



Short Communication

Influence of Trap Location in the Tree Canopy on Captures of Adventive *Trissolcus japonicus* (Hymenoptera: Scelionidae)

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Abstract

Trissolcus japonicus (Ashmead) (Hymenoptera: Scelionidae) is an egg parasitoid of the invasive Asian pest, brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae). Also native to Asia, adventive *T. japonicus* populations have been detected in North America since 2014, and are currently reported from 15 U.S. states, the District of Columbia, and two Canadian provinces. Yellow sticky cards (YSC) have proven effective for monitoring the presence, seasonal abundance, and distribution of these adventive populations. Our research has utilized YSC deployed in the midcanopy of *H. halys* host trees, following a study in which all leaves on felled tree of heaven, *Ailanthus altissima* (Mill.) Swingle, were inspected for *H. halys* egg masses, yielding eggs parasitized by *T. japonicus* only from mid- and upper-canopy leaves. However, given that other investigators have captured *T. japonicus* using YSC deployed in the lower-canopy, and that the effect of YSC placement in trees on *T. japonicus* captures had not been examined, captures of *T. japonicus* on YSC in the mid- and lower-canopy of individual *A. altissima* were compared. Traps were replaced weekly for five weeks and assessed for scelionid species. In 2020 and 2021, *T. japonicus* represented ≥53% of all Scelionidae captured, and there was not a significant effect of YSC location in the canopy on its captures. Deploying YSC at either canopy height was effective for measuring the relative abundance of *T. japonicus*, but sampling from the lower canopy substantially improved the efficiency and convenience of *T. japonicus* surveillance.

Key words: Samurai wasp, sampling, brown marmorated stink bug, yellow sticky trap

Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) is an invasive pest from Asia that was detected in North America in the late 1990s (Hoebeke and Carter 2003) and has become established or been detected in 47 U.S. states (www.stopbmsb.org), several European countries, and Chile (Leskey and Nielsen 2018). Feeding on >170 wild and cultivated hosts (Leskey and Nielsen 2018), *H. halys* caused tremendous losses to the Mid-Atlantic, U.S. tree fruit crop during its initial outbreak in 2010 (Leskey et al. 2012), and continues to threaten specialty crop production in the invaded ranges (Acebes-Doria et al. 2016, Bosco et al. 2018, Moore et al. 2019, Bergh et al. 2019, 2021). Furthermore, adults can be a significant nuisance when they invade and overwinter in buildings (Inkley 2012, Bergh and Quinn 2018, Hancock et al. 2019). Management of *H. halys*

in crops has relied on repeated applications of broad-spectrum insecticides (Kuhar and Kamminga 2017b), which have disrupted Integrated Pest Management programs and increased the incidence of secondary pest outbreaks in some systems (Leskey et al. 2012). Thus, the potential for biological control of *H. halys* has become an important research focus.

In North America, various *H. halys* life stages are attacked by a suite of native predators and parasitoids (Cornelius et al. 2016, Morrison et al. 2016, Abram et al. 2017, Dieckhoff et al. 2017), but their combined effects have not suppressed its populations adequately (Abram et al. 2017). In Asia, the egg parasitoid, *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae), is the predominant, co-evolved natural enemy of *H. halys* (Zhang et al. 2017),

and parasitism rates from *T. japonicus* of 50-90% have been reported (Yang et al. 2009, Zhang et al. 2017). *Trissolcus japonicus* from China was evaluated in quarantine in the U.S. for its potential as a classical biocontrol agent (Buffington et al. 2018). However, detections of an adventive *T. japonicus* population in Maryland, U.S. in 2014 (Talamas et al. 2015a, Herlihy et al. 2016) were followed by its detection in 15 U.S. states and Washington, DC (www.stopbmsb.org), two Canadian provinces (Abram et al. 2019), and several European countries (Sabbatini Peverieri et al. 2018, Stahl et al. 2019, Haye et al. 2020, Dieckhoff et al. 2021). Niche models suggest that *T. japonicus* may establish in many regions where *H. halys* occurs (Avila and Charles 2018), and ongoing surveillance efforts are tracking its presence and range expansion.

Initial surveys for *H. halys* egg parasitoids utilized naturally-occurring *H. halys* egg masses (Jones et al. 2014, Ogburn et al. 2016, Zhang et al. 2017) and/or sentinel *H. halys* eggs from laboratory colonies (Herlihy et al. 2016, Hedstrom et al. 2017, Holthouse et al. 2020, Tillman et al. 2020). While these are essential for generating field data on the taxa that attack *H. halys* eggs and rates of parasitism, they are not optimally efficient for parasitoid surveillance across large geographic areas, as discussed by Quinn et al. (2019a). More recently, yellow sticky cards (YSC) also have been used to track the presence, relative abundance, seasonal phenology, and distribution of *T. japonicus* (Holthouse et al. 2021, Peterson et al. 2021, Quinn et al. 2021). In Virginia, Quinn et al. (2019b) found that *H. halys* adults, nymphs, and egg masses were more abundant in the mid- and upper-canopy of *H. halys* host trees than in the lower- canopy, and that *T. japonicus* detections occurred most frequently from egg masses found in the midcanopy. Consequently, most of our sampling for *T. japonicus* in Virginia has used YSC deployed in the midcanopy of trees, presuming an improved likelihood of its detection. However, investigators in other areas have captured *T. japonicus* in YSC deployed in the lower-canopy (Holthouse et al. 2021, Peterson et al. 2021), raising the question of whether its captures are affected by trap location in the tree, an important consideration for optimization of surveillance efforts. Here, we report the results of studies in two consecutive seasons that compared *T. japonicus* captures in YSC deployed simultaneously in the lower- and midcanopy of individual host trees.

Materials and Methods

T. japonicus was sampled from individual mature, female tree of heaven, *Ailanthus altissima* (Mill.) Swingle (Sapindales: Simaroubaceae) growing in tree lines or isolated patches adjoining fruit orchards in Frederick County, VA, in which this parasitoid is well established. All trees selected for sampling had branching and foliage from the lower portion of the trunk to the top, and the mean distance between the selected trees/sites was 6.68 ± 1.64 km and 10.65 ± 1.79 km in 2020 and 2021, respectively. Following Quinn et al. (2021), sampling used a backfolding, double-sided YSC (46 × 28 cm; AlphaScents, Inc., West Linn, OR) affixed to the top of a bamboo pole suspended from a branch via a wire hook below the YSC. Deployment of YSCs in the lower- and midcanopy, respectively, utilized 1.0 m and 4.6 m poles, and the mean elevation of YSC in the lower- and midcanopy was 2.3 ± 0.14 m and 5.80 ± 0.16 m. YSC were deployed in pairs in the same tree (Fig. 1), using 5 and 7 trees in 2020 and 2021, respectively, and replaced weekly for five weeks between 16 July and 20 August, 2020 and 6 July to 10 August, 2021, spanning the period of peak seasonal abundance of *T. japonicus* in this area (Quinn et al. 2021, Dyer unpublished). The trees used in 2020 were reused the following year. Upon retrieval, YSC were inspected under



Fig. 1. Backfolding yellow sticky cards (YSC) affixed at the top of bamboo poles deployed in pairs from branches in the lower- and midcanopy of individual female *Ailanthus altissima* in Frederick County, VA, 2020 and 2021.

a dissecting microscope and all scelionid parasitoids were removed *in situ* on a small piece of the YSC for identification to species or genus, following Talamas et al. (2015b). Antennal morphology was used to determine the sex of *T. japonicus* specimens (Yang et al. 2016).

Statistical Analysis

Statistical analyses used SAS Studio 3.8 (SAS Institute 2018) with $\alpha = 0.05$. For each year, comparisons of *T. japonicus* captures between trap locations (lower- vs. midcanopy) used a generalized linear mixed model (GLMM) with Laplace method for fit and assumed a Poisson distribution. Trap location in the canopy, sampling site, and the interaction between trap location and sampling site were main effects, with sampling date as a random effect.

Results

In 2020 and 2021, respectively, 359 and 317 Scelionidae parasitoids were captured (Table 1). *Trissolcus japonicus* comprised 52.9% of all captures in 2020 and 56.5% in 2021, and its captures were female-biased in 2020 (70.0% female) and 2021 (70.4% female). Trap location in the tree canopy did not have a significant effect on weekly *T. japonicus* captures in 2020 ($P = 0.3471$, $F_{1,36} = 0.91$) or 2021 ($P = 0.0684$, $F_{1,52} = 3.46$) (Fig. 2). While *T. japonicus* was captured in all trees sampled, there was a significant effect of sampling site on captures in 2020 ($P < 0.0001$, $F_{4,36} = 19.00$) (Fig. 3) and 2021 ($P < 0.0001$, $F_{6,52} = 19.39$) (Fig. 4). There was a significant interaction between sampling site and trap location on *T. japonicus* captures in 2020 ($P < 0.0001$, $F_{4,36} = 5.43$), but not in 2021 ($P = 0.5859$, $F_{6,52} = 0.78$).

Discussion

Yellow sticky cards deployed in the lower- or midcanopy of mature *A. altissima* were equally effective for capturing the *H. halys*

Table 1. Scelionid parasitoids¹ captured in YSC deployed in the lower- and midcanopy of *Ailanthus altissima* in Frederick County, VA from 16 July to 20 August, 2020 and 6 July to 10 August, 2021

Treatment	Trissolcus					Telenomus				Gryon/Hadronotus ²	
	<i>japonicus</i>	<i>thyaetae</i>	<i>bullensis</i>	<i>euschisti</i>	<i>brochymenae</i>	<i>podisi</i>	<i>persimilis</i>	<i>cristatus</i>	spp.	spp.	
2020											
Lower- canopy	136	7	1	28	9	59	0	0	5		6
Mid-canopy	54	1	1	9	2	36	0	0	1		4
2021											
Lower- canopy	68	6	2	13	8	24	2	2	1		27
Mid-canopy	111	2	0	15	2	17	1	1	1		14

¹All parasitoid species, with the exception of *Telenomus cristatus*, have been documented attacking *H. halys* egg masses in the field (Cornelius et al. 2016, Ogburn et al. 2016, Abram et al. 2017, Dieckhoff et al. 2017).

²Talamas et al. 2021

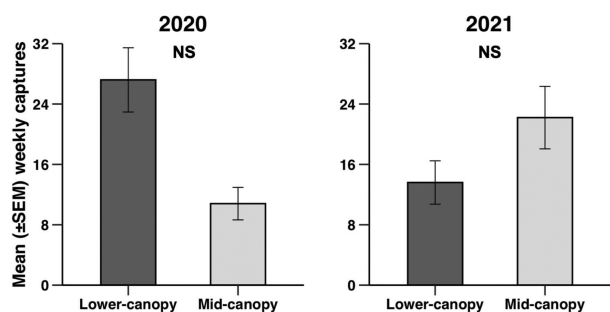


Fig. 2. Mean (\pm SEM) weekly captures of *Trissolcus japonicus* in YSC deployed in the lower- and midcanopy of individual *Ailanthus altissima* in 2020 and 2021. Traps were deployed and replaced weekly for five weeks from 16 July to 20 August, 2020 and from 6 July to 10 August, 2021. Comparisons used a generalized linear mixed model with Laplace method for fit and assumed a Poisson distribution. NS indicates no significant difference between trap locations at $P < 0.05$.

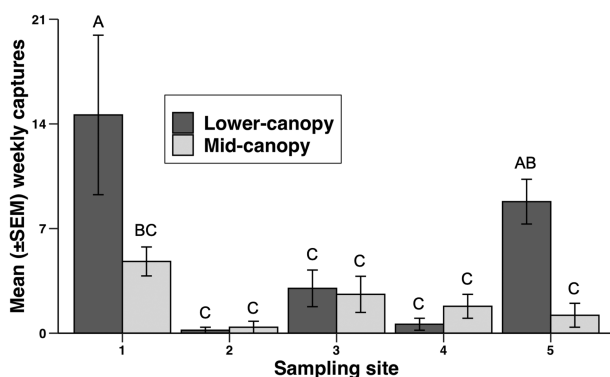


Fig. 3. Mean (\pm SEM) weekly captures of *Trissolcus japonicus* in YSC across sampling sites in 2020. Comparisons used a generalized linear mixed model with Laplace method for fit and assumed a Poisson distribution. Bars with different letter(s) indicate a significant difference at $P < 0.05$.

egg parasitoid, *T. japonicus*. This result has important implications for ongoing efforts to track its presence and range expansion, as deploying, retrieving, and replacing YSC in the lower tree canopy is much more efficient and less time-consuming than at higher elevations in the tree. While the use of YSC for surveillance is more time-efficient than sentinel eggs (Quinn et al. 2019a), placing them in the midcanopy of trees has attendant drawbacks. When attached atop a 4.6 m bamboo pole, YSC must be carefully manipulated to

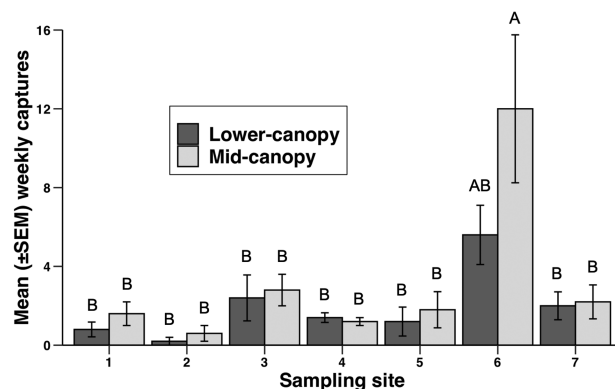


Fig. 4. Mean (\pm SEM) weekly captures of *Trissolcus japonicus* in YSC across sampling sites in 2021. Comparisons used a generalized linear mixed model with Laplace method for fit and assumed a Poisson distribution. Bars with different letter(s) indicate a significant difference at $P < 0.05$.

avoid entanglement with leaves, especially during windy conditions, which also may occasionally lead to the poles being dislodged during the sampling interval. These issues were largely mitigated by placing YSC atop short poles on branches in the lower- canopy, and yielded detections of *T. japonicus* and other *H. halys* parasitoids that were equivalent to those in midcanopy.

Although Quinn et al. (2019b) reported that *H. halys* egg masses and egg masses parasitized by *T. japonicus* were most abundant in the midcanopy of felled *A. altissima*, other studies using visual surveys from the ground have reported *H. halys* egg masses that were presumably in the lower portion of tree canopies (Bakken et al. 2015, Formella et al. 2020). Given that female *T. japonicus* use host-associated olfactory cues for host location, recognition, and acceptance (Zhong et al. 2017, Boyle et al. 2020, Malek et al. 2021), results from the present study suggest that it forages throughout the canopy, or at least is attracted to the visual cue from YSC from various locations in the canopy. Many insects are attracted to the color yellow (Prokopy and Owens 1983), including Scelionidae (Ferreira Santos de Aquino et al. 2012). While neither the distance over which *T. japonicus* responds to YSC nor the relative strength of its response to YSC versus host cues is known, it appears that YSC are a sensitive tool for monitoring this species.

In Utah and Pennsylvania, respectively, Holthouse et al. (2021) and Peterson et al. (2021) reported *T. japonicus* detections using YSC in the lower tree canopy, although in both studies it represented

a small percentage of total Scelionidae captures. Similarly, sampling in Frederick County, VA in 2016 and 2017 yielded relatively few *T. japonicus* in YSC (Quinn et al. 2019a). Given that this species was first detected in Frederick County, VA, in 2015, the data from Quinn et al. (2019a) may have reflected an adventive population early in its establishment. Indeed, total *T. japonicus* captures across the 2018 and 2019 seasons were 101 and 104, respectively (Quinn et al. 2021), and despite only 5 weeks of sampling per year in the present study, >170 *T. japonicus* were captured each year, representing over half of all Scelionidae captures. Moreover, other studies in Frederick County in 2020 and 2021 yielded 180 and 389 *T. japonicus* in YSC, respectively (Dyer, unpublished), and as in the present study, captures at all sampling sites. Thus, it is apparent that the adventive *T. japonicus* population in this area has persisted, appears to have increased in relative abundance, and is widely distributed, potentially boding well for its impact on *H. halys* populations.

While mean weekly *T. japonicus* captures were not significantly different in either year of the present study, significant differences among sites/trees were observed in both years, with a significant interaction between site and YSC location in 2020. Interestingly, the two sites at which there was a significant effect of YSC location in 2020 were those with greatest *T. japonicus* captures. In both cases, captures were significantly greater in the lower-canopy, but this effect was not observed at the same sites in 2021. It seems highly plausible that the YSC with highest *T. japonicus* captures in 2020 (>20 in a single week) were in close proximity to a parasitized egg mass, and Quinn et al. (2019a) reported a similar finding. Thus, site-specific factors appear to have had a stronger influence on *T. japonicus* captures than trap location in the tree canopy, possibly related to differences in *H. halys* density. These results were based exclusively on sampling from *A. altissima*, but Quinn et al. (2021) found that *T. japonicus* captures in several common tree hosts of *H. halys* were not affected by tree species or by the habitat in which *A. altissima* were sampled (i.e. thin tree lines, forest edge, isolated patches). In summary, deploying YSC in the lower canopy of *A. altissima*, or presumably other *H. halys* host trees, can improve the efficiency and convenience of this sampling tactic for generating information on the presence, relative abundance, distribution, and range expansion of adventive *T. japonicus*.

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