Overwintering developmental stages of emerald ash borer in North Carolina

Christine A. Nalepa1,*, Kelly L. F. Oten2,3, and Matthew A. Bertone4

Abstract

The invasive woodboring beetle emerald ash borer Agrilus planipennis Fairmaire (Coleoptera: Buprestidae) first was detected in the US in 2002 near Detroit, Michigan, USA. Since then it has continued to expand its range into the southern and midwestern sections of the country. Emerald ash borer was discovered in North Carolina, USA, in 2013, and is currently reported from more than 60 counties in the state. The present study was undertaken to begin determining the phenology of emerald ash borer in its newly expanded range below 40 °N latitude in North America. Here we report 4 yr of data on the overwintering stages of emerald ash borer in north-central North Carolina, obtained by debarking infested trees harvested from a single site near the northern border with Virginia, USA, with 1-yr additional data from a site about 39 km away. Results indicated that most emerald ash borers overwinter as fourth instars, with a small proportion advancing to the J-larva stage. Parasitoids that emerged from cocoons collected from emerald ash borer galleries and from logs held in emergence cages also were identified. These Hymenoptera include specimens of Xorides (Exomus) humerals (Say) (Ichneumonidae), Atanycolus cf. cappaerti Marsh and Strazanac (Braconidae), Balcha indica (Mani & Kau) (Eupelmidae), Spathius sp. Nees (Braconidae), and Wroughtonia sp. Cameron (Braconidae).

Key Words: Agrilus planipennis; life history; parasitoids

Resumo

El invasor coleoptero conocido come barrenador esmeralda del fresno Agrilus planipennis Fairmaire (Coleoptera: Buprestidae) se detectó por primera vez en los EE. UU. en el 2002 cerca de Detroit, Michigan, EE. UU. Desde entonces, ha seguido ampliando su área de distribución en las áreas del sur y de medio oeste del país. El barrenador esmeralda del fresno se detectó por primera vez en Carolina del Norte, EE. UU., en el 2013, y actualmente se informa en más de 60 condados de ese Estado. Se realizó el presente estudio para comenzar a determinar la fenología del barrenador esmeralda del fresno en su rango recientemente ampliado por debajo de los 40 °N de latitud en América del Norte. Aquí presentamos 4 años de datos sobre los estádios de hibernación del barrenador esmeralda del fresno en el centro-norte de Carolina del Norte, obtenidos al descorzear árboles infestados cosechados en un solo sitio cerca de la frontera norte con Virginia, EE. UU., con datos adicionales de 1 año de un sitio a unos 39 km de distancia. Los resultados indicaron que la mayoría de los barrenadores esmeralda del fresno invernan como en el cuarto estadio, y una pequeña proporción avanza al estadio de J-larva. También, se identificaron parasitoides que emergieron de pupas recolectadas de galerías de barrenadores de fresno esmeralda y de troncos mantenidos en jaulas de emergencia. Estos himenópteros incluyen especímenes de Xorides (Exomus) humerals (Say) (Ichneumonidae), Atanycolus cf. cappaerti Marsh & Strazanac (Braconidae), Balcha indica (Mani & Kau) (Eupelmidae), Spathius sp. Nees (Braconidae) y una especie del género Wroughtonia Cameron (Braconidae).

Palabras Clave: Agrilus planipennis; historia de vida; parasitoides

Emerald ash borer Agrilus planipennis Fairmaire (Coleoptera: Buprestidae), a highly destructive pest of ash trees (Fraxinus L.; Oleaceae), is native to East Asia and first was detected in North America (Michigan, USA) in 2002 (Haack et al. 2002). Since then it has spread progressively into the northeastern and southern US and is considered the most destructive and costly wood boring pest to invade the country (Aukema et al. 2011). The leading long-term strategy for managing emerald ash borer in forest settings is classical biological control, using natural enemies collected from its native range in Asia (Hermes & McCullough 2014; Gaudon & Smith 2020).

Four hymenopteran parasitoid species from the natural range of this pest in China (Oobius agrili Zhang & Huang [Hymenoptera: Encyrtidae], Tetrastichus planipennisi Yang [Hymenoptera: Eulophidae], Spathius agrili Yang [Hymenoptera: Braconidae]) and Russia (Spathius galinae Belokobylskij [Hymenoptera: Braconidae]) have been released by the United States Department of Agriculture (USDA) and its partners for control of emerald ash borer in the US (Duan et al. 2018). However, only the egg parasitoid O. agrili and the larval parasitoid T. planipennisi have been recovered consistently more than a yr after release in the northern half of the US (USDA-APHIS 2015). Furthermore, it is too soon to assess establishment by the larval parasitoid S. galinae, thought to be adapted to higher latitudes and first released in 2015, 8 yr after the initial releases of the other 3. Tetrastichus planipennisi and O. agrili have failed to establish in the southern US (Duan et al. 2018).
Spathius agrili is a parasitoid of particular interest to the southern US, because individuals of S. agrili that were released in the US originated from the southern limit of the emerald ash borer range in China (about 39°N) where it is a significant source of emerald ash borer parasitism (Liu et al. 2003; Yang et al. 2005). In this part of its range in China, emerald ash borer is primarily univoltine (Wei et al. 2007) and S. agrili emerges over a mo later than adult emerald ash borer, when parasitoids susceptible emerald ash borer larvae are available as hosts (Wang et al. 2010). Thus, this wasp may be best suited to the warmer climates of the US, particularly in states located below 40°N latitude (Bauer et al. 2015). Spathius agrili failed to establish in the northeastern US (Jones et al. 2020), but establishment has been confirmed at 1 site in Maryland, USA (Duan et al. 2018), and at a release site in eastern Tennessee, USA. Although the latter finding indicates that S. agrili may overwinter below 40°N latitude, it may be too soon to indicate that it is established (Hooie et al. 2015). The limited success of S. agrili is thought to be a result of failure to release the parasitoids when a suitable stage of the host is available (Bauer et al. 2015; USDA-APHIS 2015). Larval parasitoids imported for release in the US are host stage specific, typically using the third or fourth instar emerald ash borer (Duan et al. 2018). It is therefore critical to determine the life cycle of emerald ash borer in all parts of its range so that parasitoids are released when they temporally coincide with the host stages susceptible to parasitism, thus giving them the optimal chance for establishment. In the northern US, the life cycle of emerald ash borer is well characterized; the insect completes its life cycle in 1 or 2 yr. Not every member of each generation reaches the pupation stage in a given yr, resulting in an asynchronous pattern of development and overlapping life stages. Therefore, larval parasitoids presumably have a higher probability of finding a host in the appropriate stage (late larval instars) throughout the year (Cappaert et al. 2005; Duan et al. 2010). The life cycle of emerald ash borer in the southern half of its recently expanded range is less well-defined, with a single study in Maryland, USA, finding it to be completed in 1 yr, i.e., the insect is univoltine in that location (Abell et al. 2019).

The present study was conducted as a first step in determining the phenology of emerald ash borer in North Carolina, USA. We collected 4 yr of data on the overwintering stages of this destructive pest in Granville County, North Carolina, USA, located near where emerald ash borer first was detected in North Carolina in 2013. We also collected parasitoids associated with emerald ash borer, either as cocoons collected from emerald ash borer galleries and reared to emergence, or from emerald ash borer-infested ash logs held in emergence cages. The goal was to determine native parasitoids that may be using emerald ash borer as a host in this state, because North America has a rich complex of native natural enemies of Agrilus beetles, many with the potential to use emerald ash borer for development (Duan et al. 2018; Gaudon & Smith 2020).

Materials and Methods

STUDY AREA AND SAMPLING

Green ash trees (Fraxinus pennsylvanica Marshall; Oleaceae) infested with emerald ash borer were selected and felled to quantify emerald ash borer overwintering stages in North Carolina. Live trees with signs of decline, such as bark splits, epicormic shoots, or emerald ash borer exit holes were chosen from a 3-ha area of bottomland hardwood forest; selected trees were at least 3 m apart. Each tree was cut near the soil line and the bole sawed into manageable sections labelled sequentially from the base to the top; log sections ranged from 7 to 28 cm in diameter. These were transported to a North Carolina Department of Agriculture & Consumer Services property, Raleigh, North Carolina, USA, where the logs were debarked and inspected for life stages of emerald ash borer.

In 2017, we worked in 2 sites in Granville County, near the northern border of North Carolina with Virginia: a residential property north of Stovall (36.463046°N, 78.566499°W), and a state-owned forestland in Butner (36.15290°N, 78.767530°W). The 2 sites are approximately 39 km apart. Two ash trees were felled in Stovall and 3 in Butner on 28 Feb 2017; 4 trees were felled in Butner on 9 Feb 2018 and 5 Feb 2019. Because our 2017 results indicated that the emerald ash borer infestation in Stovall had already progressed to near total mortality of the trees, our studies in 2018 to 2020 were conducted exclusively at the site in Butner.

Debarking took place 1 to 14 Mar 2017, 12 to 21 Feb 2018, and 6 to 13 Feb 2019. In 2017, the results from the Stovall and Butner sites were combined; just 15% (9 of 59) of the insects collected were from Stovall. On 4 Feb 2020, we travelled to the Butner site with the intention of again felling trees for debarking in the laboratory, but the ash had reached near complete mortality. Instead, trees were debarked in the field until we located emerald ash borer life stages. Eventually these were found in 3 trees, where n = 13, 1, and 1 live emerald ash borer life stages were found, respectively.

The number of cumulative developmental degree d on the date of tree harvest were taken from the Duarte 2013 OSU IPPC model, base 50 (http://uspest.org/cgi-bin/ddmodel.us; last accessed 8 Apr 2021). The weather station used was at Creedmoor, located 8 km southeast of the Butner collection site.

DETERMINING DEVELOPMENTAL STAGES

The developmental stage of each emerald ash borer (larva, J-larva, pupa) was recorded, and those that were undamaged during collection were preserved in alcohol. The instar of each alcohol-preserved larva was determined by measuring, from the dorsal aspect, the length of sclerotized terminal processes on the abdomen using an ocular micrometer (0.05 mm) on a dissecting microscope (Nikon SMZ1500, Melville, New York, USA). The length of these terminal processes, also called urogomphi (see Chamorro et al. 2012), are a consistent character for separating larval instars of emerald ash borer (Wang et al. 2005; Orlova-Bienkowskaja & Bienkowski 2016). The formula we used for categorizing instars was a combination of the ranges published in Wang et al. (2005) and Orlova-Bienkowskaja and Bienkowski (2016) as follows: < 0.2 mm (first instar), 0.21 to 0.37 mm (second instar), 0.38 to 0.72 mm (third instar), and > 0.73 (fourth instar).

COLLECTION AND IDENTIFICATION OF POSSIBLE PARASITOIDs

From 2017 to 2020, cocoons of possible parasitoids encountered during debarking were collected from emerald ash borer overwintering chambers and reared to maturity. Adult wasps that successfully emerged were identified and photographed by M. Bertone. We note that our technique did not allow for identification of larvae endoparasitoids and those failing to emerge, disallowing estimates of parasitism rates. Three emerald ash borer-infested trees additional to the ones used for debarking were harvested at the Butner site on 13 Mar 2019 to better screen for emergence of overwintering parasitoids. These trees were sectioned into logs of a length that would fit into 61 cm L × 61 cm W × 49 cm H laboratory built Plexiglas emergence cages (n = 42 logs in 30 cages), held at 24 to 25 °C, and checked every 1 to 3 d for emerged Hymenoptera. The insects have been deposited in the North Carolina State University Insect Museum, Raleigh, North Carolina, USA.
Results

EMERALD ASH BORER DEVELOPMENT

In 2017, 252 degree d already had accumulated near the field sites by 28 Feb; the majority (85%) of emerald ash borer collected (n = 59) had developed to the pupal stage. In 2018 and 2019, a combination of earlier log harvesting and a winter season more typical for the area led to a better reflection of emerald ash borer development prior to the onset of spring warming (harvested at 78.3 and 76.6 degree d, respectively). In both yr, more than 92% of emerald ash borer overwintered as larvae, with just a small percentage classified as J-larvae (Table 1).

Urogomphi length indicated that all collected emerald ash borer larvae fell into the range reported for the fourth instar in 2018; in 2019 all but 1 larva (n = 466) measured as fourth instar (Fig. 1). The lone exception measured 0.70 mm; however, 2 additional larvae measured at 0.75 mm, which might be interpreted as third instar according to the criteria presented by Wang et al. (2005).

PARASITOIDS ASSOCIATED WITH EMERALD ASH BORER GALLERIES

Three specimens identified as Xorides (Exomus) humeralis (Say) (Hymenoptera: Ichneumonidae) (Fig. 2E) were dissected from cocoons collected from emerald ash borer galleries in 2017 (reported in Bertone et al. 2017). In 2018, 7 adult specimens of Atanycolus cf. cappaerti Marsh and Strazanac (Hymenoptera: Braconidae) (Fig. 2D) were reared from cocoons. One specimen of Eurytoma sp. (Hymenoptera: Eurytomidae) also emerged from the collected material (Fig. 2B), but because Eurytoma is a known hyperparasitoid of Atanycolus (Cappaert & McCullough 2008), it is uncertain whether this wasp was parasitizing emerald ash borer or Atanycolus. In 2019, 6 adult specimens of Atanycolus cf. cappaerti and 1 Spathius sp. (Fig. 2C) were reared from cocoons collected from the emerald ash borer galleries. The single Spathius specimen did not match any species known (in litt. Robert Kula, USDA-SEL), including species introduced for control of emerald ash borer (S. agrili and S. gallinatae). Currently, it appears to be an undescribed species, though more specimens are needed to assess that hypothesis and formally describe the species. Three possible parasitoids of emerald ash borer collected from emergence cages awaited further study: a species of Atanycolus, a species of Wroughtonia, and the species of Spathius mentioned above. Morphologically, the Atanycolus identifies as Atanycolus cf. cappaerti, but a BLAST analysis (Basic Local Alignment Search Tool) places it closer to Atanycolus hicroiae Shenefelt (Hymenoptera: Braconidae); these 2 species are difficult to distinguish (Marsh et al. 2009).

Discussion

EMERALD ASH BORER DEVELOPMENT IN NORTH CAROLINA

Overall, our results indicate that emerald ash borer development is synchronous in north-central North Carolina, with the majority overwintering as fourth instar larvae that advance to the J-larva stage as degree d accumulate in the new yr. Although 15% of collected emerald ash borer in 2017 were classified as fourth instar larvae by measuring their urogomphi, these likely were prepupae, but not noted as such at the time of collection. Prepupae are the stage between J-larva and pupa, when the larva contracts prior to pupation; urogomphi length, however, remains the same in fourth instars, J-larvae, and prepupae. The distinction between fourth instars and prepupae is not crucial, because both are likely to develop to the emergent adult stage in early spring. On the other hand, a recent laboratory study (Jian et al. 2021) suggests that only those emerald ash borers overwintering as J-larvae emerge as adults when the growing season begins, because it is the only stage that undergoes an obligatory diapause. All other larval stages seem to require another growing season to reach adulthood. Only field sampling that continues throughout the yr will determine if this is the case in North Carolina.

A key result is that no early instars overwintered, thus supporting the idea that the different life cycle in the South may influence the timing of release of parasitoids for classical biological control and the subsequent establishment of these wasps in the southern US. It has been noted that as one moves from north to south in the US, the proportion of emerald ash borer overwintering as fourth instar larvae versus prepupae decreases until in the Deep South it reaches 0% (Jones et al. 2020). Although we acknowledge the limitations of primarily using a single sampling site in our study, proportions of the different developmental stages overwintering would depend not only on the location but the yr, because winter temperatures can vary widely in North

Table 1. Developmental stages of overwintering emerald ash borer (Agrilus planipennis) during winter in Granville County, North Carolina, ranked in order of increasing accumulated degree d on the date of tree harvest. Degree d were based on model of Duarte 2013 OSU IPPC, base 50, Version 5.52.

| Year | Date  | Degree d | Total | 3rd | 4th | Jr | Jr-pupa |
|------|-------|----------|-------|-----|-----|----|---------|
| 2019 | 5 Feb | 77.5     | 783   | 92.3| 7.7 | 0  | 0       |
| 2018 | 9 Feb | 78.1     | 84    | 95.2| 4.8 | 0  | 0       |
| 2020 | 4 Feb | 131.7    | 15    | 46.7| 53.3| 0  | 0       |
| 2017 | 28 Feb| 252.0    | 59    | 15.3| 84.7| 0  | 84.7    |

*These likely were prepupae (the stage after J-larvae, prior to pupation)
Carolina. In 2019, for example, there were 77.5 accumulated degree d on 5 Feb at our experimental site, but 131.7 degree d on 4 Feb in 2020 (Table 1).

EMERGED PARASITOIDs

Recorded hosts of *X. humeralis* in the US include *Dicerca* Eschscholtz (Coleoptera: Buprestidae) (Porter 2005), but other species of *Xorides* are reported to parasitize *Agrilus* in Michigan and Europe (Kenis & Hilszczanski 2007; Petrice & Haack 2014). Related species in the genus use emerald ash borer as hosts in China (Wei et al. 2004; Wang et al. 2016). *Wroughtonia* species are known parasitoids of Coleoptera, but may attack both Cerambycidae and Buprestidae (Taylor et al. 2012). We collected several adults of the cerambycid *Obrium rufulum* Gahan (Coleoptera: Cerambycidae) from our emergence cages, and therefore cannot be certain if *Wroughtonia* was attacking *O. rufulum*, emerald ash borer, or possibly both.

![Fig. 2.](image)

**Fig. 2.** (A) *Balcha indica* (Eupelmidae); (B) *Eurytoma* sp. (Eurytomidae); (C) *Spathius* sp. (Braconidae: Doryctinae); (D) *Atanycolus* cf. *cappaerti* (Braconidae: Bracoinae); (E) *Xorides humeralis* (Ichneumonidae: Xoridinae). Not to scale. Photographs by Matt Bertone.

*Atanycolus* is a cosmopolitan genus of solitary ectoparasitoids that attack the larvae of various wood-boring beetles (Wang et al 2009). There are at least 7 species throughout the Holarctic that use emerald ash borer as host (Taylor et al. 2012), but exact determination of *Atanycolus* species is extremely difficult (Abell et al. 2012), and individual *Atanycolus* species often attack both buprestid and cerambycid larvae (P. Marsh, personal communication). *Atanycolus cappaerti* is native to North America and appears to be the native species with most potential to have a role in managing emerald ash borer (Cappaert & McCullough 2008). It has been considered a candidate for potential mass rearing for augmentative biocontrol (Taylor et al. 2012; Duan & Schmude 2016).

In Michigan, *A. cappaerti* emerges from overwintering cocoons and attacks emerald ash borer larvae that overwinter as early instars (Cappaert & McCullough 2008). It is thought that in a univoltine host, emerging wasps have a minimal window of opportunity and may not encounter suitable hosts (second, third, and fourth instar larvae) for
most of their life span (Cappaert & McCullough 2008). It will be interesting then to see how host usage or the life history of this native parasitoid may have shifted to accommodate emerald ash borer in North Carolina, where emerald ash borer in the site we studied overwinters as late stage fourth instars, pupates in late winter or early spring, and emerges as adults shortly after. This and ongoing work will inform release decisions on future biocontrol efforts in the southern US.

Acknowledgments

We thank all cooperators who participated in felling trees, transporting logs, debarking, supplying space and equipment, or determining emerald ash borer larval instars: John Banask, Kevin Carpen- ter, Jessica Grant, Wayne Langston, Sam Larsen, Nathan LaSala, Rob Montague, James Slye, Rob Trickel, and Steve Turner. The need for an overwintering study in North Carolina was suggested by Julie Gould (USDA-APHIS).

References Cited

Abell K, Duan JJ, Bauer L, Leitio JP, Van Driesche RG. 2012. The effect of bark thickness on host partitioning between Tetrastichus planipennisi (Hymenoptera: Eulophidae) and Atanycolus spp. (Hymenoptera: Braconidae), two parasitoids of emerald ash borer (Coleoptera: Buprestidae). Biological Control 63: 320–325.

Abell K, Duan JJ, Shrewsbury PM. 2019. Determining optimal parasitoid release timing for the biological control of emerald ash borer (Coleoptera: Buprestidae). Florida Entomologist 102: 691–694.

Aukema JE, Leung B, Kovacs K, Chivers C, Britton KO, Englin J, Frankel SJ, Haight AG, Holmes TP, Liebhold AM, McCullough DG, Von Holle B. 2011. Economic impacts of non-native forest insects in the United States. PLoS One 6: e24587. https://doi.org/10.1371/journal.pone.0024587

Bauer LS, Duan JJ, Leitio JP, Liu H, Gould JR. 2015. Biology of emerald ash borer parasitoids, pp. 97–112 In Van Driesche RG, Reardon RC [eds.], Biology and Control of Emerald Ash Borer, Publication #FHTET-2014-09. US Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team, Morgantown, West Virginia, USA.

Bertone MA, Nalepa CA, Oten KL, Turner SP. 2017. Record of the hymenopteran Aukema JE, Leung B, Kovacs K, Chivers C, Britton KO, Englin J, Frankel SJ, Haight AG, Holmes TP, Liebhold AM, McCullough DG, Von Holle B. 2011. Economic impacts of non-native forest insects in the United States. PLoS One 6: e24587. https://doi.org/10.1371/journal.pone.0024587

Bauer LS, Duan JJ, Leitio JP, Liu H, Gould JR. 2015. Biology of emerald ash borer parasitoids, pp. 97–112 In Van Driesche RG, Reardon RC [eds.], Biology and Control of Emerald Ash Borer, Publication #FHTET-2014-09. US Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team, Morgantown, West Virginia, USA.

Bertone MA, Nalepa CA, Oten KL, Turner SP. 2017. Record of the hymenopteran parasitoid Xorides (Examus) humeralis (Ichneumonidae: Xoridinae) from emerald ash borer galleries (Coleoptera: Buprestidae) in North Carolina. Proceedings of the Entomological Society of Washington 119: 514–517.

Cappaert D, McCullough DG. 2008. Occurrence and seasonal abundance of Atanycolus cappaerti (Hymenoptera: Braconidae) a native parasitoid of emerald ash borer, Agrilus planipennis (Coleoptera: Buprestidae). Great Lakes Entomologist 42: 16–29.

Cappaert D, McCullough DG, Poland TM, Siegett NW. 2005. Emerald ash borer in North America: a research and regulatory challenge. American Entomologist 51: 152–165.

Chamorro ML, Volkovitch MG, Poland TM, Haack RA, Langfelter SW. 2012. Preimaginal stages of the emerald ash borer, Agrilus planipennis Fairmaire (Coleoptera: Buprestidae): an invasive pest on ash trees (Fraxinus). PlOS One 7: 12. doi:10.1371/journal.pone.0033185

Duan J, Bauer L, van Driesche R, Gould J. 2018. Progress and challenges of protecting North American ash trees from the emerald ash borer using biological control. Forests 9, 142. doi.org/10.3390/f9030142

Duan J, Schmude J. 2016. Biology and life history of Atanycolus cappaerti (Hy- menoptera: Braconidae), a North American larval parasitoid attacking the invasive emerald ash borer (Coleoptera: Buprestidae). Florida Entomologist 99: 722–728.

Duan J, Ulyshen MD, Bauer LS, Gould J, Van Driesche R. 2010. Measuring the impact of biotic factors on populations of immature emerald ash borer (Coleoptera: Buprestidae). Environmental Entomology 39: 1513–1522.

Gaudron JM, Smith SM. 2020. Augmentation of native North American natural enemies for the biological control of the introduced emerald ash borer in central Canada. BioControl 65: 71–79.

Haack RA, Liu EJ, Marchant KR, Petrice TR, Poland TM, He H. 2002. The emerald ash borer: a new exotic pest in North America. Newsletter of the Michigan Entomological Society 47: 1–5.

Hermes DA, McCullough DG. 2014. Emerald ash borer invasion of North America: history, biology, ecology, impacts, and management. Annual Review of Entomology 59: 13–30.

Hooie NA, Wiggins GJ, Lambertin PL, Grant JT, Powell SD, Leitio JP. 2015. Native parasitoids and recovery of Spathius agrili from areas of release against emerald ash borer in eastern Tennessee, USA. Biocontrol Science and Technology 25: 345–351.

Jian JJ, Schmude JM, Larson KM. 2021. Effects of low temperature exposure on diapause development, and reproductive fitness of the emerald ash borer (Coleoptera: Buprestidae): implications for voltinism and laboratory rearing. Journal of Economic Entomology 114: 201–208.

Jones MI, Gould JR, Mahon HJ, Fierke MK. 2020. Phenology of emerald ash borer (Coleoptera: Buprestidae) and its introduced larval parasitoids in the northeastern United States. Journal of Economic Entomology 113: 622–632.

Kenis M, Hiliszczanski J. 2007. Natural enemies of Cerambycidae and Bupresti- dae infesting living trees, pp. 475–498 In Lieftinck F, Day KR, Battist A, Gré- goire JC, Evans HF [eds.], Bark and Wood Boring Insects in Living Trees in Europe, a Synthesis. Springer, Dordrecht, The Netherlands.

Liu H, Bauer LS, Gao R, Zhao T, Petrice TR, Haack RA. 2003. Exploratory survey for the emerald ash borer, Agrilus planipennis (Coleoptera: Buprestidae), and its natural enemies in China. The Great Lakes Entomologist 36: 191–204.

Marsh PM, Stranac JS, Laurusonis SY. 2009. Description of a new species of Atanycolus (Hymenoptera: Braconidae) from Michigan reared from the emerald ash borer, Agrilus planipennis (Coleoptera: Buprestidae). AGRILUS planipennis (Coleoptera: Buprestidae). The Great Lakes Entomologist 42: 9. https://scholar.google.com/t/https://doi.org/10.4419/LGJ.V42.I19.0251

Orlova-Bienkowskaja M, Bienkowski A. 2016. The life cycle of the emerald ash borer Agrilus planipennis in European Russia and comparison with its life cycle in Asia and North America. Agricultural and Forest Entomology 18: 182–188.

Petrice TR, Haack RA. 2014. Biology of the European oak borer in Michigan, United States of America, with comparisons to the native twolined chestnut borer. The Canadian Entomologist 146: 36–51.

Porter CC. 2005. New records of Xorides (Hymenoptera: Ichneumonidae: Xoridi- nae) from Florida. Insecta Mundi 19: 187–190.

Taylor PB, Duan JJ, Fuertes RW, Hoddle M, Van Driesche R. 2012. Parasitoid guilds of Agrilus woodborers (Coleoptera: Buprestidae): their diversity and potential for use in biological control. Psyche: A Journal of Entomology 2012: 813929. doi.org/10.1155/2012/813929

USDA-APHIS. 2015. Field release of the parasitoid Spathius galinae for the bio- logical control of the emerald ash borer (Agrilus planipennis) in the contiguous United States. Environmental Assessment, March 2015. https://www. google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=2ah_UK&url=http%3A%2F%2Fwww.aphis.usda.gov%2Fplant_health%2Fpages%2F2015%2Fspathius-galinae-eab-biocontrol.pdf&usg=AOvVaw14YV1-Ltb46R7ioFejROU (last accessed 8 Apr 2021).

Wang Y-P, Shi M, Chen X-X, He J-H. 2009. The genus Agrilus (Coleoptera: Buprestidae) in China. Journal of Economic Entomology 47: 636–642.

Yang Z-Q, Strazanac JS, Marsh PM, Van Achterberg C, Choi W-Y. 2005. First record of parasitoids from areas of release against emerald ash borer (Coleoptera: Buprestidae): a new species of Spathius (Hymenoptera: Braconidae: Doryctinae). Annals of the Entomological Society of America 98: 636–642.