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Recent advances in biological control of important native and invasive forest pests in China

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HIGHLIGHTS

- The fall webworm was controlled by *Chouioia cunea* and HcNPV virus.
- *Monochamus alternatus* was controlled by *Sclerodermus* sp. and *Dastarcus helophoroides*.
- *Dendroctonus valens* was controlled by predator *Rhizophagus grandis*.
- *Massicus raddei* was controlled by a special black light and two parasitoids.
- Four new parasitoid species were founded parasitizing emerald ash borer.

GRAPHICAL ABSTRACT

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ABSTRACT

In recent decades, China has suffered severe attacks by both native and invasive forest pests. We have carried out a series of research projects on biological control of these pests. The fall webworm, *Hyphantria cunea* (Drury) (Lepidoptera: Arctiidae) has been sustainably controlled by an effective gregarious pupal endoparasitoid, *Chouioia cunea* Yang (Chalcidoidea: Eulophidae), which is native to China, and spraying HcNPV virus against the pest's larval stage. Pine wilt disease, caused by the pine wood nematode (*Bursaphelenchus xylophilus* (Steiner *et* Buhrer) Nickle) (Aphelenchida: Aphelenchidae), is currently the number one pest in China. The strategy for controlling the disease is to manipulate the nematode's vector, *Monochamus alternatus* Hope (Coleoptera: Cerambycidae). We discovered that *Dastarcus helophoroides* (Fairmaire) (Coleoptera: Bothrideridae) is the most important natural enemy in China pine forests. Mass rearing and release techniques were studied and developed. By releasing the parasitoid, 92.6% of the *M. alternatus* were parasitized in the first year. Meanwhile, three elaterid beetle species were found to prey on the larva of *M. alternatus*. The red turpentine beetle, *Dendroctonus valens* (LeConte) (Coleoptera:Scolytidae) was suppressed by a predator, *Rhizophagus grandis* Gyllenhal (Coleoptera: Rhizophagidae) introduced from Belgium and a total 3334 ha. of pine forests were protected. The oak longhorned beetle, *Massicus raddei* (Blessig) (Coleoptera: Cerambycidae) is the number one pest in the northeast forests of China, where it damages trunk of oaks, mainly *Quercus liaotungensis* and *Q. mongolicus*. An integrated management technique was developed for controlling the longhorned beetle: a special black light was invented for trapping the adults; the parasitoid *Sclerodermus pupariae* Yang *et* Yao (Hymenoptera: Bethylidae) was released against young larvae; and the parasitoid *Dastarcus helophoroides* eggs and/or adults were released when the hosts were mature larvae and/or pupae. By applying the technique for five years in northeastern China oak forests, the oak longhorned beetle has been controlled to a large extent. The emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), is native to eastern Asia, including China, and feeding by larvae damages ash trees. Natural enemies of the emerald ash borer were investigated and seven species were found in China, of which *Spathius agrili* Yang (Hymenoptera:

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Braconidae), *Tetrastichus planipennisi* Yang (Hymenoptera: Eulophiae), *Sclerodermus pupariae* Yang *et* Yao and *Oobius agrili* Zhang *et* Huang (Hymenoptera: Encyrtidae) are predominant and have high potential for biocontrol of the pest. The biology, behavior, ecology and mass rearing techniques of the parasitoids were studied.

With the rapid increase of large scale forest plantations in China in recent decades, as well as brisk international business and trade, many native and invasive pests have reached outbreak levels and have caused massive destruction of forests environments. China has suffered greatly from severe damage caused by forest pests. The reforestation in large scale always uses for nonnative species in China, such as *Pinus taeda*, *Pinus elliottii*, *Fraxinus velutina*. Sometimes, some native pests may not damage the host plants very severely as their native phenology. But once another similar host plants have been introduced, the pest would rather infest the new plants than the original hosts. Additionally, some invasive pests may not outbreak in their original distribution areas, but once they invaded another country or area, they could make serious destroy to the native plant species. As these cases, we have discussed some native and invasive forest pests in China. The following five species are currently serious problems in China forests and have particularly caused great economic and environmental losses.

Fall webworm, *Hyphantria cunea* (Drury) (Lepidoptera: Arctiidae) (invasive species). Pine sawyer beetle, *Monochamus alternatus* Hope (Coleoptera: Cerambycidae) (native species), which vectors the Pine wood nematode, *Bursaphelenchus xylophilus* (Steiner *et* Buhrer) Nickle (invasive species). Red turpentine beetle, *Dendroctonus valens* (LeConte) (Coleoptera: Scolytidae) (invasive species). The Oak longhorn beetle, *Massicus raddei* (Blessig) (Coleoptera: Cerambycidae) (native species). Emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) (native species).

To effectively suppress both the exotic and native forest pests, as well as to obtain sustainable control without toxic pesticides, our biological control research group in the Research Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry has been carrying out a series of research projects applying biocontrol agents and many achievements have been obtained (Yang, 2007). They are summarized below for each species mentioned above.

1. Fall webworm (*Hyphantria cunea* (Drury)) (Lepidoptera: Arctiidae)

The fall webworm is an invasive pest that has caused severe damage to forest and ornamental trees in China since it was first discovered in 1979 in Dandong City, Liaoning Province (Plate 1: 1, 2). It spread to Beijing in 2003 and threatened the successful execution of "the Green Olympics" in Beijing in 2008. Drawing on lessons learned from the unsuccessful classical biological control of fall webworm in the former USSR and Yugoslavia by introductions of parasitoids from USA and Canada carried out during 1952–1965 (Clausen, 1978); we focused on utilizing parasitoids native to China to control the pest.

1.1. Investigation of China native insect natural enemies

An investigation of potential natural enemies was conducted from 1983 to 2004 in five provinces and one municipality of China in order to discover effective biological control agents. Two carabid predators (Coleoptera) and 26 parasitoid species were found, of which 23 were parasitic wasps (Hymenoptera), including five hyperparasitic species, and two tachinid flies (Diptera). The two carabids preyed on young larvae in the web, two braconid wasps parasitized larvae and 18 parasitoid species attacked the fall webworm in its pupal and/or "larval-pupal" stages. Of these parasitoids there was one genus and ten species new to science, and four species new to China which were described and published by Yang (1989), Yang and Wei (2003), Yang and Hannes (2004), Yang et al. (2001, 2002, 2003a,b). The average parasitism rates of the overwintering pupae and the 1st generation (summer generation) of fall webworm were 25.8% and 16.1%, respectively.

1.2. Select the pupal parasitoid Chouioia cunea Yang as biological control agent

These findings revealed that natural enemies native to China played an important role in the natural control of the pest. A gregarious pupal endo-parasitoid, *Chouioia cunea* Yang (Hymenoptera: Eulophidae) (gen. & sp. nov.) was the most effective parasitoid of the fall webworm (Yang, 1989) (Plate 1: 3, 4, 5). It was therefore recommended as a promising biological control agent against the pest in China (Yang et al., 2008b). The biology, behavior, ecology, female reproductive system anatomy and mass rearing of the parasitoid have subsequently been studied (Yang, 1995; Yang and Xie, 1998; Yang et al., 2006b; Yang and Zhang, 2007). Alternative hosts of *Chouioia cunea* were tested to find potential substitute hosts for mass rearing. The oak silkworm, *Antheraea pernyi* Guerin-Meneville (Lepidoptera: Saturniidae), was chosen as a surrogate host because its pupa could produce a maximum of 11,256 and an average of 8552 individual offspring of the parasitoid per pupa. Meanwhile, research on techniques for releasing the parasitoid was conducted (Su et al., 2004; Yang, 2000).

The total number of parasitoids to be released in an area can be calculated using the formula below:

$$TN = W \bullet AN \bullet 3$$

(where TN is the total numbers of the adult wasps to be released in an area; W is the total numbers of the webs of fall webworm in the area and AN is the average number of fall webworm larvae per web).

To calculate the average number of fall webworm larvae per web, at least 15 webs were sampled at random. Then the number of webs was counted from at least 50 trees to determine the average number of webs on a tree. Based on the number of trees, we calculated the total number of fall webworm in the area to be controlled by the parasitoid.

A total of about 325.54 billion individual adult wasps of *Chouioia cunea* were reared between 1986 and 2012 in Liaoning, Shandong, Hebei, Shaanxi and Henan provinces, as well as in Beijing and Tianjin municipalities. The biocontrol area totaled 235,000 ha, which accounts for approximately two thirds of the current total infestation area of the fall webworm in China. The highest rate of parasitism by *Chouioia cunea* in the experimental release areas was 88% (average 67.7%), while parasitism in the control plots was only 4.7–12.9%. Other native parasitoids, such as *Coccygomimus disparis* (Viereck), *Coccygomimus parnasae* (Viereck) (Hymenoptera:Ichneumonidae), *Tetrastichus septentrionalis* Yang, *Tetrastichus nigricoxae* Yang (Hymenoptera: Eulophidae) and *Exorita japonica* Townes (Diptera: Tachnidae) increased the total average parasitism rate to over 90.3% on average, with the maximum 96.28% in the release areas. Consequently, the population of the pest and its damage was effectively controlled. The population of the fall webworm decreased significantly following the release of the wasps in the experimental areas.