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EXPLORATORY SURVEY FOR THE EMERALD ASH BORER, *AGRILUS PLANIPENNIS* (COLEOPTERA: BUPRESTIDAE), AND ITS NATURAL ENEMIES IN CHINA

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ABSTRACT

An exploratory survey for the emerald ash borer, *Agrilus planipennis*, and its natural enemies was conducted in China during October and November 2003. We examined 29 field plots in six provinces. We visually inspected living *Fraxinus chinensis*, *F. mandshurica*, *F. pennsylvanica*, *F. rhynchophylla*, and *F. velutina* then peeled off the bark in search of *A. planipennis* and associated natural enemies. We found active *A. planipennis* infestations in nine of the 29 field plots, including plots in the provinces of Hebei, Heilongjiang, Jilin, Liaoning, and the provincial level city of Tianjin. Signs of past *A. planipennis* infestations were found in five of the 20 plots where no active infestations were present. The distribution of *A. planipennis* was patchy within the forest, and larval densities varied greatly among trees and at different heights within the same tree. *Agrilus planipennis* densities ranged from 0 to 284 larvae/m^2 of bark surface for 1-m log sections. The Nearctic ash species, *F. pennsylvanica* and *F. velutina,* planted in China were apparently more susceptible to *A. planipennis* attack than were the native Chinese ash species. Similarly, ash trees growing along streets or in plantations or city parks were more susceptible to *A. planipennis* infestation compared with trees in natural forests. We identified two species of natural enemies attacking *A. planipennis* during this survey. In Changchun City, Jilin Province and Guangang District, Tianjin City, we found a previously reported but undescribed species of *Spathius* sp. (Braconidae) parasitizing an average of 6.3% *A. planipennis* larvae in individual trees, ranging from 0 to 50%. In Changchun City, Jilin Province and in Benxi County, Liaoning Province, we discovered a previously unknown gregarious endoparasitoid of *A. planipennis* larvae, *Tetrastichus* nov. sp. (Eulophidae), with a total parasitism rate of 6.6% in individual trees, ranging from 0 to 50%. We discussed the potential role of natural enemies in the management of *A. planipennis* in North America.

The emerald ash borer, *Agrilus planipennis* Fairmaire (Buprestidae), is a new pest of economic significance to North America's ash trees (*Fraxinus* spp.). It was first discovered attacking ash trees in southeastern Michigan and neighboring Ontario, Canada, in 2002 (Haack et al. 2002). Larval feeding in the cambial region creates S-shaped galleries that disrupt the flow of nutrients in the phloem, usually causing tree death after two to three years of serial attack. Crown dieback and epicormic shoots along the lower trunk are the most common symptoms of early-stage *A. planipennis* infestation. The preferred hosts throughout the Great Lakes region include varieties of green ash (*Fraxinus pennsylvanica* Marsh.), white ash (*F. americana* L.), black ash (*F. nigra* Marsh.), and blue ash (*F. quadrangulata* Michx.). Over 5 million ash trees have been infested in Michigan alone (Michigan Agricultural Experiment Station 2003, USDA Forest Service, State and Private Forestry 2004). As of November 2004, additional infestations have been found

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in Indiana, Ohio, Maryland, and Virginia, primarily a result of inadvertent transport of infested ash nursery stock, firewood, and logs (Fig. 1). The potential economic, ecological, and social impacts of this pest are tremendous given that ash is an important timber and landscape species throughout North America. It is estimated that there are more than 7 billion ash trees in the United States, of which more than 700 million occur in Michigan, 280 million in Ohio, and 150 million in Indiana (USDA Forest Service, Northeastern Research Station 2004). If *A. planipennis* becomes widely established in Michigan, it could result in a total loss of 307 million board feet of ash saw logs and veneer with a compensatory value as high as $18.9 billion in Michigan alone (Michigan Agricultural Experiment Station 2003, USDA Forest Service, Northeastern Research Station 2004).

Agrilus planipennis is native to northeastern Asia, including portions of China, Japan, Korea, Mongolia, Russia, and Taiwan (Chinese Academy of Science 1986, Haack et al. 2002, Xu 2003, Yu 1992). Synonyms of *A. planipennis* include *A. marcopoli* Obenberger (in China), *A. marcopoli ulmi* Korosawa (in Korea and Japan), and *A. feretrius* Obenberger (in Taiwan) (Jendek 1994). In China, its host range is limited to *Fraxinus* spp., including the native species of *F. chinensis* Roxb., *F. mandshurica* Rupr., and *F. rhynchophylla* Hance (Chinese Academy of Science 1986, Xu 2003, Yu 1992), as well as introduced Nearctic species *F. americana* L. (Liu 1966), *F. velutina* Torr. (Liu et al. 1996, Zhang et al. 1995), and *F. pennsylvanica* (R-T. Gao, personal observation). *Fraxinus americana* is no longer planted in China and *F. pennsylvanica* occurs only in localized areas because of past *A. planipennis* attack. *Fraxinus velutina*, however, is still widely used in the coastal areas of northeastern China because of its fast growth rate and tolerance of alkaline soils. In Japan, *A. planipennis* is recorded from *F. mandshurica* var. *japonica* Maxim., *Juglans mandshurica* var. *sieboldiana* (Maxim.) CK Schneid, *J. mandshurica* var. *sachalinensis* (Miyabe et Kudo) Kitamura, *Pterocarya rhoifolia* Sied. et Zucc., and *Ulmus davidiana* var. *japonica* (Rehd.) Nakai (Akiyama and Ohmomo 1997, Sugiura 1999). To date in North America, *A. planipennis* has been found to complete development only on ash trees.

Eradication is the strategy adopted by regulatory agencies in both the United States and Canada. The magnitude of infestation and complexity of this problem, however, suggest other management tools will be needed if eradication proves unsuccessful. Moreover, environmental and health concerns regarding the long-term use of conventional insecticides for tree protection may also force managers to look for other solutions such as biological controls.

We began research on *A. planipennis* natural enemies in 2002, shortly after its discovery in Michigan. We found parasitoids of *A. planipennis* are rare in local populations, with a combined parasitism rate by all parasitoid species less than 1% (Liu et al. unpublished data). Larval-pupal parasitoids included *Spathius simillimus* Ashmend (Braconidae), *Heterospilus* sp. (Braconidae), *Phasgonophora sulcata* Westwood (Chalcididae), *Balcha* sp. (Eupelmidae), and *Eupelmus* sp. (Eupelmidae), whereas egg parasitoids were represented by a single species of *Pediobius* sp. (Eulophidae) (Bauer et al. 2004). Predators found attacking *A. planipennis* larvae and pupae in Michigan include *Enoclerus* sp. (Cleridae), *Catogenus rufus* (F.)(Passandridae), and *Tenebroides* sp. (Trogossitidae) (Bauer et al. 2004). Pathogenic fungi *Beauveria bassiana* (Balsamo) Vuillemin, *Paecilomyces farinosus* (Holm ex SF Gray) Brown & Smith, *Paecilomyces fumosoroseus* (Wize) Brown & Smith, *Verticillium lecanii* (Zimmerman) Viegas, and *Metarhizium anisopliae* (Metschnikoff) Sorokin were also recovered in Michigan from field collected *A. planipennis* larvae, pupae, and adults (Bauer et al. 2004).

Little is known about the distribution or biology of *A. planipennis* in China where no systematic survey of its natural enemies was conducted prior to that reported here. At the start of our study in China in 2003, outbreaks were known only from *F. mandshurica* in Harbin City, Heilongjiang Province (X. Wei, personal communication) and *F. velutina* in Guangang District, Tianjin City (Liu et al. 1996, Zhang et al. 1995). One larval parasitoid, a *Spathius* sp. (Braconidae),

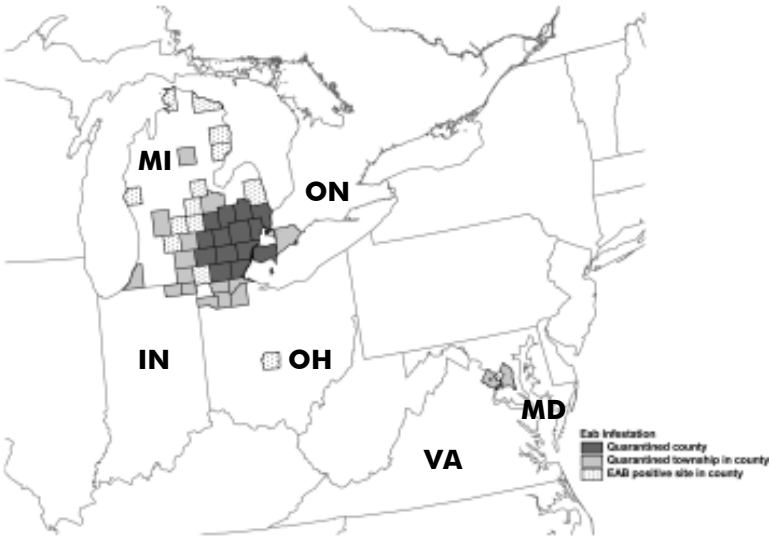

Fig. 1. Current distribution of *Agrilus planipennis* in North America (12 November 2004): IN = Indiana, MI = Michigan, MD = Maryland, OH = Ohio, ON = Ontario, and VA = Virginia.

was reported (Xu 2003). This gregarious ectoparasitoid was responsible for 10-50% larval mortality in some areas of Guangang District of Tianjin City (R-T. Gao, personal observation). Our interest was to identify *A. planipennis* natural enemies for possible use in a biological control program in North America. To this end, we conducted several intensive field surveys in China from 20 October to 9 November 2003 as both *A. planipennis* and its potential natural enemies were completing development in the field, the results of which are presented below.

MATERIALS AND METHODS

Site selection. We selected 11 regional sites in five Chinese provinces and one provincial-level city: Harbin and Shangzhi in Heilongjiang Province; Changchun, Jilin, and Jiaohe in Jilin Province; Shenyang and Benxi in Liaoning Province; Tangshan in Hebei Province; Binzhou in Shandong Province; and Guangang and Jinnan in Tianjin City (Fig. 2). By selecting these six administrative regions, we were able to target all Chinese provinces where *A. planipennis* was previously recorded (Xu 2003, Yu 1992) except Inner Mongolia. Two to six study plots were chosen in each regional site to survey. We selected study plots from a wide range of habitats, including natural forests, plantations, and parks; each plot encompassed a uniform habitat with a range of 30 to 200 ash trees. Details for each study plot are given in Table 1. We focused on sites with *Fraxinus chinensis*, *F. mandshurica*, *F. rhynchophylla,* and *F. velutina* given that these were the only *A. planipennis* hosts previously reported from China (Chinese Academy of Science 1986, Hou 1993, Xu 2003, Yu 1992, Zhang et al. 1995). Plantings of *F. pennsylvanica* were added as they were found during our survey efforts.

Survey methods. We visually examined 30 to 60 ash trees at each plot for signs and symptoms of *A. planipennis* infestation such as crown dieback, epicormic shoots, longitudinal bark splits, and D-shaped adult exit holes. For suspect trees, we removed the outer bark and looked for *A. planipennis* larval galleries. If *A. planipennis* infestation was confirmed, we debarked the lower two meters of trunk and collected *A. planipennis* and any natural enemies. At

Fig. 2. Provincial outline map of China, indicating the historical distribution of *Agrilus planipennis* within China (shaded area, provinces A–G), and the regional study sites we surveyed (1-11, see description in Table 1). A – Heilongjiang, B – Jilin, C – Liaoning, D – Hebei, E – Tianjin, F – Shandong, G – Inner Mongolia. Distribution of *Agrilus planipennis* based on Chinese Academy of Science (1986), Hou (1993), Xu (2003), Yu (1992).

selected plots, *A. planipennis*-infested ash trees were felled and trunks and branches with a diameter > 3 cm were cut into 1-m log sections for dissection. All log sections were dissected on site with chisels and hammers. Larval density was standardized by dividing the total number of larvae obtained from each log section by its bark surface area. Live *A. planipennis* larvae were placed individually in 35-mm polystyrene petri dishes (VWR International, Batavia, IL) for further observation, whereas dead larvae were stored separately in 0.5-ml microcentrifuge tubes (Life Science Products, Inc., Denver, CO) to be examined for fungal pathogens by encouraging outgrowth under saturated conditions. Immature stages of potential *A. planipennis* natural enemies were collected in the field, reared to adults in the laboratory, and preserved in 70% ethanol for later determination. We searched for potential predators of *A. planipennis* during visual examinations and tree dissections in the field.

Specimen determination. The identity of *Tetrastichus* sp. was determined by taxonomists at the Institute of Zoology, Chinese Academy of Science, Beijing, China and USDA, Agriculture Research Services, Systematic Entomology Laboratory, Beltsville, MD. We deposited voucher specimens in museums at these institutions and Michigan State University in East Lansing, MI.

RESULTS

Infestations in China. Within the 11 survey sites, 29 plots were surveyed, including seven ash plantations, six urban settings, six natural forests, seven street plantings, two city parks, and one nursery. We sampled *F. mandshurica* at 10 plots, *F. velutina* at 10 plots, *F. rhynchophylla* at five plots, *F. pennsylvanica* at three plots, and *F. chinensis* at one plot (Table 1). Our overall survey for *A. planipennis* and associated natural enemies involved examining ca. 1,000 ash trees with diameters

Table 1. Summary data for the 29 field plots surveyed for *Agrilus planipennis* in China during October and November 2003.

Province, City[a]	Ownership	Ash species	Age (yrs)	Forest type	Tree condition[b]	Description
Heilongjiang						
1. Harbin	Northeast Forestry University, Experimental Forest	*F. mandshurica*	> 30	Plantation	Fair	Monoculture of ca. 200 ash with significant understory vegetation.
	Northeast Forestry University, Campus	*F. mandshurica*	> 30	Urban setting	Very poor	Ca. 50 even-aged ash trees near buildings. More than half of them were dead or dying.
2. Shangzhi	Maoershan Experimental Forest, plot A	*F. mandshurica*	15-20	Plantation	Good	Monoculture of ca. 100 ash trees in natural forest of Korean pine, *Pinus koraiensis*, and other hardwoods.
	Maoershan Experimental Forest, Hongming village	*F. mandshurica*	5-40	Natural forest	Very good	Ca. 200 ash trees mixed with Mongolian Scots pine (*P. sylvertris* var. *mongolia*) and other hardwoods.
	Maoershan Experimental Forest, Headquarters	*F. mandshurica*	25	Urban setting	Good	Ca. 40 even-aged trees in the front yard.
Jilin						
3. Changchun	Jingyuetan Forest Park, Dingjiagou	*F. mandshurica*	> 30	City park	Good	Ca. 100 ash trees mixed with oak (*Quercus* spp.) and pine (*Pinus* spp.)
	Jingyuetan Forest Park, Qingsongling	*F. mandshurica*	20	City park	Good	Ca. 200 ash trees mixed with oak (*Quercus* spp.) and pine (*Pinus* spp.)

Table 1. Continued.

Province, City[a]	Ownership	Ash species	Age (yrs)	Forest type	Tree condition[b]	Description
4. Jilin	Songhuahu Nature Reserve, plot A	*F. rhynchophylla*	5-40	Natural forest	Very good	Ca. 200 dominant ash trees mixed with oak (*Quercus* spp.) and birch (*Betula* spp.)
	Songhuahu Nature Reserve, plot B	*F. mandshurica*	40-50	Plantation	Fair	Ca. 200 ash trees with crown damage, mixed with oak (*Quercus* spp.) and pine (*Pinus* spp.)
5. Jiaohe	Jiaohe Experimental Forest, Dongdapo	*F. rhynchophylla*	>20	Natural forest	Very good	Ca. 200 dominant ash trees mixed with *Catalpa* spp. and elm (*Ulmus* spp.)
	Jiaohe Experimental Forest, Qingchaguan	*F. rhynchophylla*	>20	Natural forest	Very good	Ca. 200 dominant ash trees mixed with *Catalpa* spp. and elm (*Ulmus* spp.)
	Jiaohe Experimental Forest, Headquarters	*F. rhynchophylla*	>30	Natural forest	Good	Ca. 200 dominant ash trees mixed with elm (*Ulmus* spp.), pine (*Pinus* spp.) and *Phellodendron* spp.
Liaoning						
6. Shenyang	Urban, Heping Street	*F. chinensis*	8	Street	Poor	Monoculture of ca. 100 ash trees planted in 2000.
	Suburb, Dongbeixie City Forest	*F. mandshurica*	5	Plantation	Poor	Monoculture of ca. 200 ash trees planted in 2002.
7. Benxi	Tianshifu Township, Xibeitian	*F. rhynchophylla*	5-20	Natural forest	Very good	Ca. 200 ash trees mixed with oak (*Quercus* spp.), pine (*Pinus* spp.) and *Catalpa* spp.
	Jianchang Township, Changzui	*F. mandshurica*	9	Street	Fair	Monoculture of ca. 200 ash trees planted in 2000.

Table 1. Continued.

Province, City[a]	Ownership	Ash species	Age (yrs)	Forest type	Tree condition[b]	Description
Hebei						
8. Tangshan	Fengnan District, Mengzhuang	*F. velutina*	30	Street	Fair	Monoculture of ca. 200 ash trees.
	Fengnan District, Yujiabo	*F. velutina*	3	Nursery	Very good	Monoculture of ca. 200 ash trees neighboring poplar (*Populus* spp.) and elm (*Ulmus* spp.) plots.
Tianjin						
9. Guangang	City forest, plot A	*F. pennsylvanica*	10	Plantation	Fair	Monoculture of ca. 200 ash trees planted in 2000.
	City forest, plot B	*F. pennsylvanica*	10	Plantation	Fair	Monoculture of ca. 200 ash trees planted in 2000.
	City forest, plot C	*F. pennsylvanica*	10	Plantation	Fair	Monoculture of ca. 200 ash trees planted in 2000.
10. Jinnan	Xianshuigu Township, Zhangzhuang	*F. velutina*	25-30	Urban setting	Very poor	Ca. 30 ash trees, mostly dead.
	Xianshuigu Township, Jinggu Road	*F. velutina*	12	Street	Fair	Monoculture of ca. 200 ash trees.
Shandong						
11. Binzhou	Urban, Bohai No. 8 Road	*F. velutina*	25	Street	Poor	Monoculture of ca. 100 ash trees.
	City Hall, plot A	*F. velutina*	20	Urban setting	Fair	Monoculture of ca. 50 ash trees.
	City Hall, plot B	*F. velutina*	20	Urban setting	Fair	Monoculture of ca. 50 ash trees.
	Urban, Huanghe No. 5 Road	*F. velutina*	8	Street	Poor	Monoculture of ca. 200 ash trees planted in 2001.
	Urban, Huanghe No. 8 Road	*F. velutina*	30	Street	Fair	Monoculture of ca. 100 ash trees.
	Environment Protection Bureau	*F. velutina*	20	Urban setting	Poor	Monoculture of ca. 30 ash trees.

[a] Regional study sites are numbered 1-11 and are shown in Fig. 1.

[b] Very good = no decline, good = < 5% decline, fair = 6 - 25% decline, poor = 26 - 50% decline, very poor = > 50% decline.

ranging from 2 to 28 cm and heights from 4 to > 15 m; ca. 100 ash trees were dissected. We found live *A. planipennis* larvae in five of six provinces, in six of the 11 regional study areas, and nine of the 29 study plots surveyed. In total, we collected 39 *A. planipennis* larvae from the lower trunk of eight peeled trees and 482 *A. planipennis* larvae from four dissected trees (Table 2).

Five of the 10 *F. mandshurica* plots were infested with *A. planipennis* and three *F. mandshurica* plots (Northeast Forestry University campus in Harbin, Maoershan Experimental Forest plot A and headquarters plot in Shangzhi) showed signs of past *A. planipennis* infestation, including old exit holes and calloused larval galleries (Tables 1, 2). We found *A. planipennis* larvae in the three *F. pennsylvanica* plots and one of the 10 *F. velutina* plots, as well as an old *A. planipennis* infestation in *F. velutina* in the Zhangzhuang plot of Xianshuiguo Township in Jinnan (Tables 1, 2). No *A. planipennis* infestations were detected in the *F. chinensis* plot in Shenyang, *F. rhynchophylla* plots in Jilin, Jiaohe, or Benxi, except for an old *A. planipennis* gallery in a *F. rhynchophylla* tree at the Jiaohe Experimental Forest headquarters (Table 1).

The distribution of *A. planipennis* was patchy in our study plots, with infested trees scattered among healthy ash trees under apparently similar conditions. Results of the whole-tree dissections showed that *A. planipennis* larvae were present along the entire trunk, from the base upwards to branches of 4-5 cm in diameter. Larval population of *A. planipennis* varied greatly among individual infested trees and at different heights within the same tree. Larval densities ranged from 0 to 284 larvae/m^2 of bark surface area in 1-m log sections ranging in diameter from 3.9 to 13.7 cm.

Ash trees along roadsides, in plantations, or city parks were more likely to be attacked by *A. planipennis*, possibly because they experienced greater stress compared with trees in natural forests. Of the nine plots with active *A. planipennis* infestations, two were found along roadsides, five in plantations, and two in city parks (Tables 1, 2).

Natural enemies. We found two species of parasitoids attacking *A. planipennis* larvae during this survey, with a total parasitism rate of 6.3 and 6.6% for *Spathius* sp. and *Tetrastichus* sp., respectively (Table 2). No predatory insects were observed during our field investigations or log dissections. Moreover, no fungal pathogens were isolated from larvae that we collected.

Spathius wasps (Braconidae) are gregarious ectoparasitoids of larvae in the families of Buprestidae, Cerambycidae, Curculionidae, and Scolytidae (Matthews 1970). We found mature larvae and pupae of a single *Spathius* sp. on the surface of *A. planipennis* larvae within their galleries on *F. mandshurica* in Changchun (Jingyuetan forest park-Dingjiagou) and on *F. pennsylvanica* in Guangang (City forest-Plot A), resulting in a parasitism rate of 1, 25, and 50% for the three trees examined (Table 2). Parasitoid larvae were cream colored, legless and tapered at both ends. They fed by inserting their mouth hooks through the body wall along the abdomen of *A. planipennis* larvae. Multiple individuals were usually found on each host (Fig. 3). The number of *Spathius* sp. larvae found on *A. planipennis* larvae ranged from 1 to 12 (Mean ± SEM = 6.2 ± 0.9, n = 13 parasitized larvae). Only a thin layer of external cuticle remained of the *A. planipennis* host as a result of parasitism. A white to grayish silky cocoon was later formed by each parasitoid larva inside the gallery by early November. Multiple cocoons were associated with each *A. planipennis* host and were arranged end to end, maintaining the original shape of the host larva (Fig. 3). Adults of this new species of *Spathius* are light brown, 3.5 – 4.5 mm in length; a description is underway in China (Z-Q. Yang, personal communication).

We also discovered *Tetrastichus* nov. sp. (Eulophidae), a gregarious endoparasitoid of *A. planipennis* larvae on *F. mandshurica*. Three adults and nine larvae of *Tetrastichus* nov. sp. were collected from a single *A. planipennis* larva inside its gallery at Qingsongling of Jingyuetan forest park in Changchun.

Table 2. Summary data for the field plots in which *Agrilus planipennis* and its natural enemies were found in China during October and November 2003.

Province, City, Plot	Tree #	Ash species	DBH (cm)	Survey method	No. of EAB collected[a]	No. of EAB being parasitized			
						Spathius sp.	%	*Tetrastichus* nov. sp.	%
Heilongjiang, Harbin, Northeast Forestry University, Experimental Forest	1	*F. mandshurica*	20	Bark peeling	3	0	0	0	0
Jilin, Changchun, Jingyuetan Forest Park, Dingjiagou	1	*F. mandshurica*	14.5	Bark peeling	4	1	25	0	0
	2	*F. mandshurica*	16	Bark peeling	22	11	50	0	0
Jilin, Changchun, Jingyuetan Forest Park, Qingsongling	1	*F. mandshurica*	10	Bark peeling	2	0	0	1	50
	2	*F. mandshurica*	13.9	Bark peeling	2	0	0	0	0
Jilin, Jilin, Songhuahu Nature Reserve, plot B	1	*F. mandshurica*	27.2	Bark peeling	3	0	0	0	0
Liaoning, Benxi, Jianchang Township, Changzui	1	*F. mandshurica*	5.6	Whole tree dissection	73	0	0	2	3
	2	*F. mandshurica*	6.1	Whole tree dissection	23	0	0	6	26
Hebei, Tangshan, Fengnan District, Mengzhuang	1	*F. velutina*	12.9	Whole tree dissection	277	0	0	0	0
Tianjin, Guangang, City forest - plot A	1	*F. pennsylvanica*	11.4	Whole tree dissection	109	1	1	0	0

Table 2. Continued.

Province, City, Plot	Tree #	Ash species	DBH (cm)	Survey method	No. of EAB collected[a]	No. of EAB being parasitized			
						Spathius sp.	%	*Tetrastichus* nov. sp.	%
Tianjin, Guangang, City forest – plot B	1	*F. pennsylvanica*	7.2	Bark peeling	2	0	0	0	0
Tianjin, Guangang, City forest – plot C	1	*F. pennsylvanica*	6.1	Bark peeling	1	0	0	0	0
Total					521	13	6.3[b]	9	6.6[b]

[a] All stages observed, including dead and parasitized.
[b] Statistical mean.

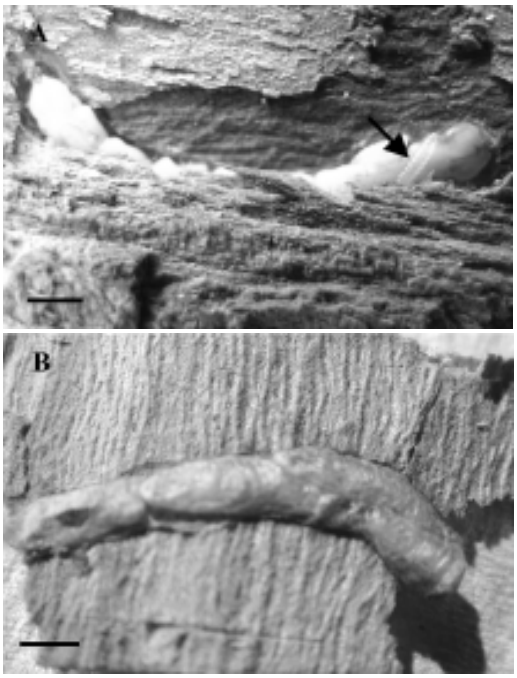

Fig. 3. *Spathius* sp. (Braconidae) from *Agrilus planipennis* (Buprestidae) collected in China in November 2003. A. *Spathius* larvae on host surface. B. *Spathius* cocoons inside host larval gallery. Bar = 5 mm.

We also found *Tetrastichus* larvae attacking *A. planipennis* larvae removed from two ash trees at Changzui of Jianchang Township in Benxi. The *A. planipennis* parasitism rates by *Tetrastichus* nov. sp. were 3, 26, and 50% for the three trees on which we found this parasitoid (Table 2). The larvae of this parasitoid are legless and creamy white in color, with multiple parasitoid larvae inside host larvae (Fig. 4). The number of *Tetrastichus* sp. in each host ranged from 4 to 29 and averaged 9.4 ± 2.7 (n = 9 parasitized larvae). Some *Tetrastichus* sp. larvae were present in *A. planipennis* galleries after erupting from the host body prior to pupation. We found *Tetrastichus* sp. larvae, pupae, and adults arranged within the *A. planipennis* galleries in such a way as to reflect the body shape of the host (Fig. 4). Pupae are exarate, initially white to yellowish with red compound eyes, but within a few days, the pupae become black in color (Fig. 4). *Tetrastichus* sp. adults are black; females and males are ca. 5.0 and 2.5 mm in length, respectively (Fig. 4). A species description for *Tetrastichus* nov. sp. is in preparation in China using specimens collected at our newly discovered site in Benxi during March 2004 (Z-Q. Yang, personal communication).

DISCUSSION

Fraxinus spp. are important timber and ornamental tree species in China due to high wood quality, attractive crown and trunk, rapid growth, and generally high resistance to pests. Tolerance to wet, alkaline soils makes certain *Fraxinus* spp. suitable for afforestation programs in coastal areas. *Fraxinus velutina*, native to the southwestern United States, was introduced to the eastern provinces of Hebei, Jiangsu, Shandong and the provincial level city of Tianjin in the 1950's (Zhang et al. 1995), whereas *F. americana* and possibly *F. pennsylvanica* were brought to the cities of Shenyang and Harbin from the eastern United States in the 1960's (X. Wei, personal communication).

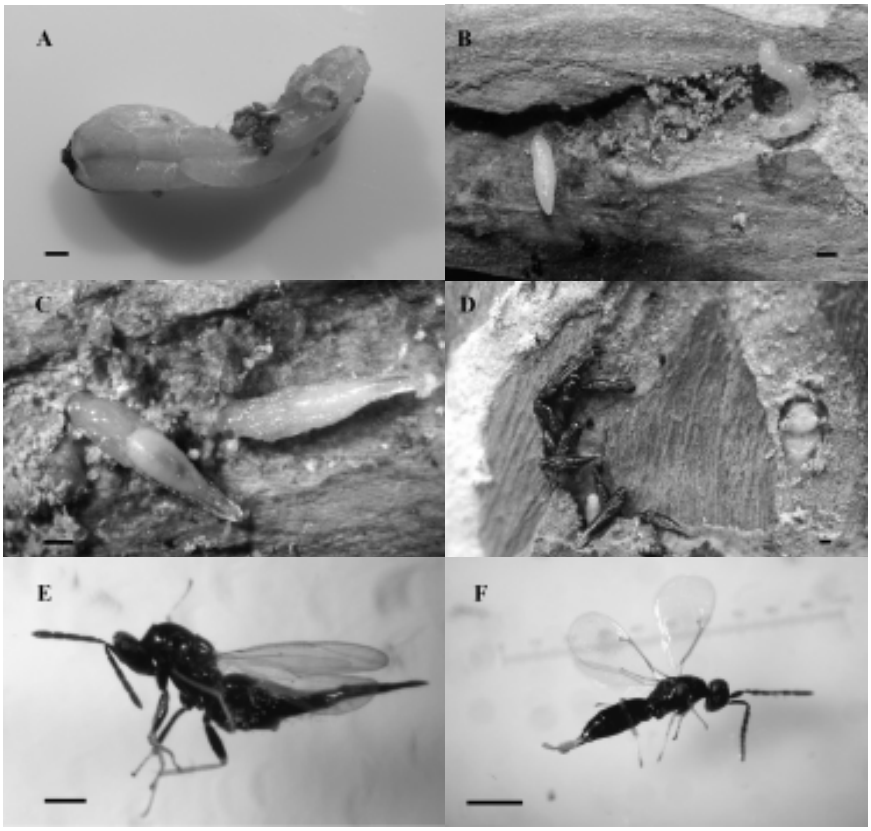

Fig. 4. *Tetrastichus* nov. sp. (Eulophidae) from *Agrilus planipennis* (Buprestidae) collected in China in November 2003. A. Host larvae with *Tetrastichus* larvae inside. B. *Tetrastichus* larvae in gallery. C. *Tetrastichus* early stage pupae in host gallery. D. Mature *Tetrastichus* pupae in host gallery. E. *Tetrastichus* female. F. *Tetrastichus* male. Bar = 1 mm.

Agrilus planipennis is considered an occasional pest of *Fraxinus* spp. native to China, outbreaks are rare. In the 1960's, however, *A. planipennis* outbreaks were common in the Nearctic *F. americana* plantings in Harbin, Heilongjiang Province (X. Wei, personal communication) and in Shenyang, Liaoning Province (Liu 1966). The *A. planipennis* outbreak in Shenyang collapsed in the late 1960's, but only after all *F. americana* trees within the city died. Similarly, at the experimental forest of Northeast Forestry University in Harbin, *A. planipennis* eliminated plantings of *F. americana.* Since that time, low populations of *A. planipennis* remained in nearby *F. mandshurica* forests (X. Wei, personal communication). The most recent *A. planipennis* outbreak was reported in Tianjin City in 1989 where thousands of *F. velutina* trees were infested along streets and in city parks (Zhang et al. 1995). As a result of our study, four new locations (Changchun and Jilin in Jilin, Benxi in Liaoning, and Tangshan in Hebei), one new host species (*F. pennsylvanica*), and a new species of parasitoid (*Tetrastichus* nov. sp.) are now known for *A. planipennis* in China.

Evidence from current and past *A. planipennis* outbreaks in China demonstrate different levels of host resistance against *A. planipennis* between native Chinese ash species and those introduced from North America. In China, native ash species such as *F. chinensis, F. mandshurica,* and *F. rhynchophylla* are less likely to be infested by *A. planipennis* than are *F. americana*, *F. pennsylvanica*, and *F. velutina*. Lack of coevolution between *A. planipennis* and Nearctic *Fraxinus* spp. may explain this. On the other hand, growing conditions of individual trees may play a role in resistance of Chinese *Fraxinus* spp. - For example, *A. planipennis* populations were very low on *F. mandshurica* in natural forests, whereas seedlings taken from these same forests and planted along roadsides in Jianchang Township in Benxi suffered heavy *A. planipennis* attack three years later (H-T. Zhang, personal communication) (Table 2). Trees may become more susceptible to *A. planipennis* due to the stress of transplanting.

Two *A. planipennis* natural enemies were found in China during this survey, one a previously reported but undescribed *Spathius* sp., and the other a new species of *Tetrastichus*. Compared to their North American counterparts, where combined parasitism by all parasitoid species was less than 1%, rates of parasitism reached up to 50%, suggesting that parasitoids from China may be better adapted to *A. planipennis*. The natural enemies of *Agrilus* spp. indigenous to North America may be slow to switch from their current hosts to the newly introduced *A. planipennis*. Therefore, the introduction of Chinese *A. planipennis* natural enemies could be considered if eradication efforts failed. Successful utilization of these two Chinese parasitoids in future *A. planipennis* management programs in North America, however, will require additional studies on parasitoid biology, host specificity, mass-rearing techniques, and adaptation to local environments.

We found that *A. planipennis* is not a major pest for native ash species in China. A combination of inherent tree resistance and natural enemies may be critical in maintaining *A. planipennis* populations below an economic injury threshold. The introduction and wide utilization of Nearctic ash species from North America, however, have brought new challenges to the management of *A. planipennis* in China. New approaches such as using native *Fraxinus* spp. in plantations and urban settings may also have assisted in elevating the status of *A. planipennis* as a pest in localized areas. Although we identified some potential enemies for possible use as biocontrol agents of *A. planipennis* in North America, further study in Asia is needed to identify other natural enemies.

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