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Review Article

Parasitoid Guilds of *Agrilus* Woodborers (Coleoptera: Buprestidae): Their Diversity and Potential for Use in Biological Control

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Literature studies in North America (US and Canada), Europe, and Asia (particularly Russia, China, Japan, and the Korean peninsula) were reviewed to identify parasitoid guilds associated with *Agrilus* woodborers. There are at least 12 species of hymenopteran parasitoids attacking eggs of *Agrilus* beetles and 56 species (36 genera), attacking *Agrilus* larvae infesting various host plants in North America, Asia, and Europe. While most of the egg parasitoids (9 species) belong to the family Encyrtidae, a majority of the larval parasitoids are members of five families: Braconidae (24 species/11 genera), Eulophidae (8 species/4 genera), Ichneumonidae (10 species/9 genera), and Eupelmidae (6 species/5 genera). The highest rate of *Agrilus* egg parasitism (>50%) was exerted by encyrtid wasps (4 species) in North America, Asia, and Europe. In contrast, the highest rate of *Agrilus* larval parasitism (>50%) was caused by species in two genera of braconids: *Atanycolus* (North America) and *Spathius* (Asia), and one eulophid genus, *Tetrastichus* (Asia and Europe). Reported rate of *Agrilus* larval parasitism ichneumonids was frequent in North America, but generally low (<1%). Potential for success in biological control of emerald ash borer (*Agrilus planipennis* Fairmaire) in the USA with North American native parasitoids and old-association Asian parasitoids is discussed.

1. Introduction

Agrilus is the largest genus within the family Buprestidae (Coleoptera), with nearly 3,000 described species worldwide [1]. Generally, *Agrilus* spp. only attack angiosperms and do not develop in conifers [2]. Moreover, they tend to be specialists, most species being confined to a single genus or species of host plant. While most *Agrilus* species are not considered to be serious pests of agriculture or forests, at least two species have recently become seriously damaging in forests in their newly invaded areas in North America: the emerald ash borer (EAB), *A. planipennis* Fairmaire, and the gold spotted oak borer (GSOB), *A. auroguttatus* Shaefer. EAB was accidentally introduced to Michigan in late 1990s from its native range (northeast Asia, in parts of China, Russia, and Korea) possibly via wooden crates or pallets for cargo shipment [3]; it has since spread to 14 additional US states and two Canadian provinces and killed millions of North American ash (*Fraxinus* spp.) since its detection in 2002 [4, 5]. By contrast, GSOB is native to the oak forests of southwestern Arizona, and while its damage to oak trees in its invaded range has been on a smaller scale, it has killed more than 25,000 oaks in the oak savannahs of California since first discovered there in 2002 [6–8]. A few other exotic *Agrilus* species have also been recently detected in the United States (e.g., soapberry borer—*A. prionurus* Chevrolat in Texas [9]) and Canada (e.g., European oak borer—*A. sulcicollis* Lacordaire in Ontario [10]). Although some of the recently detected, exotic *Agrilus* species have not become as widespread or damaging as EAB and GSOB, the pest status of *Agrilus* borers as a whole along with other woodborers appears to have increased in recent years [11].

Table 1: Summary of online database search for *Agrilus* and associated parasitoids.

Search database	Years searched	*Agrilus* hits	Search hits combined with parasitoid (parasite, natural enemy, or biological control)
Agricola	1970-date	302	38
BioAbstracts (BIOS)	1926-date	507	43
Biological and Agricultural Index Plus	1983-date	30	2
Biological Sciences Set	1982-date	273	23
CSA Illumina		265	22
CAB Abstracts	1985-date	354	94
ISI Web of Science	1900-date	211	25
	No duplicates[a]		−105
	Total publications	1,942	142

[a] We did not review all 1,942 to exclude duplicates.

Management for the invasive (exotic) *Agrilus* woodborers (EAB and GSOB) in the United States initially focused on attempted eradication but changed to integration of several approaches when eradication failed to reduce the pests' populations in infested areas and slow spread of the pests to the noninfested areas [12, 13]. In some cases, control methods being used include delimitation of infested areas, regulatory restriction of movement of pest-infested wood or plant materials, insecticide treatment or physical destruction of infested trees [12–14], and biological control via introduction and release of natural enemies collected from pests' native ranges [7, 15–18]. Although none of these approaches individually is adequate, biological control, which relies on self-propagating and dispersing natural enemies, has potential to reduce invasive pest populations, particularly in forests [19–21].

Agrilus adults normally lay their eggs under loose bark or in crevices of host plant tissues and rarely cause significant damage; in contrast, *Agrilus* larvae typically bore into the living tissue (stems, trunks, branches, or roots) of their host plants, interrupt the translocation of water and nutrients as they feed, and can kill plants within one or a few years of infestation (e.g., EAB [22]; GSOB [6]; *A. prionurus* [9]). In their native habitats, *Agrilus* populations are generally suppressed by a diverse group of natural enemies and/or host tree resistance and only occasionally become serious pests. However, when introduced into ecosystems where host plants lack coevolutionary resistance, or where appropriate specialized natural enemies are absent, they can become severe pests. The recent invasions of North America by EAB from northeast Asia and GSOB from southwestern Arizona are excellent examples of this. For example, EAB is considered a sporadic pest of ash stands in its native range in Asia [23–26] but has become a serious pest threatening the existence of North American ash trees since it was accidentally introduced there [22]. Similar observations have been made for GSOB in its home range. Field studies in Asia found that a complex of natural enemies (primarily parasitoids) and host plant resistance by Asian ash trees appear to be the factors responsible for suppressing EAB populations and preventing them from frequently causing ash mortalities [15, 19].

Deliberate efforts have been recently undertaken in the United States to achieve biological control of EAB and GSOB through introduction of natural enemies (parasitoids) from the native ranges of these pests [7, 17]. These classical biological control efforts for EAB have led to the discovery and introduction of several egg and larval parasitoids that have the potential to establish and suppress the pests' populations in the newly introduced regions [19–21, 27]. Similar programs for GSOB commenced in 2010 and are too immature to reach tentative conclusions about natural enemy diversity and impacts. In reviewing the literature, we found that many groups of parasitoids and other natural enemies have reported attacking *Agrilus* beetles. An overview of the composition of the parasitoid guild attacking this group of woodborers will contribute to the current and future development of biological control programs to manage these pests, particularly those *Agrilus* that have invaded new regions or environments. In the present study, we first review the diversity of natural enemy complexes in particular, hymenopteran parasitoid guilds associated with egg and larval stages of *Agrilus* species, and then discuss the potential of those parasitoids for use as agents of classical biological control against this group of pests.

2. Literature Reviewed

We searched seven major online data bases using the key word "*Agrilus*" either alone or in combination with any of the key words "parasitoid," "parasite", "natural enemy", or "biological control" to locate relevant literature. Databases examined were (1) Agricola, (2) BioAbstracts (BIOS), (3) Biological Sciences Set, (4) Biological and Agricultural Index Plus, (5) CSA Illumina, (6) CAB Abstract, and (7) ISI Web of Sciences set. The key word "*Agrilus*" alone resulted in 1942 articles (Table 1), of which 142 articles remained when combined with "parasitoid or parasite, natural enemies, or biological control." It must be noted that database searches concluded in March 2011. For this paper, we included only

Table 2: Parasitoid guilds associated with *Agrilus* woodborers in North America and Asia.

Parasitoid guilds	Order: Family	Species	Recorded *Agrilus* host	Habitat	Native range in distribution	Level of parasitism	Reference sources
Egg parasitoids	Hym: Aphelinidae	*Ablerus sp.*	*A. anxius*	Birch trees	Northeastern USA/Canada	<0.2%	[28]
		Avetianella sp.	*A. anxius*; *A. subcinctus*	Birch trees; ash trees	Northeastern USA/Canada	<3.5%	[28, 34]
	Hym: Encyrtidae	*Coccidencyrtus sp.*	*A. liragus*	Poplar trees	Northeastern USA/Canada	~55%	[35]
		Ooencyrtus erionotae	*A. sexsignatus*	Eucalyptus trees	Southeast Asia (Philippines)	32–57%	[31, 32]
		Ooencyrtus sp.	*A. anxius*	Birch trees	Northeastern USA/Canada	<2.4%	[28]
		Oobius agrili	*A. planipennis*	Ash trees	China/northeast China-Jilin province	>50%	[15, 36]
		Oobius agrili	*A. planipennis*	Ash trees	United States/Michigan	Not reported	[19]
		Oobius zahaikevitshi	*A. viridis and A. planipennis*	Hazelnut and ash trees, resp.	Northern Italy/Russian	8 –58%	[37, 38]
		Orianos brazai	*A. sexsignatus*	Eucalyptus trees	Southeast Asia (Philippines)	0–47%	[39]
		Signichorini tribe	*A. anxius*	Birch trees	Northeastern USA/Canada	<1%	[28]
		Ptinobius magniflcus	*A. ruficollis*	Raspberry, Blackberry, Dewberry	North America	Not reported	[40, 41]
	Hym: Signiphoridae	*Thysanus* sp.	*A. liragus*	Poplar trees	Northeastern USA/Canada	~12%	[35]
	Hym: Eulophidae	*Pediobius* sp.	*A. planipennis*	Ash trees	United States/Michigan	Not reported	[42]
Larval Parasitoids	Hym: Braconidae	*Atanycolus charus*	*A. anxius* and *A. liragus*	Birch and poplar trees	Northeastern USA/Canada	0.3–52%	[29, 35]
		Atanycolus cappaerti	*A. planipennis; A. liragus and A. bilineatus*	Ash trees; poplar and chestnut trees	Northeastern USA/Canada	9–71%	[33]
		Atanycolus disputabilis	*A. planipennis* and other North American native woodborers	Oak trees	Northeastern USA/Canada	<1%	[43]
		Atanycolus simplex	*A. planipennis; A. liragus and A. bilineatus*	Ash trees; poplar and chestnut trees	Northeastern USA/Canada	<1%	[35, 44]
		Atanycolus hicorie	*A. planipennis and* other native *Agrilus* woodborers	Ash trees	Northeastern USA/Canada	<2%	[45, 46]
		Atanycolus nigropopyga	*A. planipennis* and other North American native woodborers	Ash trees	Northeastern US/Canada	<3%	JJD (unpublished)

Table 2: Continued.

Parasitoid guilds	Order: Family	Species	Recorded *Agrilus* host	Habitat	Native range in distribution	Level of parasitism	Reference sources
		Atanycolus picipes	*A. planipennis*	Ash trees	Vladivostok, Russia	<5%	JJD (unpublished), [25]
		Doryctes farthus	*A. anxius* and *A. liragus*	Birch and poplar trees	Northeastern US/Canada	<0.1%	[44]
		Doryctes rufipes	*A. anxius* and *A. liragus*	Birch and poplar trees	Northeastern USA/Canada	<0.1%	[44]
		Doryctes atripes	*A. anxius*	Birch tree	Northeastern USA/Canada	<0.1%	[44]
		Iphiaulaz impostor	*A. biguttatus*	Poplar trees	Europe	~13%	[47]
		Leluthia astigma	*A. planipennis; A. difficilis* and other *Agrilus* spp.	Ash trees; honey locust trees	USA	~2.1%	[48, 49]
		Spathius agrili	*A. planipennis*	Ash trees	China	60–90%	[50–56]
		Spathius agrili	*A. planipennis*	Ash trees	USA/Michigan	Not reported	[21, 57]
		Spathius agrilivorus	*A. planipennis*	Ash trees	Vladivostok, Russia	~64%	JJD (unpublished), [25]
		Spathius curvicaudis	*A. biguttatus*	Oak trees	Europe	~25%	[47, 58]
		Spathius floridanus	*A. planipennis* and other North American native woodborers	Ash trees	USA	<0.5%	JJD (unpublished)
		Spathius laflammei	*A. planipennis* and other North American native woodborers	Ash trees	USA	<1%	JJD (unpublished)
		Spathius simillimus	*A. anxius and A. liragus/; A. planipennis*	Birch and poplar tree; ash trees	USA/Canada	<0.5%	[18]
		Wroughtonia (Helconidea) ligator	*A. anxius, A. liragus and A. bilineatus*	Birch, poplar and chestnut trees	northeastern USA/Canada	<1%	[29, 44]
		Ecphylus sp.	*A. subcinctus*	Ash trees	USA	Not reported	[34]
		Heterospilus sp.	*A. subcinctus*	Ash trees	USA	Not reported	[34]
		Pareucorystes varinervis	*A. viridis*	Hazelnut	Europe/Russia	Not reported	[59]
		Monogonogastra agrili	*A. arcuatus*	Hickory, pecan	North America	Not reported	[60]
		Microbracon xanthostigmus	*A. ruficollis*	Raspberry, blackberry, dewberry	North America	Not reported	[40, 41]
	Hym: Chalcididae	*Phasgonophora sulcata*	*A. anxius, A. bilineatus and A. liragus; A. planipennis*	Birch, chestnut and poplar tree; ash trees	USA/Canada	2–20%	[28–30, 35]

Table 2: Continued.

Parasitoid guilds	Order: Family	Species	Recorded *Agrilus* host	Habitat	Native range in distribution	Level of parasitism	Reference sources
	Hym: Eulophidae	*Tetrastichus nr.rugglesi*	*A. anxius and A. liragus; A. planipennis*	Birch and poplar trees; ash trees	USA/Canada	<0.1%	[29, 35]
		Tetrastichus heeringi	*A. sinuatus and A.aurichalceus*	Pear trees and raspberries, resp.	Europe	55–75%	[61–63]
		Tetrastichus heeringi	*A. ribesi*	Black current	Europe	Not reported	[64]
		Tetrastichus sp.	*A. sexignatus*	Eucalyptus trees	Southeast Asia (Philippines)	2–50%	[31, 32]
		Tetrastichus planipennisi	*A. planipennis*	Ash trees	Northeastern China/Russian Far East	22–40%	[15, 65, 66]
		Tetrastichus planipennisi	*A. planipennis*	Ash trees	USA Michigan	0.80%	[27, 57, 67]
		Baryscapus agrilorum	*A. aurichalceus*	Raspberry	Europe/Hungary	Not reported	[62, 68]
		near Hadrotrichodes	*A. subcinctus*	Ash trees	USA	Not reported	[34]
		Entodon epicharis	*A. surorovi/*	Poplar	China	Not reported	[69]
		Entodon zanara	*A. surorovi*	Poplar	China	Not reported	[69]
	Hym: Eupelmidae	*Balcha indica*	*A. planipennis* and other Asia and North American woodborers	Ash trees	Southeast Asia/North America	<4%	[70–72]
		Calosota elongata	*A. auroguttatus*	Oak trees	USA/Mexico	15%	[6]
		Eupelmus pini	*A. planipennis*	Ash trees and weevils	North America	<0.2%	[70]
		Metapelma sp.	*A. subcinctus*	Ash trees	USA	Not reported	[34]
		Calosota agrili	*A. salicis*	Willow	Europe/Poland and Russia	Not reported	[73, 74]
		Pentacladia hatayensis	*Agrilus* sp.	Fig	Turkey	Not reported	[75]
	Hym: Eurytomidae	*Bephratoides agrili*	*A. anxius*	Birch trees	North America	<1%	[29]
		Eurytoma rosae	*A. rubicola* and *A. bilineatus*	Rose and chestnut trees		Not reported	
		Eurytoma sp.	*A. anxius*	Birch trees	North America	<1%	[29]
		Eurytoma sp.	*A. subcinctus*	Ash trees	North America	Not reported	[34]
	Hym: Ichneumonidae	*Cunocephalus sp.*	*A. planipennis*	Ash trees—to be confirmed	North America	<0.2%	[70]
		Dolichomitus messorperlongus	*A. anxius* and *A. liragus*	Birch trees	North America	<0.4%	[29]
		Dolichomitus vitticrus	*A. planipennis* and other native woodborers	Ash trees	North America	<0.2%	[70]
		Ephialtes sp.	*A. anxius* and *A. liragus*	Birch trees	North America	<0.4%	[35]

Table 2: Continued.

Parasitoid guilds	Order: Family	Species	Recorded *Agrilus* host	Habitat	Native range in distribution	Level of parasitism	Reference sources
		Glypta sp.	*A. anxius*	Birch trees	North America	<1%	[44]
		Ichneumon sp.	*A. anxius*	Birch trees	North America	<1%	[44]
		Olesicampe sp.	*A. anxius*	Birch trees	North America	<1%	[44]
		Unknown spp.	*A. suvorovi-populneus*	Poplar trees	Europe/Hungary	4-5%	[76]
		Orthizema sp.	*A. anxius; A. planipennis*	Birch trees; ash trees	North America	<1%	[44, 70]
		Pimploterus sp.	*A. anxius*	Birch trees	North America	<1%	[44]
		Labena apicaulis	*A. arcuatus*	Hickory, pecan	North America	Not reported	[60]
	Hym: Stephanidae	*Foenatopus sp.*	*A. sexsignatus*	Eucalyptus trees	Southeast Asia (Philippines)	2–50%	[31, 32]
	Hym: Pteromalidae	*Zatropus* sp.	*A. arcuatus*	Hickory, pecan	North America	Not reported	[60]
		Oodera sp.	*A. subcinctus*	Ash trees	USA	Not reported	[34]
	Hym: Bethylidae	*Sclerodermus pupariae*	*A. planipennis*	Ash trees	China	Not reported	[77]

those original research articles that provide information on parasitoid identity at the family, genus, or species levels (Table 2).

In addition to searching databases, we contacted colleagues who work on invasive EAB and GSOB beetles and their biological control in the United States and Canada for information on parasitoid guilds of these species. All relevant studies were read and analyzed for mention of *Agrilus* species, associated parasitoids, known host associations, host plants, and geographic distributions. If available, parasitism rates by each group, guild, or species of parasitoids were noted.

3. Results and Discussion

At the genus level, the guilds of egg and larval parasitoids of *Agrilus* species were similar in North America, Europe, and Asia. While several families of North American parasitoids (including Braconidae, Chalcididae, Ichneumonidae, and Eupelmidae) are capable of utilizing larvae of the newly introduced emerald ash borer (*A. planipennis*) as a novel host, some Asiatic species of parasitoids appear to be more specific and only utilize Asian *Agrilus* species as hosts. From the geographic distribution point of view, it appears that there is more diversity in the parasitoid complex associated with *Agrilus* beetles in North American than in Asia and Europe. However, this geographic difference in parasitoid diversity may actually reflect different levels of research activities on the subject. For example, the invasion of North America by EAB has certainly resulted in much more research activities on the parasitoid complex of this group of woodborers in North America.

There are at least 12 species of hymenopteran parasitoids that attack eggs of *Agrilus* beetles and 56 parasitoid species that attack *Agrilus* larvae in various plants in North America, Asia, or Europe (Table 2). While most of these egg parasitoids (9 species) belong to the family Encyrtidae, a majority of the larval parasitoids are members of five families: Braconidae (24 species/11 genera), Eulophidae (8 species/4 genera), Ichneumonidae (10 species/9 genera), and Eupelmidae (6 species/5 genera). One species of larval parasitoid (*Phasgnophora sulcata* Westwood) (Chalcididae) is frequently associated with native *Agrilus* woodborers in North America [28–30]. In addition, there is one larval parasitoid (*Foenatopus* sp.) in the family Stephanidae that was reported attacking *A. sexsignatus* (Fisher) infesting Eucalyptus trees in southeast Asia [31, 32].

The highest rates of *Agrilus* egg parasitism (>50%) occurred with four species of encyrtid wasps reported in North America, Asia, and Europe (Table 2). In contrast, the highest rates of *Agrilus* larval parasitism (>50%) were caused by two groups of braconid wasps: *Atanycolus* spp. (in North America) and *Spathius* spp. (in Asia), and three species of eulophid wasps (in Asia and Europe). Although ichneumonid wasps were frequently reported attacking *Agrilus* woodborers in North America, the reported rate of parasitism was very low (<1%) for all the ichneumonid species.

It is interesting to note that several species of North American native parasitoids, *Atanycolus* spp., *Spathius floridanus* Ashmead, *S. laflammei* Provancher, *S. simillimus* Ashmead, *Phasgonophora sulcata* Westwood, and one accidentally introduced Asiatic wasp *Balcha indica* (Mani and Kaul), have been recently reported attacking the invasive emerald ash borer. One group of native parasitoids, *Atanycolus* spp., has recently become the dominant mortality factor associated with emerald ash borer, attacking >50% of *A. planipennis* larvae at some forest sites in Michigan (USA) [19, 33]. The potential of both the native (new-association) parasitoids and the introduced (old-association) parasitoids

(e.g., *Oobius agrili* Zhang and Huang, *Tetrastichus planipennisi* Yang, and *Spathius agrili* Yang) for biological control of EAB, in the USA, needs further investigation.

A diverse group of hymenopteran parasitoids attacks eggs and larvae of *Agrilus* woodborers in North America, Asia, and Europe. Literature review of this genus, in regards to its parasitoid guild, has interest due to the introduction of two species in North America (GSOB and EAB). In biological control, parasitoid species of invasive pests are often introduced from the land of origin, if proved to be safe (not become a pest themselves). In addition, new-association parasitoids that inhabit the region prior to the pest introduction sometimes exert pressure on this newly arrived pest and offer opportunity for research and augmentation of indigenous parasitoid populations. Our literature review has provided documentation of research activities for 12 egg parasitoid species and 56 larval parasitoid species. These parasitoids are identified from 19 species of *Agrilus*, a small representation of almost 3000 described, that attack 18 recorded plant types (13 hardwoods, 5 shrubs). Being a diverse genus, these results show a wealth of research opportunities for further work on *Agrilus* parasitoids worldwide. Nearly two thirds (64.3%) of the literature found was published after year 2000. Twenty-seven of 83 entries (32.5%), in Table 2, reference *A. planipennis*. These findings are results of EAB postdetection in 2002.

Although *Agrilus* species are relatively host specific, because of larvae's concealed nature, early stages and damage are difficult to assess and take much effort to obtain. This has implications on finding and identifying parasitoid complexes for biocontrol and may be a reason for so little literature. Of those parasitoid species found in association with EAB, some are ectoparasitoids and known to attack woodborers in different families (e.g., Cerambycidae). While data from the current literature do not show any particular relationship between host specificity and mode of parasitization (endo- versus ectoparasitoids), further research is needed to investigate such relationship.

Some species occur on multiple *Agrilus* spp., such as egg parasitoid *Oobius zahaikevitshi*. *Atanycolus cappaerti* is known to attack *A. planipennis*, *A. liragus*, and *A. bilineatus*, while *Leluthia astigma* attacks *A. planipennis*, *A. difficilis*, and other *Agrilus* spp. These may provide better access of parasitoids where poplar, chestnut, honey locust, and ash occur together.

The parasitoid guild of *Agrilus* in China, Russia, and North America and EAB distribution may provide species for introduction or augmentation. Though most of the parasitism rates are low (<10%), a few worthy candidates not yet used for introduction or augmentation include egg parasitoid, *O. zahaikevitshi* from Russia, and larval parasitoids *Atanycolus cappaerti, Spathius agrilovorus*, and *Spathius floridanus*. These species in the USA have not yet been reared in large numbers, and further studies on rearing methods need pursuing. It appears also that braconids and eulophids have provided the best potential for biological control, and the number of studies the last five years bear this out. It also indicates that species size and morphology (ovipositor length) for accessing the host from outside the host plant are important for success.

Finally, parasitoid work in biological control efforts often lack taxonomic expertise to provide accurate identifications. Some of these newly known parasitoid species are not well understood. Egg parasitoids are often disregarded due to size and inaccessibility of host eggs. These hamper ongoing biological control of invasive or cyclic native pest populations. A concluding question is should work be done now on conspecifics that have the potential to be invasive (e.g., *A. coxalis* attacks oaks in Mexico—California has a history of acquiring pests from MX, could *A. coxalis* be another threat to CA's besieged oaks forests?).

References

[1] C. L. Bellamy, "Two new species of *Sambomorpha* Obenberger, 1924 (Coleoptera: Buprestidae) from Costa Rica and Panama," *The Coleopterists Bulletin*, vol. 61, no. 3, pp. 471–475, 2007.

[2] W. S. Fisher, *A Revision of the North American Species of Buprestid Beetles Belonging to the Genus Agrilus*, Smithsonian Institute United States National Museum, Bulletin 145, United States Govenment Printing Office, Washington, DC, USA, 1928.

[3] A. M. Bray, L. S. Bauer, T. M. Poland, R. A. Haack, A. I. Cognato, and J. J. Smith, "Genetic analysis of emerald ash borer (*Agrilus planipennis* Fairmaire) populations in Asia and North America," *Biological Invasions*, vol. 13, no. 12, pp. 2869–2887, 2011.

[4] R. A. Haack, E. Jendek, H. Liu et al., "The emerald ash borer: a new exotic pest in North America," *Newsletter of the Michigan Entomological Society*, vol. 47, no. 3, pp. 1–5, 2002.

[5] K. F. Kovacs, R. G. Haight, D. G. McCullough, R. J. Mercader, N. W. Siegert, and A. M. Liebhold, "Cost of potential emerald ash borer damage in U.S. communities, 2009–2019," *Ecological Economics*, vol. 69, no. 3, pp. 569–578, 2010.

[6] T. W. Coleman, N. E. Grulke, M. Daly et al., "Coast live oak, *Quercus agrifolia*, susceptibility and response to goldspotted oak borer, *Agrilus auroguttatus*, injury in southern California," *Forest Ecology and Management*, vol. 261, no. 11, pp. 1852–1865, 2011.

[7] T. W. Coleman and S. J. Seybold, "Collection history and comparison of the interactions of the goldspotted oak borer, *Agrilus auroguttatus* schaeffer (Coleoptera: Buprestidae), with host oaks in Southern California and Southeastern Arizona, U.S.A," *Coleopterists Bulletin*, vol. 65, no. 2, pp. 93–108, 2011.

[8] T. W. Coleman and S. J. Seybold, "Previously unrecorded damage to oak, *Quercus* spp., in southern California by the goldspotted oak borer, *Agrilus coxalis* Waterhouse (Coleoptera: Buprestidae)," *Pan-Pacific Entomologist*, vol. 84, no. 4, pp. 288–300, 2008.

[9] R. F. Billings, D. M. Grosman, and H. A. Pase III, "Soapberry borer, *Agrilus prionurus* (Coleoptera: Buprestidae): an invasive pest of western soapberry," in *Proceedings of the North America Forest Insect Workshop, May 9–15, 2011*, Portland, Ore, USA, 2011.

[10] E. Jendek and V. V. Grebennikov, "*Agrilus sulcicollis* (Coleoptera: Buprestidae), a new alien species in North America," *Canadian Entomologist*, vol. 141, no. 3, pp. 236–245, 2009.

[11] J. E. Aukema, D. G. McCullough, B. V. Holle, A. M. Liebhold, K. Britton, and S. J. Frankel, "Historical accumulation of nonindigenous forest pests in the continental United States," *BioScience*, vol. 60, no. 11, pp. 886–897, 2010.

[12] T. M. Poland, D. G. McCullough, and A. C. Anulewicz, "Evaluation of double-decker traps for emerald ash borer (Coleoptera: Buprestidae)," *Journal of Economic Entomology*, vol. 104, no. 2, pp. 517–531, 2011.

[13] R. J. Mercader, N. W. Siegert, A. M. Liebhold, and D. G. McCullough, "Simulating the effectiveness of three potential management options to slow the spread of emerald ash borer (*Agrilus planipennis*) populations in localized outlier sites," *Canadian Journal of Forest Research*, vol. 41, no. 2, pp. 254–264, 2011.

[14] D. G. McCullough, T. M. Poland, and D. Cappaert, "Attraction of the emerald ash borer to ash trees stressed by girdling, herbicide treatment, or wounding," *Canadian Journal of Forest Research*, vol. 39, no. 7, pp. 1331–1345, 2009.

[15] H. Liu, L. S. Bauer, D. L. Miller et al., "Seasonal abundance of *Agrilus planipennis* (Coleoptera: Buprestidae) and its natural enemies *Oobius agrili* (Hymenoptera: Encyrtidae) and *Tetrastichus planipennisi* (Hymenoptera: Eulophidae) in China," *Biological Control: Theory and Application in Pest Management*, vol. 42, no. 1, pp. 61–71, 2007.

[16] H. Liu, T. R. Petrice, R. A. Haack, T. Zhao, L. S. Bauer, and R. Gao, "Exploratory survey for the emerald ash borer, *Agrilus planipennis* (Coleoptera: Buprestidae), and its natural enemies in China," *Great Lakes Entomologist*, vol. 36, no. 3-4, pp. 191–204, 2003.

[17] USDA-APHIS, "The proposed release of three parasitoids for the biological control of the emerald ash borer (*Agrilus planipennis*) in the continental United States: environmental assessment," Federal Register APHIS-2007-0060, 2007.

[18] L. S. Bauer, H.-P. Liu, R. A. Haack et al., "Emerald ash borer natural enemy surveys in Michigan and China," in *Proceedings of the Emerald Ash Borer Research and Technology Development Meeting; USDA FS FHTET-2004-15*, Forest Health Technology Enterprise Team, Romulus, Mich, USA, 2005.

[19] J. J. Duan, L. S. Bauer, M. D. Ulyshen, J. R. Gould, and R. van Driesche, "Development of methods for the field evaluation of *Oobius agrili* (Hymenoptera: Encyrtidae) in North America, a newly introduced egg parasitoid of the emerald ash borer (Coleoptera: Buprestidae)," *Biological Control*, vol. 56, no. 2, pp. 170–174, 2011.

[20] J. R. Gould, T. Ayer, and I. Fraser, "Effects of rearing conditions on reproduction of *Spathius agrili* (Hymenoptera: Braconidae), a parasitoid of the emerald ash borer (Coleoptera: Buprestidae)," *Journal of Economic Entomology*, vol. 104, no. 2, pp. 379–387, 2011.

[21] L. S. Bauer, J. R. Gould, and J. J. Duan, "Can biological control of emerald ash borer save our ash?" *Michigan Entomological Society Newsletter*, vol. 55, pp. 26–27, 2010.

[22] D. Cappaert, D. G. McCullough, T. M. Poland, and N. W. Siegert, "Emerald ash borer in North America: a research and regulatory challenge," *American Entomologist*, vol. 51, no. 3, pp. 152–165, 2005.

[23] G.-T. Xu, "*Agrilus marcopoli* Obenberger," in *Atlas of Ornamental Pests and Diseases*, pp. 321–322, China Agriculture Press, Beijing, China, 2003.

[24] X. Wei, D. Reardon, Y. Wu, and J. H. Sun, "Emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera; Buprestidae), in China: a review and distribution survey," *Acta Entomologica Sinica*, vol. 47, no. 5, pp. 679–685, 2004.

[25] G. I. Yurchenko, G. I. Turova, and E. A. Kuzmin, "The distribution and ecology of emerald ash borer (*Agrilus planipennis* Fairmare) in the Russian Far East," in *Proceedings of the A.I. Kuretsov's Annual Memorial Meetings*, pp. 94–98, Dalnauka, Vladivostok, Russia, 2007.

[26] C. Yu, "*Agrilus marcopoli* Obenberger," in *Forest Insects of China*, G. Xiao, Ed., pp. 400–401, China Forestry Publishing House, Beijing, China, 1992.

[27] J. J. Duan, M. D. Ulyshen, L. S. Bauer, J. Gould, and R. V. Driesche, "Measuring the impact of biotic factors on populations of immature emerald ash borers (Coleoptera: Buprestidae)," *Environmental Entomology*, vol. 39, no. 5, pp. 1513–1522, 2010.

[28] C. R. Loerch and E. A. Cameron, "Natural enemies of immature stages of the bronze birch borer, *Agrilus anxius* (Coleoptera: Buprestidae), in Pennsylvania," *Environmental Entomology*, vol. 12, no. 6, pp. 1798–1801, 1983.

[29] G. W. Barter, "Studies of the bronze birch borer, *Agrilus anxius* Gory, in New Brunswick," *Canadian Entomologist*, vol. 89, no. 1, pp. 12–36, 1957.

[30] W. A. Cote and D. C. Allen, "Biology of 2-lined chestnut borer, *Agrilus bilineatus*, in Pennsylvania and New-York (Coleoptera, Buprestidae)," *Annals of the Entomological Society of America*, vol. 73, no. 4, pp. 409–413, 1980.

[31] R. D. Braza, "Control of varicose borer in PICOP's bagras plantation," *Canopy International*, vol. 14, no. 2, pp. 7–9, 1988.

[32] R. D. Braza, "Parasitoids of immature stages of *Agrilus sexsignatus* (Fisher) (Coleoptera: Buprestidae) attacking *Eucalyptus deglupta* Blume in Surigao del Sur," *Philippine Entomologist*, vol. 7, no. 5, pp. 479–483, 1989.

[33] D. Cappaert and D. G. McCullough, "Occurrence and seasonal abundance of *Atanycolus cappaerti* (hymenoptera: Braconidae) a native parasitoid of emerald ash borer, *Agrilus planipennis* (coleoptera: Buprestidae)," *Great Lakes Entomologist*, vol. 42, no. 1-2, pp. 16–29, 2009.

[34] T. R. Petrice, R. A. Haack, J. S. Strazanac, and J. P. Lelito, "Biology and larval morphology of *Agrilus subcinctus* (Coleoptera: Buprestidae), with comparisons to the Emerald ash borer, *Agrilus planipennis*," *Great Lakes Entomologist*, vol. 42, no. 3-4, pp. 173–184, 2009.

[35] G. W. Barter, "Survival and development of the bronze poplar borer *Agrilus liragus* Barter & Brown (Coleoptera: Buprestidae)," *Canadian Entomologist*, vol. 97, no. 10, pp. 1063–1068, 1965.

[36] Y. Z. Zhang, D. W. Huang, T. H. Zhao, H. P. Liu, and L. S. Bauer, "Two new species of egg parasitoids (Hymenoptera: Encyrtidae) of wood-boring beetle pests from China," *Phytoparasitica*, vol. 33, no. 3, pp. 253–260, 2005.

[37] M. Corte, S. Moraglio, and L. Tavella, "First surveys on *Agrilus* spp. (Coleoptera: Buprestidae) infesting hazelnut in Northwestern Italy," *ISHS Acta Horticulturae*, vol. 845, pp. 531–534, 2009.

[38] S. S. Izhevskii and E. G. Mozolevskaya, "*Agrilus planipennis* fairmaire in Moscow ash trees," *Russian Journal of Biological Invasions*, vol. 1, no. 3, pp. 153–155, 2010.

[39] J. S. Noyes, "A new genus and species of encyrtid (Hymenoptera, Chalcidoidea) parasitoid of the eggs of the varicose borer, *Agrilus sexsignatus* (Fisher) (Coleoptera, Buprestidae), a pest of bagras (*Eucalyptus deglupta* Blume) in the Philippines," *Journal of Natural History*, vol. 24, no. 1, pp. 21–25, 1990.

[40] F. H. Chittenden, "The red-necked raspberry cane-borer," in *Farmers' Bulletin / United States Department of Agriculture*, no. 1286, U.S. Department of Agriculture, Washington, DC, USA, 1922.

[41] A. D. Hopkins, "Raspberry gouty-gall beetle," in *Bulletin / West Virginia Agricultural Experiment Station*, no. 15, p. 81, West Virginia Agricultural Experiment Station, Morgantown, Wva, USA, 1891.

[42] L. Pons, "Working to I.D. foes of emerald ash borers," *Agricultural Research*, vol. 53, no. 2, pp. 22–22, 2005.

[43] J. J. Duan, L. S. Bauer, K. Abell, and R. van Driesche, "Population responses of hymenopteranparasitoids to the EAB (Coleoptera: Buprestidae) in North Central United States," *Biocontrol*.

[44] R. W. Nash, E. J. Duda, and N. H. Gray, "Studies on extensive dying, regeneration, and management of birch," in *Maine Forest Service Bulletin*, no. 15, 1951.

[45] P. M. Marsh, *Family Braconidae*, Smithsonian Institution Press, Washington, DC, USA, 1979.

[46] L. S. Bauer, H.-P. Liu, R. A. Haack, D. L. Miller, and T. R. Petrice, "Natural enemies of emerald ash borer in southeastern Michigan," in *Proceedings of the Emerald Ash Borer Research and Technology Meeting, October 5-6, 2004*, USDA FS FTET, Port Huron, Mich, USA, 2004.

[47] D. S. Kailidis, "Beobachtungen über zwei Pappelschädlinge in Griechenland. [Observations on two poplar pests in Greece.]," *Anzeiger für Schädlingskunde*, vol. 41, pp. 38–41, 1968.

[48] R. R. Kula, D. L. Cappaert, J. K. Gandhi, K. S. Knight, L. S. Bauer, and J. Rebbeck, "*Leluthia astigma* (Ashmead) (Hymenoptera: Braconidae: Doryctinae) as a parasitoid of *Agrilus planipennis* fairmaire (Coleoptera: Buprestidae: Agrilinae), with an assessment of host associations for nearctic species of *Leluthia* cameron," *Proceedings of the Entomological Society of Washington*, vol. 112, no. 2, pp. 246–257, 2010.

[49] C. F. W. Muesebeck and L. M. Walkley, "Family Braconidae," in *Hymenoptera of America North of Mexico—Synoptic catalog*, C. F. W. Muesebeck, K. V. Krombein, and H. K. Townes, Eds., pp. 90–184, U.S. Department of Agriculture Monograph, 1951.

[50] Z. Q. Yang, X. Y. Wang, J. R. Gould, and H. Wu, "Host specificity of *Spathius agrili* Yang (Hymenoptera: Braconidae), an important parasitoid of the emerald ash borer," *Biological Control*, vol. 47, no. 2, pp. 216–221, 2008.

[51] Z. Q. Yang, C. V. Achterberg, W. Y. Choi, J. S. Strazanac, and P. M. Marsh, "First recorded parasitoid from China of *Agrilus planipennis*: a new species of Spathius (Hymenoptera: Braconidae: Doryctinae)," *Annals of the Entomological Society of America*, vol. 98, no. 5, pp. 636–642, 2005.

[52] Z. Q. Yang, X. Y. Wang, J. R. Gould et al., "Biology and behavior of *Spathius agrili*, a parasitoid of the emerald ash borer, *Agrilus planipennis*, in China," *Journal of Insect Science*, vol. 10, no. 30, 2010.

[53] J. Tian, X. Wang, Z. Yang et al., "Effects of temperature on development and reproduction of parasitic wasp *Spathius agrili* Yang (Hymenoptera: Braconidae), an effective parastoid of emerald ash borer," *Acta Entomologica Sinica*, vol. 52, no. 11, pp. 1223–1228, 2009.

[54] X. Y. Wang, Z. Q. Yang, J. R. Gould, H. Wu, and J. H. Ma, "Host-seeking behavior and parasitism by *Spathius agrili* Yang (Hymenoptera: Braconidae), a parasitoid of the emerald ash borer," *Biological Control*, vol. 52, no. 1, pp. 24–29, 2010.

[55] X. Wang, Z. Yang, H. Wu, S. Liu, H. Wang, and L. Bai, "Parasitism and reproductive biology of *Spathius agrili* Yang (Hymenoptera: Braconidae)," *Acta Entomologica Sinica*, vol. 50, no. 9, pp. 920–926, 2007.

[56] X. Wang, Z. Yang, G. Liu, and E. Liu, "Relationships between the emergence and oviposition of ectoparasitoid *Spathius agrili* Yang and its host emerald ash borer, *Agrilus planipennis* Fairmaire," *Frontiers of Forestry in China*, vol. 2, no. 4, pp. 453–458, 2007.

[57] M. D. Ulyshen, L. S. Bauer, and J. J. Duan, "Interactions between *Spathius agrili* (Hymenoptera: Braconidae) and *Tetrastichus planipennisi* (Hymenoptera: Eulophidae), larval parasitoids of *Agrilus planipennis* (Coleoptera: Buprestidae) [electronic resource]," *Biological Control: Theory and Application in Pest Management*, vol. 52, no. 2, pp. 188–193, 2010.

[58] L. G. Moraal and C. van Achterberg, "*Spathius curvicaudis* (Hymenoptera: Braconidae) new for The Netherlands; a parasitoid of the oak buprestid beetle, *Agrilus biguttatus* (Coleoptera: Buprestidae)," *Entomologische Berichten*, vol. 61, no. 11, pp. 165–168, 2001.

[59] V. I. Tobias, "A new genus of the tribe Doryctini (Hymenoptera, Braconidae) and its taxonomic significance [English summ.] Novyi rod iz triby Doryctini (Hymenoptera, braconidae) i ego taksonomicheskoe znachenie," *Zoologicheskiy Zhurna*, vol. 40, no. 4, pp. 529–535, 1961.

[60] F. E. Brooks, "Life history of the hickory spiral borer, *Agrilus arcuatus* Say," *Journal of Agricultural Research*, vol. 33, no. 4, pp. 331–338, 1926.

[61] O. Jancke, "Der Birnprachtkäfer (*Agrilus sinuatus* Oliv., Buprestidae), [The pear Buprestid (*A. sinuatus*)]," *Anzeiger für Schädlingskunde*, vol. 22, no. 4, pp. 51–57, 1949.

[62] G. Vétek and B. Pénzes, "The incidence of cane pests in a traditional and an autumn-fruiting raspberry plantation. /Vesszokártevok elofordulása termovesszon és sarjon termo málnaültetvényekben," *Növényvédelem*, vol. 40, no. 1, pp. 3–10, 2004.

[63] J. Idinger, "Investigations on the distribution, biology, ecology and possibilities of prognosis and control of *Agrilus aurichalceus* Redt./Untersuchungen zur Verbreitung, Biologie, Ökologie sowie Prognose- und Bekämpfungsmöglichkeiten von Agrilus aurichalceus Redt. (Himbeerprachtkäfer)," *Pflanzenschutz (Wien)*, vol. 2, pp. 3–4, 1991.

[64] E. Tsolova and N. Stoyanova, "Biological peculiarities of *Tetrastichus heeringi* Del (Hymenoptera; Eulophidae) and its role in regulating the density of *Agrilus ribesi* Schaffer (Coleoptera: Buprestidae)," *Rasteniev'dni Nauki*, vol. 44, no. 4, pp. 295–298, 2007.

[65] H. Liu, L. S. Bauer, R. Gao, T. Zhao, T. R. Petrice, and R. A. Haack, "Exploratory survey for the emerald ash borer, *Agrilus planipennis* (Coleoptera: Buprestidae), and its natural enemies in China," *Great Lakes Entomologist*, vol. 36, no. 3-4, pp. 191–204, 2003.

[66] Z. Q. Yang, J. S. Strazanac, Y. X. Yao, and X. Y. Wang, "A new species of emerald ash borer parasitoid from China belonging to the genus *Tetrastichus* haliday (Hymenoptera: Eulophidae)," in *Proceedings of the Entomological Society of Washington*, vol. 108, pp. 550–558, Entomological Society of Washington, Washington, DC, USA, 2006.

[67] M. D. Ulyshen, J. J. Duan, L. S. Bauer, and I. Fraser, "Suitability and accessibility of immature *Agrilus planipennis* (Coleoptera: Buprestidae) stages to *Tetrastichus planipennisi* (Hymenoptera: Eulophidae)," *Journal of Economic Entomology*, vol. 103, no. 4, pp. 1080–1085, 2010.

[68] G. Vétek and B. Pénzes, "The effect of different growing methods on the incidence of cane pests in Hungarian raspberry plantations," *Bulletin OILB/SROP*, vol. 28, no. 7, pp. 229–232, 2005.

[69] G. J. Wang, R. Z. Zhao, D. W. Huang, G. Z. Wang, and D. M. Shi, "Three species of Eulophidae parasitizing some borers of poplar in Jilin Province," *Acta Entomologica Sinica*, vol. 34, no. 2, pp. 230–233, 1991.

[70] J. J. Duan, R. W. Fuester, J. Wildonger, P. B. Taylor, S. Barth, and S. E. Spichiger, "Parasitoids attacking the emerald ash

borer (Coleoptera: Buprestidae) in Western Pennsylvania," *Florida Entomologist*, vol. 92, no. 4, pp. 588–592, 2009.

[71] G. A. P. Gibson, "The world species of *Balcha* Walker (Hymenoptera: Chalcidoidea: Eupelmidae), parasitoids of woodboring beetles," *Zootaxa*, no. 1033, pp. 1–62, 2005.

[72] L. Pons, "Working To I.D. foes of emerald ash borers," *Agricultural Research*, vol. 53, no. 2, p. 22, 2005.

[73] B. Wiśniowski and M. Mikowski, "*Calosota agrili* Nikolskaya—the chalcid wasp new to the fauna of Poland (Hymenoptera: Eupelmidae) reared from *Agrilus salicis* Frivaldszki (Coleoptera: Buprestidae). /*Calosota agrili* Nikolskaya—nowy dla Polski gatunek bleskotki (Hymenoptera: Eupelmidae) wyhodowany z *Agrilus salicis* Frivaldszki (Coleoptera: Buprestidae)," *Wiadomości Entomologiczne*, vol. 24, no. 4, pp. 250–251, 2005.

[74] M. N. Nikol'Skaia, "[Chalcidoidea of the fauna of the U.S.S.R], Khal'tsidy fauny SSSR," *Opredeliteli Po Faune SSSR Izd Zool Inst Akad Nauk SSSR*, vol. 44, pp. 1–575, 1952.

[75] M. Doganlar, "A new species of *Pentacladia* Westwood, 1835 (Hymenoptera, Chalcidoidea, Eupelmidae) from Yayladag, Hatay, Turkey," *Türkiye Entomoloji Derneği & Dergisi*, vol. 27, no. 2, pp. 83–90, 2003.

[76] P. Szontagh, "The life cycle and damage caused by *Agrilus suvorovi-populneus* Coleoptera Buprestidae," *Allattani Kozlemenyek*, vol. 62, no. 1–4, pp. 129–134, 1975.

[77] H. Wu, X.-Y. Wang, M.-L. Li et al., "Biology and mass rearing of *Sclerodermus pupariae* Yang et Yao (Hymenoptera : Bethylidae), an important ectoparasitoid of the emerald ash borer, *Agrilus planipennis*(Coleoptera : Buprestidae) in China," *Acta Entomologica Sinica*, vol. 51, no. 1, pp. 46–54, 2008.