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ARTICLE

North American hymenopteran parasitoids of emerald ash borer larvae: seasonal abundance and interaction with introduced Asian parasitoids

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Abstract

In Michigan, United States of America, where Asian parasitoids were released to manage emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), we monitored four native parasitoids that also attack the invasive beetle – *Atanycolus cappaerti* Marsh and Strazanac, *A. simplex* (Cresson), and *Spathius laflammei* Provancher (all Hymenoptera: Braconidae), and *Phasgonophora sulcata* Westwood (Hymenoptera: Chalcididae) – using yellow pan traps and tree dissections. Adult *A. cappaerti,* followed by *A. simplex*, had the broadest seasonal activity, *S. laflammei* was captured primarily in the first half of the growing season, and *P. sulcata* was restricted to mid-summer. Adult abundances of native species varied among years but, except for *P. sulcata*, were never significantly lower than the established Asian emerald ash borer larval parasitoids, *Tetrastichus planipennisi* Yang (Hymenoptera: Eulophidae) and *Spathius galinae* Belokobylskij and Strazanac (Hymenoptera: Braconidae). Densities of emerald ash borer larvae parasitised by *A. cappaerti* or *P. sulcata* did not differ significantly from those of the two Asian species. Although adult *A. simplex* and *S. laflammei* were frequently captured, we did not confirm parasitisation of any emerald ash borer larvae by these two species, suggesting that they rarely attack emerald ash borer. We did not find any negative correlations between adult or immature parasitoid abundance of any parasitoid species, suggesting that any interspecific competition that may be occurring is negligible.

Introduction

Emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), has killed hundreds of millions of ash trees, *Fraxinus* spp. (Oleaceae), in North America since it was discovered in 2002 (Haack *et al.* 2002; Herms and McCullough 2014). Emerald ash borer has spread throughout much of eastern North America, with isolated populations established as far west as Oregon in the United States of America, and British Columbia in Canada. With the aim of reducing the impacts of emerald ash borer on North America's ash resources, a classical biological control programme was initiated in 2007 as part of a long-term emerald ash borer management strategy (Liu *et al.* 2003; Bauer *et al.* 2015a; Duan *et al.* 2022, 2023a).

*Retired

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To date, the Asian larval parasitoids, *Spathius agrili* Yang (Hymenoptera: Braconidae), *Spathius galinae* Belokobylskij and Strazanac (Hymenoptera: Braconidae), and *Tetrastichus planipennisi* Yang (Hymenoptera: Eulophidae), and the egg parasitoid, *Oobius agrili* Huang and Zhang (Hymenoptera: Encyrtidae), from emerald ash borer's native range have been approved for release against emerald ash borer in the United States of America (Bauer *et al.* 2015a; Duan *et al.* 2018) and Canada (Canadian Food Inspection Agency 2024). Post-release studies have confirmed that *O. agrili*, *S. galinae*, and *T. planipennisi* have established and persist in many areas of the upper midwestern and northeastern United States of America (Duan *et al.* 2023a, 2023b) and in some areas of Ontario and Québec, Canada (Butler *et al.* 2022; MapBioControl 2024). *Spathius agrili* has failed to establish in northern climates of North America, and releases of this species are now restricted to areas with warmer climates below 40° latitude (Bauer *et al.* 2015a; Duan *et al.* 2022).

Studies over the last two decades also document several native North American hymenopteran species parasitising emerald ash borer larvae (Liu *et al.* 2003; Cappaert and McCullough 2009; Taylor *et al.* 2012; Duan *et al.* 2013; Hooie *et al.* 2015; Roscoe *et al.* 2016). Many of these species are known parasitoids of North American *Agrilus* species and include members of the braconid genera *Atanycolus*, *Leluthia*, and *Spathius* (Hymenoptera: Braconidae); the chalcidid genus *Phasgonophora* (Hymenoptera: Chalcididae); the eupelmid genus *Eupelmus* (Hymenoptera: Eupelmidae); and the ichneumonid genera *Cunocephalus* (not confirmed) and *Dolichomitus* (Hymenoptera: Ichneumonidae). In addition, the adventive species, *Balcha indica* Mani and Kaul (Hymenoptera: Eupelmidae), also attacks emerald ash borer larvae (Liu *et al.* 2003; Duan *et al.* 2013; Bauer *et al.* 2015b). The native species most frequently documented to parasitise emerald ash borer include *Atanycolus cappaerti* Marsh and Strazanac (Hymenoptera: Braconidae), *Phasgonophora sulcata* Westwood (Hymenoptera: Chalcididae), and multiple *Spathius* species. Both *Atanycolus* and *Spathius* species primarily attack third- and fourth-instar emerald ash borer larvae (emerald ash borer has four larval instars), and *P. sulcata* attacks early-instar larvae (Duan *et al.* 2013; Duan and Schmude 2016; Roscoe *et al.* 2016).

Emerald ash borer parasitism by native larval parasitoids has been highly variable but generally low, *e.g.*, less than 1–5% (Liu *et al.* 2003; Duan *et al.* 2009, 2010, 2013). However, some studies have documented similar emerald ash borer parasitism rates to those of introduced emerald ash borer–larval parasitoids. For example, Cappaert and McCullough (2009) reported emerald ash borer parasitism by *A. cappaerti* as high as 71% at one site in Michigan, United States of America, and Duan *et al.* (2015) reported average parasitism by *Atanycolus* spp. as high as 62% across six sites in Michigan. Also, Roscoe *et al.* (2016) observed emerald ash borer–larval parasitism by *P. sulcata* as high as 34% at a site in Ontario, Canada. Factors affecting the variability in emerald ash borer parasitism rates by native parasitoids species are unclear.

Long-term management of emerald ash borer using biological control requires a better understanding of the variability in emerald ash borer–larval parasitism contributed by native hymenopteran species. Although the studies cited above reported emerald ash borer parasitism rates from native parasitoids, few have examined adult parasitoid seasonal abundance, which would affect their synchrony with susceptible emerald ash borer–larval stages. It is also unclear if interspecific competition between introduced Asian and native larval parasitoids occurs at sites where they coexist. Therefore, we conducted studies with the objective of determining the seasonal abundance of several native hymenopteran parasitoid species that attack emerald ash borer larvae. We also examined relationships in abundance between native emerald ash borer parasitoids and the Asian larval parasitoids, *S. galinae* and *T. planipennisi*. To accomplish this, we collected parasitoid adults throughout the growing season over a four-year period (2016–2019) using yellow pan traps placed on ash trees at sites where emerald ash borer and Asian parasitoids were established. We also debarked infested ash trees to estimate densities of emerald ash borer larvae parasitised by each species. Information gathered as part of this study will be useful for further investigation of the potential impacts of native hymenopteran parasitoids on emerald ash borer population dynamics and their interactions with introduced Asian emerald ash borer parasitoids.

Methods

During 2016–2019, we monitored emerald ash borer–larval parasitoid activity and abundance using yellow pan traps and tree dissections at three sites in south-central Michigan, United States of America (Gratiot-Saginaw State Game Area in Gratiot County, and Harris Nature Center and Legg Park in Ingham County), where *T. planipennisi* was first released in 2008 and where *S. galinae* was released in 2015. These stands were composed of mixed hardwoods with *Fraxinus* as a major component. Detailed information on parasitoid release and establishment histories for these three sites can be found in Petrice *et al.* (2023) and MapBioControl (2024).

Yellow pan traps were constructed following instructions provided in the Emerald Ash Borer Biocontrol Guidelines (United States Department of Agriculture, Animal and Plant Health Inspection Service – Agricultural Research Service – Forest Service 2021). Traps were placed on the south side of ash trees, 1.75 m above the ground. A solution of 50% food-grade propylene glycol (ChemWorld.com, Taylor, Michigan, United States of America) and 50% water was added to the nested bowl to kill and preserve trapped insects. We added approximately 5 mL/L of unscented dish soap to the solution to reduce surface tension. Samples were collected once every two weeks in 2016 and once every week in 2017–2019. In 2016, we placed yellow pan traps on live ash trees that showed evidence of recent emerald ash borer attack (*e.g.,* fresh woodpecker feeding holes, epicormic sprouts, and/or canopy dieback) within a 0.25-ha plot at each study site. The number of traps per site varied between 12 and 28, depending on the number of ash trees with recent emerald ash borer attack that were present. In 2017–2019, we placed 10 yellow pan traps on live ash trees within the same plots on trees with evidence of recent emerald ash borer attack. Sample trees ranged from 5.0 to 30.3 cm in diameter at breast height (DBH, 1.37 m above ground). Adult parasitoids were identified using species keys, illustrations, and descriptions from the following resources: Yang *et al.* (2006), Marsh and Strazanac (2009), Marsh *et al.* (2009), and Belokobylskij *et al.* (2012).

In fall 2016 and 2017 and in early spring 2019, we felled and dissected 4–5 small ash trees per site that ranged between 8.0 and 15.6 cm DBH to recover emerald ash borer larvae parasitised during the 2016, 2017, and 2018 growing seasons, respectively. In addition, we felled and dissected 10 sapling-sized ash trees (range: 2.6–5.8 cm DBH) at each site in early spring 2019. Emerald ash borer larvae from the 2019 growing season were not sampled in spring 2020 due to COVID-19 restrictions. Trees and saplings selected for dissection had evidence of recent emerald ash borer attack (*i.e.,* woodpecker feeding holes, bark splits, and/or epicormic sprouts) and were within 50 m of the 0.25-ha plots used for yellow pan trap sampling.

Trees were dissected with a draw knife by removing the bark from the entire stem and all branches that were larger than 2.5 cm in diameter. The number of emerald ash borer larvae attacked by each parasitoid genus was recorded. Immature parasitoids were identified based on larval morphology and parasitoid biology. For example, *Tetrastichus* are gregarious endoparasitoids that exit their host when mature and form exarate pupae (Bauer *et al.* 2015b). *Spathius* are gregarious ectoparasitoids that spin silken cocoons where they will later pupate (Bauer *et al.* 2015b). *Atanycolus* are solitary ectoparasitoids that also spin silken cocoons when mature (Cappaert and McCullough 2009; Duan and Schmude 2016). *Phasgonophora sulcata* is a solitary endoparasitoid that attacks early-instar larvae and lives in the host's haemolymph until the host completes diapause (Roscoe *et al.* 2016).

To determine if emerald ash borer larvae were parasitised by *P. sulcata*, all larvae without external signs of immature parasitoids were dissected in the laboratory. We reared all undamaged immature parasitoids in the laboratory, and adults that successfully emerged were used to confirm parasitoid species identifications. We calculated immature parasitoid brood densities by dividing the number of emerald ash borer larvae parasitised by each genus or species by the total ash phloem surface area dissected for each site and year to standardise parasitised emerald ash borer–larval densities. Phloem area for each tree or sapling was calculated using models described in McCullough and Siegert (2007).

Data analysis

Seasonal abundance of adults. Data for growing degree-days (base 10 °C; GDD_{10}; Baskerville–Emin method, start date = 1 January) were downloaded from the nearest weather station for each study site (Michigan State University Enviroweather 2024). Weather stations selected were within 10 km of each study site. To improve visual interpretation of seasonal abundance of parasitoid species, we averaged the GDD_{10} accumulation across sites each year because study sites were within 60 km of one another, the difference in daily GDD_{10} accumulation ranged from only 19 to 28 GDD_{10} among sites each year, and weekly trap collections occurred on the same day or no more than two days apart. We then plotted the summed adult captures of each parasitoid species across all three sites against the average accumulated GDD_{10} for each sample week and year.

Comparison of adult and larval parasitoid abundance. Abundance of adult and immature parasitoids were compared among all parasitoid species using a generalised linear mixed model (GLMM, PROC GLIMMIX; SAS Institute 2012) with a gamma distribution. The gamma distribution provided the best model fits based on visual inspections of residuals and Shapiro–Wilk tests. Levene's tests were used to confirm homogeneity of variances. Models included parasitoid species, year, and the interaction between them as fixed effects and site as random effect. When interactions were significant between parasitoid species and year, models were run separately for each year. Degrees of freedom were calculated using the Kenward–Rodger method. Estimated marginal means that were significantly different ($P < 0.05$) were separated using the Tukey–Kramer means comparison procedure. In addition, we examined the data for correlations in abundance among native and Asian parasitoid species for both adult and immature life stages using Pearson's correlation analysis (PROC CORR; SAS Institute 2012).

Results

Adult parasitoid abundance

We identified five native parasitoid species from yellow pan trap captures that were previously reported as attacking emerald ash borer larvae. For each of these species, the total adult captures and GDD_{10} range for all sites and years were as follows: *A. cappaerti* – 75 individuals; 264–1595 GDD_{10}; *Atanycolus simplex* (Cresson) – 58; 264–1376; *P. sulcata* – 21; 653–1209; *Spathius laflammei* Provancher – 322; 184–1485; and *Spathius floridanus* Ashmead –2; 477–1294 (Fig. 1). We did not include *S. floridanus* in seasonal abundance or species abundance analyses due to the low number captured. For the two Asian larval parasitoids, total adult captures and GDD_{10} range were as follows: *T. planipennisi* – 161 individuals; 119–1549 GDD_{10}; and *S. galinae* – 59; 264–1535 (data not shown).

Adult parasitoid abundance varied significantly among species ($df = 5{,}46$; $F = 10.73$; $P < 0.0001$) and year ($df = 3, 46$; $F = 18.20$; $P < 0.0001$), with annual variation in the abundance of given parasitoid species (species × year interaction: $df = 15{,}46$; $F = 3.12$; $P = 0.002$). Because of the significant interaction between species and year, we compared abundance among parasitoids separately for each year. In 2016, *S. laflammei* had the highest adult abundance ($df = 5{,}10$; $F = 10.29$; $P = 0.001$), *S. galinae* the lowest, and the remaining species had intermediate abundance. Adult parasitoid abundance in 2017 was significantly higher for

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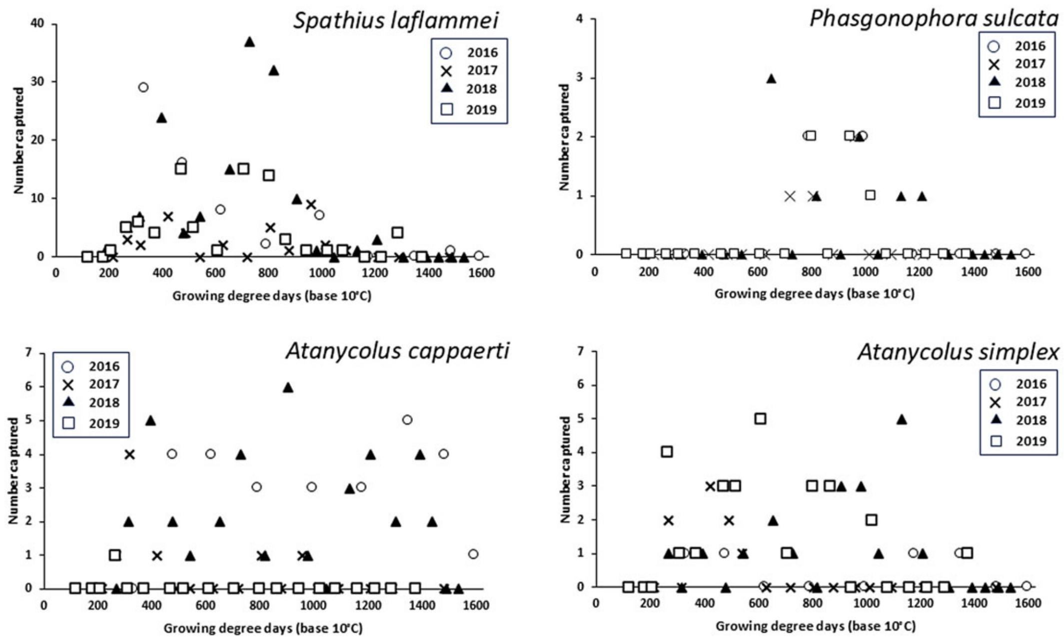

Figure 1. Adult parasitoid abundance of native emerald ash borer parasitoid species captured in yellow pan traps as a function of growing degree-days (base 10 °C; start date = 1 January) by sample year. Yearly data were pooled for three sites (12–28 traps per site in 2016, and 10 traps per site in 2017–2019) in Michigan, United States of America.

T. planipennisi than for *P. sulcata* ($df = 5{,}10$; $F = 4.60$; $P = 0.019$; Fig. 2). In 2018, abundance was significantly higher ($df = 5{,}12$; $F = 2.84$; $P = 0.069$) for *S. laflammei* than for *P. sulcata*, and abundances of the other species were intermediate (Fig. 2). Adult abundance in 2019 was significantly higher ($df = 5{,}12$; $F = 5.58$; $P = 0.007$) for *S. laflammei* than for *A. cappaerti*, and abundances of the other species were intermediate (Fig. 2).

Significant positive correlations in adult captures were revealed between *A. cappaerti* and *P. sulcata* ($P = 0.019$, $R = 0.664$), *A. cappaerti* and *T. planipennisi* ($P = 0.004$, $R = 0.768$), *P. sulcata* and *T. planipennisi* ($P = 0.001$, $R = 0.818$), and *S. laflammei* and *S. galinae* ($P = 0.001$, $R = 0.812$; Table 1). No significant negative correlations were found between adult captures of any parasitoid species (Table 1).

Immature parasitoid abundance

For immature parasitoids that were reared to adult from tree dissections, all immature *Spathius* that successfully eclosed were *S. galinae* adults, all *Atanycolus* were *A. cappaerti*, and all *Tetrastichus* were *T. planipennisi*. Immature *P. sulcata* (the only species in this genus in North America) dissected from emerald ash borer larvae were confirmed using characters described in Roscoe (2014). Therefore, we assumed that all immature parasitoids in these four genera represented these four respective species.

The density of parasitoid broods did not vary significantly among species ($df = 3{,}22$; $F = 1.51$; $P = 0.240$) or year ($df = 2{,}22$; $F = 1.02$; $P = 0.377$), but their abundances differed annually (species × year interaction: $df = 6{,}22$; $F = 3.91$; $P = 0.008$). Because significant interaction occurred between year and species, we compared immature parasitoid densities separately for each year. In 2016, density of immature parasitoids was significantly lower ($df = 3, 6$; $F = 7.11$; $P = 0.021$) for *S. galinae* than for *A. cappaerti*, *P. sulcata*, and *T. planipennisi*. Density of immature parasitoids did not vary significantly among species in 2017 ($df = 3{,}6$; $F = 1.12$; $P = 0.411$) or 2018 ($df = 3{,}6$; $F = 0.84$; $P = 0.518$; Fig. 3). *Atanycolus cappaerti* and *P. sulcata* parasitoid brood densities had a significant positive correlation ($P = 0.002$, $R = 0.795$; Table 2). Correlations of parasitoid brood densities between other species were not significant (Table 2).

Discussion

Several native North American hymenopteran parasitoid species have been documented as attacking emerald ash borer. We monitored the seasonal abundance of four of these native species and the correlation of their abundance with introduced emerald ash borer parasitoids. The seasonal abundance among native species varied, but generally the seasonal activity period was broader for species of *Spathius* and *Atanycolus* than for *Phasgonophora sulcata*. No negative correlations were found between adult or immature parasitoid abundance of any native or introduced Asian larval parasitoid species. In fact, some species were positively correlated, suggesting that they were attracted to the same host resource, but impacts of exploitative competition were minimal.

Of the species collected during our study, *S. laflammei* was frequently the most abundant parasitoid species captured in yellow pan traps. Interestingly, adult abundance of *S. laflammei* was positively correlated with its congener, *S. galinae*. To date, *S. laflammei* parasitism of emerald ash borer has been reported only by Duan *et al.* (2013). During their study, *S. laflammei* field parasitism of emerald ash borer larvae was low; however, this species frequently attacked emerald ash borer larvae in laboratory exposures (Duan *et al.* 2013). It is unclear why *S. laflammei* adult abundance was among the highest of all parasitoids in the present study, even though we never recovered it from emerald ash borer larvae. Given this, it is likely that *S. laflammei* prefers its native host(s) and attacks emerald ash borer larvae rarely and incidentally when *S. laflammei* females are searching for native host species in dying or dead ash trees. Native hosts of

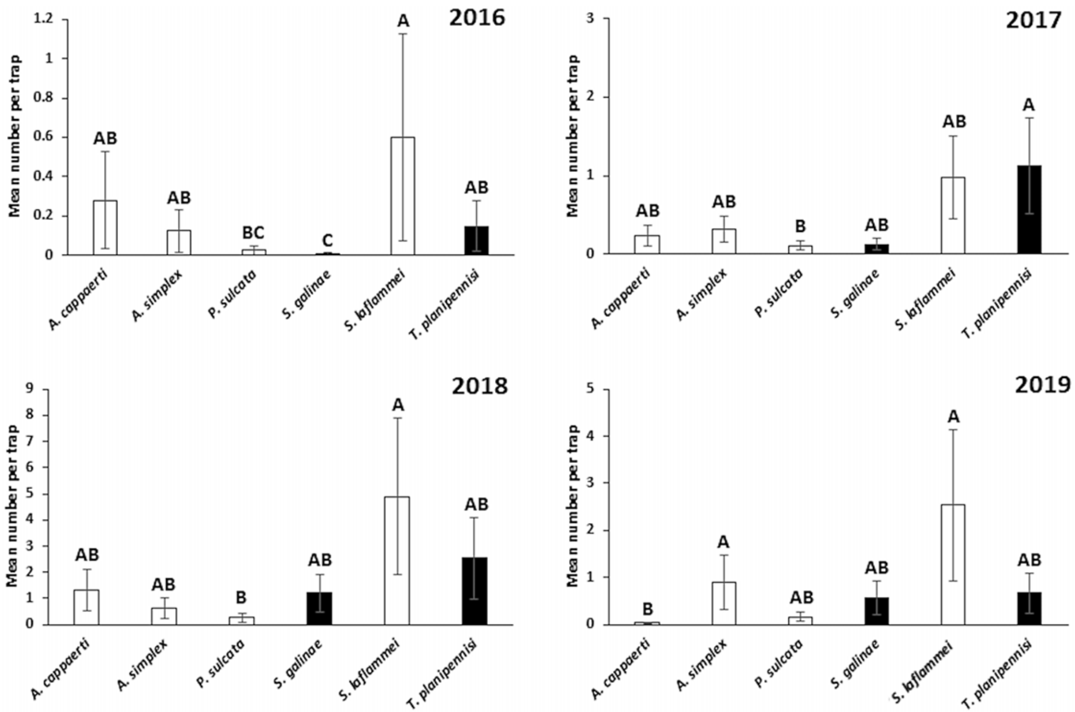

Figure 2. Comparison of mean (± standard error) adult abundance among native (white bars) and Asian (black bars) emerald ash borer parasitoid species captured in yellow pan traps. Bars with different letters differ significantly. Data were analysed using a generalised linear mixed model with a gamma distribution followed by Tukey–Kramer multiple comparison of estimated marginal means, $P < 0.05$, N = 3 sites. Estimated marginal means shown.

Table 1. Correlation matrix showing the *P*-value (*P*) and correlation coefficient (R) comparing abundance of adult parasitoid species (Asian species highlighted grey) captured in yellow pan traps. Correlations that were significant are displayed in bold; Pearson's correlation analysis, N = 3 sites

	Atanycolus cappaerti		*Atanycolus simplex*		*Phasgonophora sulcata*		*Spathius galinae*		*Spathius laflammei*	
	P	R	*P*	R	*P*	R	*P*	R	*P*	R
Atanycolus simplex	0.608	0.165								
Phasgonophora sulcata	**0.019**	**0.664**	0.606	0.166						
Spathius galinae	0.409	0.263	0.061	0.556	0.936	0.026				
Spathius laflammei	0.170	0.424	0.530	0.201	0.777	0.092	**0.001**	**0.812**		
Tetrastichus planipennisi	**0.004**	**0.768**	0.355	0.293	**0.001**	**0.818**	0.474	0.229	0.971	0.012

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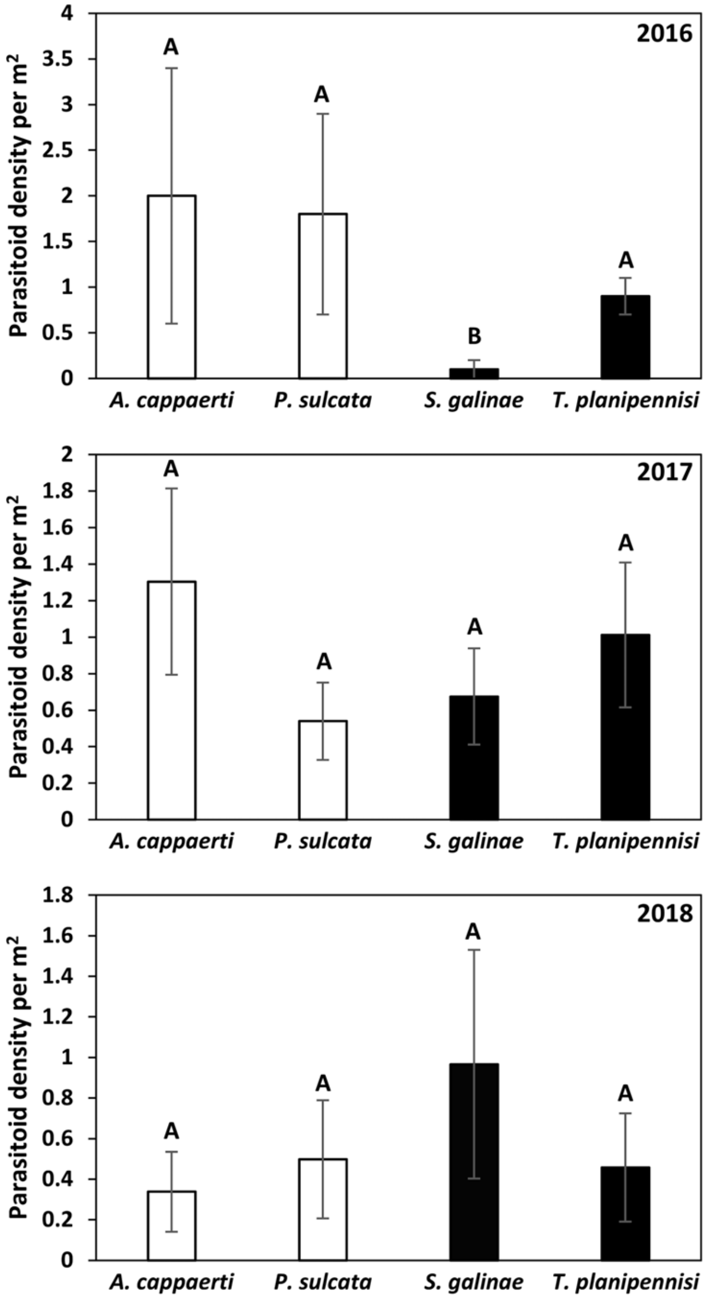

Figure 3. Comparison of mean (± standard error) immature parasitoid brood densities in ash trees among native (white bars) and Asian (black bars) emerald ash borer parasitoid species. Bars with different letters are significantly different. Data were analysed using a generalised linear mixed model with a gamma distribution followed by Tukey–Kramer multiple comparison of estimated marginal means, $P < 0.05$, $N = 3$ sites. Estimated marginal means shown.

S. laflammei include several species in the coleopteran families Cerambycidae and Curculionidae (Marsh and Strazanac 2009). During the present study, *S. laflammei* was captured mostly at or before mid-summer, and it is unclear whether *S. laflammei* is univoltine or multivoltine. Nevertheless, we suspect that the seasonal abundance of *S. laflammei* was influenced by the

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Table 2. Correlation matrix showing the *P*-value (*P*) and correlation coefficient (R) comparing densities of immature parasitoid brood densities between species (Asian species highlighted in grey). Correlations that were significant are displayed in bold; Pearson's correlation analysis, N = 3 sites

	Atanycolus cappaerti		*Phasgonophora sulcata*		*Spathius galinae*	
	P	R	*P*	R	*P*	R
Phasgonophora sulcata	**0.002**	**0.795**				
Spathius galinae	0.784	−0.089	0.913	0.035		
Tetrastichus planipennisi	0.850	0.061	0.921	−0.032	0.581	−0.177

phenology of its native host(s), given that it was less abundant later in the growing season when late-instar emerald ash borer larvae are most abundant.

Atanycolus cappaerti was intermediately abundant among the native parasitoids that were recovered. Adult captures occurred throughout the growing season without consistent trends in seasonal abundance. This was similar to the *S. galinae* and *T. planipennisi* adult seasonal abundances reported by Petrice *et al.* (2023). Similarly to those two Asian parasitoids, *Atanycolus cappaerti* is a multivoltine species, but a proportion of each generation enters obligatory diapause (Cappaert and McCullough 2009; Duan and Schmude 2016). In the present study, the density of emerald ash borer larvae parasitised by *A. cappaerti* was highly variable among sites and years but did not significantly differ from the density of the Asian larval parasitoid species, except for being higher than *S. galinae* in 2016. This difference in 2016 was likely due to the more recent release of *S. galinae* at our study sites, beginning in 2015, compared to the *T. planipennisi* releases, which occurred between 2008 and 2009 (Duan *et al.* 2013; Petrice *et al.* 2023). There is a strong potential for exploitative competition between *A. cappaerti* and *S. galinae* because both are ectoparasitoids that attack similar-sized hosts in similar-sized trees (Abell *et al.* 2012; Duan *et al.* 2021). However, as *S. galinae* abundance increased over time at our study sites, we did not see any significant negative correlations in adult or immature parasitoid abundance between these two species.

Atanycolus simplex adults were also intermediately abundant during our study, with most adult captures more restricted to the first half of the growing season than was observed for *A. cappaerti*. However, we did not confirm *A. simplex* parasitising any emerald ash borer larvae during the present study. Although the literature has reported *A. simplex* attacking emerald ash borer, it is not clear from published studies if this parasitoid–host relationship was confirmed or if *A. simplex* was reared from ash logs that contained emerald ash borer larvae but possibly other wood borers as well. According to Krombein *et al.* (1979), hosts of *A. simplex* include the buprestids *Agrilus bilineatus* (Weber) and *Chrysobothris* spp. (both Coleoptera: Buprestidae) and the cerambycids: *Phymatodes aereus* (Newman), *Rhagium inquisitor* (Linnaeus), *Saperda discoidea* Fitch, Olivier, and *Xylotrechus nauticus* (Mannerheim) (all Coleoptera: Cerambycidae). Given this relatively broad host range, it seems plausible that *A. simplex* would parasitise emerald ash borer larvae, but the failure to confirm this during the present study suggests that if these attacks occur, they are infrequent.

Although *P. sulcata* was often the least frequently recovered adult native emerald ash borer parasitoid in yellow pan traps in the present study, densities of emerald ash borer larvae parasitised by *P. sulcata* were similar to those of emerald ash borer larvae parasitised by the other species that were confirmed to be attacking emerald ash borer larvae. Gaudon *et al.* (2020) also reported low trap recoveries of adult *P. sulcata* with yellow pan traps. *Phasgonophora sulcata* also had the shortest period of seasonal abundance of all the parasitoids we monitored. Unlike the other emerald ash borer larval parasitoids, *P. sulcata* has a univoltine or semivoltine life cycle and attacks early-instar *Agrilus* larvae. This requires *P. sulcata* adult emergence to occur just after *Agrilus* egg hatch (Haack *et al.* 1981). *Phasgonophora sulcata* are solitary endoparasitoids, and their larvae persist in the haemolymph of the host, with incremental development until the host reaches the J-larval stage, which could require two years for some emerald ash borer larvae. In the spring, after overwintering within the emerald ash borer J-larvae, parasitoids rapidly consume the host larvae and mature (Roscoe *et al.* 2016). Considering that *P. sulcata* attacks early-instar emerald ash borer larvae that continue to develop after they are parasitised, multiparasitism may occur when these larvae reach the susceptible stages (*i.e.,* third and fourth instars) for other emerald ash borer parasitoids. However, we did not find any significant negative correlations between *P. sulcata* abundance and any emerald ash borer parasitoid species we monitored, suggesting that if multiparasitism is occurring, it is not having a significant effect on *P. sulcata* populations.

The present study confirmed that four native hymenopteran larval parasitoids that were reported to attack emerald ash borer remain in forest habitats where Asian emerald ash borer parasitoids have been established for multiple years. The seasonal abundance varied considerably among these species, depending on their voltinism, host stage attacked, and preferred host species. Densities of emerald ash borer larvae parasitised by two of these species, *A. cappaerti* and *P. sulcata*, did not significantly differ from the densities of emerald ash borer larvae attacked by two Asian larval parasitoid species. However, emerald ash borer parasitism by *S. laflammei* and *A. simplex* was not documented despite adults being abundant. It is likely that these two species prefer their native hosts and that attacks on emerald ash borer larvae therefore are rare. Moreover, no evidence of exploitative competition effects among any of these species was observed. Our results suggest that interspecific competition among EAB larval parasitoids is not negatively affecting the biological control services provided by both native and Asian parasitoid species that attack emerald ash borer.

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