. ningshanensis*. This information was obtained from studies conducted in the field and laboratory in China and in quarantine in the United States. Additional information on studies in China can be found in Wang et al. (2000).

Climate, Seasonality, Hosts in Native Habitat

The climate at Ningshan is similar to Middletown, Connecticut, in temperature (Figure 2). Ningshan is about 1,000 km farther south in latitude and 1,500 m higher in elevation than Middletown. The two locations differ considerably in the amount and distribution of rainfall. Ningshan is at the northwest edge of a moist subtropical zone. Thus, Ningshan has rainy summers and dry winters, which is unlike the more even distribution of rainfall in Middletown.

Hemlock in China grows on steep, rugged, mountainous terrain in the transition zone between mixed mesophytic forest and boreal forest. Hemlock is usually a scattered, minor component in forest that consist of several hardwood species in genera also found in eastern North America and conifers in the genera *Abies, Picea, Taxus, Pinus, Pseudotsuga, Cunninghamia,* and *Keteleeria* (Montgomery et al. 2000).

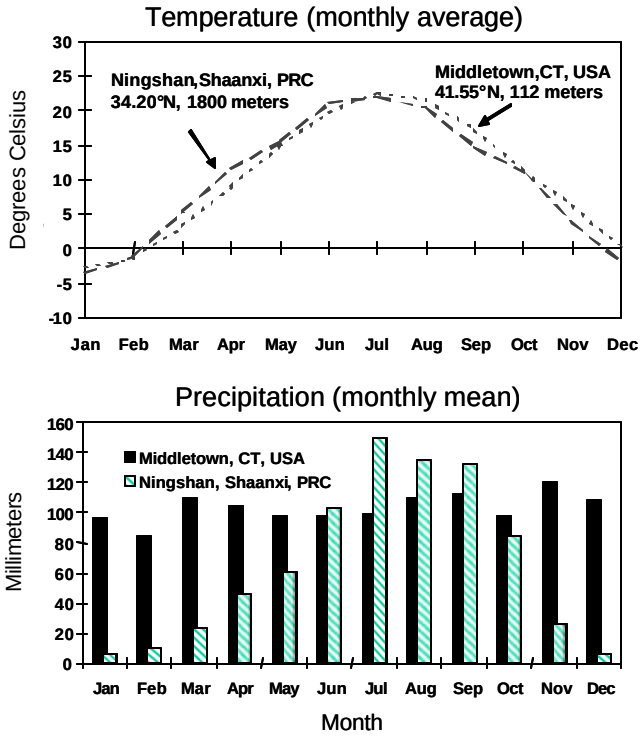

Figure 2. Average monthly temperature and precipitation for Ningshan, China, and Middletown, Connecticut. The data for Ningshan are based on interpolation of data for Xian (397 m), Baoji (712 m), Hanzhong (508 m), and Wanyuan (600 m) using a temperature lapse rate of 0.5°C/100 m.

We examined all tree species for adelgids, other Homoptera, and lady beetles. Besides hemlock, adelgids were found on spruce and the soft-needled pine *Pineus armandii* Franch. *Scymnus ningshanensis* was found only on hemlock and was not on nearby Armand pine, infested with a *Pineus* sp. adelgid on its needles. Hemlock on prime growing sites in China grows large. In such areas it was necessary to climb trees and find discarded crowns of trees cut for lumber the previous winter in order to examine foliage for beetles. Drier sites had smaller, more accessible hemlock from which it was possible to collect adult lady beetles by beating foliage over a cloth or an umbrella. We recovered larvae by examining adelgid-infested foliage with a stereomicroscope in the laboratory.

In the field in China, *S. ningshanensis* adults became active in early April when the 10-day average temperature reached 7°C. Adults were numerous on the foliage until mid-June, then were difficult to find on the foliage until early September. Adults were found on the foliage throughout September and October until the 10-day average temperature became less than 7°C. Egg laying was from April to June, when eggs of the progrediens generation of hemlock woolly adelgid were present.

Immature Development

Figure 3. Life stages of *Scymnus ningshanensis*: (a) egg inserted in bud scales (see arrow), (b) fourth instar larva, (c) pupa, (d) adults mating.

In most respects, the immature stages of *S. ningshanensis* are similar in appearance to *S. sinuanodulus* (Lu et al. in press). Eggs are laid singly, usually in bud scales, under egg sacs, and other partially concealed locations (Figure 3a). When first laid, the eggs are yellow-orange, becoming dark brown after a day or two and iridescent prior to hatch. The larvae are elongate, yellowish to reddish brown, densely setaceous on the head and plates (Figure 3b). The body has tubercles, but lacks prominent spines. Like most members of the tribe, the larvae have a waxy covering on the cuticle, but it is absent in the first instar and may not be conspicuous until the last instar. The pupae are naked, with the larval exuvium attached only to the last abdominal segment (Figure 3c). The pupae are covered with coarse setae with viscous droplets on the tips, which we believe are defensive. The adults are uniformly dull orange after emergence, with the elytral pattern appearing one to three weeks later. Mating (Figure 3d) begins when beetles are 3 weeks old, but egg laying does not occur until the following spring (exposure to cold temperature seems prerequisite). The beetles do not have an aestivation period or winter diapause, although the adults feed little during the summer and are inactive at 5°C.

The duration of each immature stage of *S. ningshanensis* is compared with *S. sinuanodulus*, which occurs farther south in Yunnan Province in (Table 1). The total time for development of *S. ningshanensis* was about 6 days faster than *S. sinuanodulus*. Although the precise duration of each instar was not recorded in the quarantine, the total duration of immature development of *S. ningshanensis* was consistently 4 to 8 days faster when both species were reared simultaneously. The longer time spent by *S. sinuanodulus* in the fourth larval instar includes several days it often spent wandering before entering the prepupal stage (Lu et al. in press). This crawling behavior at the end of larval development was not observed in *S. ningshanensis*.

Egg hatch was about 90% for both species. Storage at 5°C for two weeks did not affect hatch, but longer storage reduced percent egg hatch and was zero after 5 weeks.

Table 1. Development Time (days) of *Scymnus sinuanodulus* (Ss) at 20°C and *S. ningshanensis* (Sn) at 18-20°C.

Stage	Ss	Sn
Eggs	10.2	8.6
L1	3.1	2.8
L2	2.5	2.5
L3	2.9	3.7
L4	11.4	5.9
Pupa	10.6	11.1
Total	40.1	34.2

Oviposition

Scymnus ningshanensis lays eggs singly in concealed locations such as bud scales and at the edge of ovisacs. If the ratio of oviposition sites to beetle is low or if confinement on the foliage is for several days, multiple eggs may be found in the same place and on the twigs, under dead needles on the bottom of the cup, and in substrates added to the cup such as gauze.

Two experiments showed that hemlock woolly adelgid eggs must be present for *S. ningshanensis* to lay eggs. An experiment where adults, removed from cold storage, were given foliage either with adelgid eggs or with only adelgid nymphs (third instar) found that beetles provided adelgid eggs laid an average of 2.3 ± 0.8 eggs/week (N = 15) over a 3-week period whereas the 15 lady beetles given only nymphs laid a total of three eggs for the entire 3 weeks. These three eggs were laid in the first week. When provided a diet simulating late winter conditions, with mostly adelgid nymphs and few hemlock woolly adelgid eggs, the lady beetle laid an average of only 6.42 ± 3.54 eggs during the 4 weeks following removal from cold storage, whereas 30.42 ± 8.98 eggs were laid by the beetles when they were provided adelgids at peak oviposition.

Because *S. ningshanensis* requires adelgid eggs for egg laying and survival of the neonate larva, hemlock foliage is collected and held in cold storage in order to manipulate and prolong the period when the beetle can be reared. Adelgid-infested foliage for experiments as well as routine rearing is collected in winter or early spring prior to when the sistens generation lays eggs and again in late spring when the progrediens generation is starting to lay eggs. After being cut, the foliage is placed in water in a bucket or a water-absorbent foam block. This foliage is held in a walk-in refrigerator at 5°C and, as needed, brought to a warmer temperature to induce the adelgid to lay eggs. This method to obtain a supply of fresh adelgid eggs for several months is most successful if the foliage comes from newly infested trees in good health, the collection is made before the peak of adelgid eggs in the field, the foliage is recut and placed in new foam blocks stored in a shoe box with about one inch of water, and there is good air circulation during storage. Egg production by the lady beetles can be started anytime from December to May, if the beetles have been held at six or more weeks at cold temperature.

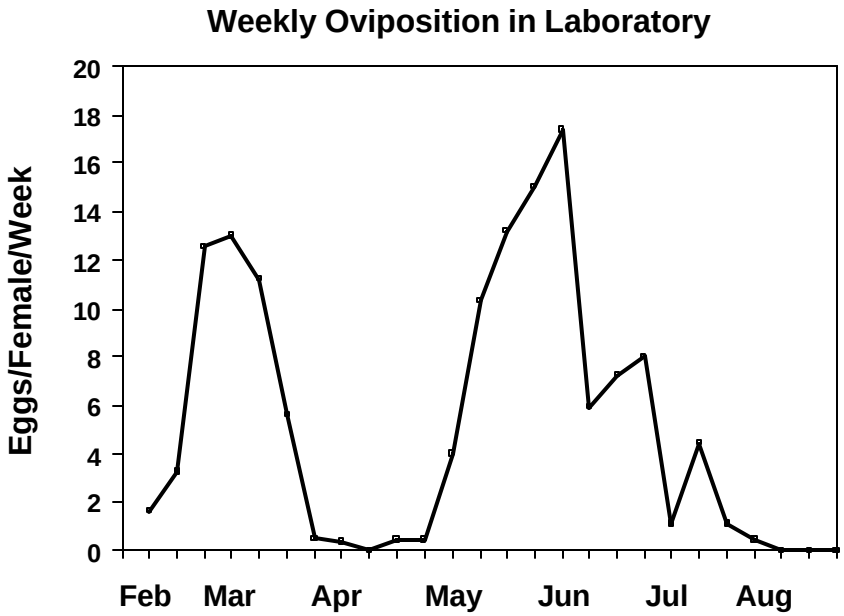

Figure 4. Weekly number of eggs deposited by *Scymnus ningshanensis* in quarantine laboratory in 1999 (n = 16).

Figure 4 shows the weekly egg production of *S. ningshanensis* monitored during the first year it was reared in quarantine. Pairs of lady beetles were held at 19°C in 16 oz. paper cups containing foliage with adelgids laying eggs. Egg laying began the week after the beetles were removed from cold storage and peaked at 4 weeks, then declined and less than one egg per female was produced for 4 weeks, followed by an increase in egg laying to a peak of 18 eggs per week, then an erratic decline during the next 8 weeks. During April, the beetles were fed foliage from trees in poor health with declining adelgid populations. In May, the source of foliage was changed to healthy trees with increasing adelgid population and the beetles continued to receive this foliage from cold storage. The egg laying pattern in Figure 4 should not be considered as representative of egg laying in the field.

The average number of eggs produced per ovipositing female in the laboratory was 28 in China and 85 in the United States. This difference likely reflects the artificially extended laying period in quarantine in the United States and the availability of foliage with a higher density of ovisacs that had about 30% more eggs/sac. A reasonable expectation for oviposition in the laboratory is one to two eggs per day for a period of 5 to 10 weeks, if good, abundant food and oviposition sites are available.

Feeding

After removal from cold storage in the quarantine laboratory, adult beetles consumed an average of 5.5 ± 0.83 nymphs/day when given only nymphs and consumed 1.0 ± 0.29 nymphs, 0.8 ± 0.31 adults, and 5.5 ± 0.23 eggs/day when given a mix of stages. Larvae in the third instar consumed 99.2 ± 11.7 adelgid eggs/day. In China, larval consumption of adelgid ovisacs during the first to fourth instar was 1.8 ± 0.6, 3.9 ± 1.5, 5.3 ± 2.0, and 11.2 ± 3.1, respectively. The adelgid ovisacs had an average of 31 ± 11 eggs/sac; thus, total consumption was 23 ovisacs, or 713 eggs.

Neonate, first instar larvae did not survive if they could not feed on adelgid eggs.

Discussion

Scymnus ningshanensis is one of three lady beetles in the *Scymnus* subgenus *Neopullus* imported from China for biological control of the hemlock woolly adelgid. Monthly temperature averages in its native habitat are similar to those in Connecticut.

Field and laboratory observations indicate that access to hemlock woolly adelgid eggs is prerequisite for oviposition and survival of the newly emerged larvae. Based on laboratory consumption rates, we estimate that a single larva will destroy the eggs in more than 20 ovisacs. Adults consume about two large nymphs or adult adelgids each day. With an average production of 20 offspring/female and adult feeding for 90 days in the spring, a single female lady beetle theoretically could eliminate more than 1,000 adelgids.

Scymnus ningshanensis appears to have good potential as a biological control. Caged field studies are currently being conducted to optimize release methods and to assess the impact of this and other imported lady beetles on the hemlock woolly adelgid under various conditions.

References

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

Lu, W, P. Souphanya, and M.E. Montgomery. Descriptions of immature stages of *Scymnus* (*Neopullus*) *sinuanodulus* Yu and Yao (Coleoptera: Coccinellidae) with notes on life history. *The Coleopterists Bulletin*. (in press).

Montgomery, M. E., D. Yao, and H. Wang. 2000. Chinese Coccinellidae for biological control of the hemlock woolly adelgid: Description of native habitat, pp. 97-102. In: McManus, K.A., K.S. Shields, and D.R. Souto (eds.). *Proceedings, Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America*, 22-24 June 1999, Durham, New Hampshire. U.S. Department of Agriculture, Forest Service, Newtown Square, Pennsylvania.

Pang, X. and G. Yu. 1993. Validity of *Scymnus* (*Parapullus*) Yang with description of a new species (Coleoptera: Coccinellidae) from Taiwan. *The Coleopterists Bulletin* 47: 288-231.

Sasaji, H. 1971. *Fauna Japonica: Coccinellidae (Insecta: Coleoptera)*. Academic Press of Japan, Tokyo.

Wang, H., G. Li, D. Yao, M.E. Montgomery, and W. Lu 2000. Preliminary study on morphology and biology of *Scymnus (Neopullus) ningshanensis*. In *Entomology toward the 21st Century*. Entomological Society of China, Beijing, in Chinese with English abstract.

Yang, J.; R. Zheng. 1991. A preliminary study of bionomics of *Scymnus* (*Neopullus*) *hoffmanni* Weise. In Huang, B. (ed.). *Proceedings of the symposium on coccinellids in China: The centenary of successful introduction of vedalia beetle, Rodolia cardinalis* (Mulsant). Shanghai Scientific and Technical Publishers, Shanghai, (in Chinese with English abstract).

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