Comparison of Monitoring Systems and Temporal Activity Patterns for Spotted-Wing Drosophila (Diptera: Drosophilidae): Implications for Integrated Pest Management[1]

Dominique N. Ebbenga[2], Suzanne J. Wold-Burkness, Wayne H. Wold, Eric C. Burkness, and William D. Hutchison

Department of Entomology, University of Minnesota, St. Paul, Minnesota 55108, USA

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Abstract Spotted-wing drosophila, *Drosophila suzukii* (Matsumura), is a significant, global invasive species first confirmed in the United States in 2008. Since the first detection in Minnesota in 2012, *D. suzukii* rapidly became a major economic pest of berry crops in the state. Effective monitoring of adult *D. suzukii* populations is a crucial aspect of developing integrated pest management (IPM) programs for at-risk crops. *Drosophila suzukii* monitoring research was conducted in 2016 and 2017 to better understand the effectiveness of two commercially available trapping systems for early detection of adults in spring and how mean trap catches compared over time. In addition, using the Scentry trap, we assessed the impact of lure age on trap performance. Finally, a study was conducted to better understand the diurnal activity pattern for adult *D. suzukii* under Minnesota summer conditions. Results comparing the trapping systems indicated each system varied in its ability to detect first catch of *D. suzukii* but that both commercial traps/lures were effective. The lure age study showed that lures can be changed less frequently than initially suggested. Temporal activity studies, as measured by trap catch via Scentry traps, indicated that adult *D. suzukii* demonstrated a crepuscular activity pattern in raspberry and blueberry. The results of these studies should benefit growers as they continue to fine-tune fruit IPM programs for *D. suzukii*.

Key Words insect traps, blueberry, raspberry, vinegar fly, fruit fly

Drosophila suzukii Matsumura, an invasive species native to East Asia (Daane et al. 2016, Walsh et al. 2011), has become a significant economic problem in the stone fruit and berry crop industries in the United States. *Drosophila suzukii*, also known as spotted-wing drosophila, was first recorded in North America in 2008 (Hauser 2011). *Drosophila suzukii* was first detected in Minnesota in 2012 and since has caused severe damage to the berry and stone fruit industry (Asplen et al. 2015). For the vast majority of drosophilid species, fruit fly females will only attack over-ripe fruit, which is the case for the commonly encountered species, *Drosophila melanogaster* (Meigen). However, *D. suzukii* has the unique ability to oviposit in fruit during early stages of ripening, or when ripe (Asplen et al. 2015). This is possible via the female's unique serrated ovipositor (Atallah et al. 2014) that permits the deposition of one or more eggs per berry and the subsequent hatch of multiple

[1]Received 17 December 2021; accepted for publication 18 January 2022.
[2]Correspondence (email: ebbe0031@umn.edu).

larvae per berry (Holle et al. 2017, Jaffe and Guedot 2019). These factors contribute to rapid increases in field infestations. Subsequently, most growers continue to experience increased production costs related to insecticide use and clean-harvest labor costs for “pick your own” and fresh-market operations; in Minnesota, these additional costs have contributed to lower profits and in some cases decisions to cease production (DiGiacomo et al. 2019).

The most common monitoring tools available for *D. suzukii* integrated pest management (IPM) programs include the use of commercially available traps and lures. (Cini et al. 2012). Various attractants have been evaluated to determine the most effective components for characterizing relative *D. suzukii* pest pressure (Cha et al. 2012, 2018; Jaffe et al. 2018; Lee et al. 2012). The purpose of using traps is to allow growers to monitor when *D. suzukii* is first present during the growing season and then to monitor the relative change in populations throughout the season as the window of susceptibility of the crop begins to overlap with *D. suzukii* activity. Once the first *D. suzukii* is detected in traps, early low-level berry infestations may be present, or soon will be, depending on the availability of susceptible fruit (Asplen et al. 2015), and growers must be prepared to initiate management options in a timely fashion.

Two commercially available monitoring systems used for tracking *D. suzukii* populations are produced by Trece, Inc. (Adair, OK) and Scentry Biologicals, Inc. (Billings, MT). Both trapping systems use a four-component lure that includes different percentages of acetic acid, ethanol, acetoin, and methionol (Cha et al. 2017). The four-component lures have gained popularity not only for their consistent catch of *D. suzukii* but also because of their specificity. The number of nontarget flies is substantially reduced compared with previous monitoring systems (Cha et al. 2014). Trece traps use a Trece lure, apple cider vinegar, and a drop of soap to break surface tension on the vinegar, which creates a drowning solution for the flies. Scentry traps use their specific four-component lure, tap water, and a drop of soap to create a drowning solution. Each trap has a similar design, both are clear 946-ml plastic jars with lids, entry holes, and a hook on the lid to hang the trap. The main difference between the two designs are the entry holes, Trece uses a red plastic mesh with 3-mm holes, whereas Scentry uses a small black piece of plastic with 3-mm holes for entry.

The use of insecticides is the most widely adopted form of control (Asplen et al. 2015, Haye et al. 2016), and with this approach, certain aspects of *D. suzukii* biology must be considered. Because *D. suzukii* females lay their eggs inside the fruit (Asplen et al. 2015, Atallah et al. 2014), the eggs and subsequent larvae are effectively protected from insecticide applications; thus, only the adult stage present during insecticide application will be significantly impacted. This complication with the *D. suzukii* life cycle has led to research focusing on adult *D. suzukii* behavior and determining when adults are most active in the crop throughout a day (Jaffe and Guédot 2019). This information may allow us to fine-tune our knowledge of when pest management tactics will be most impactful. Another complication regarding the life cycle of *D. suzukii* is the short generation period. A new generation of adult flies emerging every 8–14 d (Lee et al. 2011) during temperate summer conditions creates a scenario where multiple insecticide applications are required to suppress populations. Moreover, growers must alternate currently available insecticidal modes of action (e.g., pyrethroids, organophosphates, and spinosyn-based products), to minimize the risk of developing insecticide resistance (Gress and Zalom 2018, Haye et al. 2016). Although some high-tunnel production systems with exclusion netting or the use of netting alone, have shown promise in suppression of *D. suzukii* (Ebbenga et al. 2019, Leach et al. 2016, Rogers et al. 2016), there are currently few effective alternatives to insecticides for management (Asplen et al. 2015). For organic growers, there are even fewer control options available (Bruck et al. 2011, Haye et al. 2016), although progress is being made with biological control options (Lee et al. 2019).

Studies testing the efficacy of monitoring systems for *D. suzukii*, including methodology issues such as intervals for changing lures, and knowledge of variable adult diurnal activity, can help improve management strategies for both conventional and organic growers. Continued monitoring of *D. suzukii* populations not only aids in developing management programs but also creates a historical record regarding early-season activity (dates of first catch), seasonal phenology, and daily temporal patterns. Therefore, the first objective of this study was to evaluate mean trap catch of *D. suzukii* adults between the Trece and Scentry trapping systems and to examine dates of first catch each spring. The second objective was to determine if the age of the lure for the Scentry monitoring system affects the overall mean trap catch of *D. suzukii* adult populations. Finally, the third objective was to better understand the diel periodicity of adult *D. suzukii* activity, as measured with the Scentry-based trap system.

Materials and Methods

Trap comparison study. To conduct the trap comparison study, the monitoring systems from Trece and Scentry were used. Both trapping systems use highly attractive four-component lures, and trap designs have been optimized for efficiency. Although the details of lure composition are proprietary, they likely include some of the same components and blends documented by Cha et al. (2014, 2017). One key difference between the two systems is that the Scentry trap is water based, and the Trece trap is to be used with apple cider vinegar (ACV). The study consisted of two treatments and three replicates in 2016 and four replicates in 2017. Number of replicates was selected based on the highly attractive nature of the lures and methods from previous studies using baited traps for *D. suzukii* in fruit crops (Burrack et al. 2015, Diepenbrock et al. 2016). Replicate number is also supported by more recently published studies on *D. suzukii* involving trap use by Brilinger et al. (2021), De Groot et al. (2021), and Montgomery et al. (2021). Treatments consisted of a Trece monitoring system and a Scentry monitoring system. In both years, traps were hung from a metal stake within a row of fall-bearing raspberries at the Rosemount Research and Outreach Center in Rosemount, MN (44°43′ N, 93°05′ W). In addition, another trap comparison location was established at a berry farm near Forest Lake, MN (45°13′ N, 92°53′ W) each year. Trece and Scentry traps were paired and placed in summer-bearing raspberries, blueberries, and June-bearing strawberries, creating two treatments with three replicates. In blueberries, traps were hung from a metal stake just below the plant canopy at 1 m high. Raspberry traps were hung from the trellis system wire at 1 m high, and the strawberry traps were hung on metal stakes at 1 m high immediately adjacent to the crop along a tree line.

Initial set-up for Trece traps used 90 ml ACV and a drop of soap as the drowning solution. Scentry traps used 90 ml tap water and a drop of soap as the drowning solution. Once traps were set, the drowning solution from each trap was collected and refilled weekly. After collection, samples were transferred to the laboratory in separate 118-ml jars. Trap samples were filtered through a medium nylon mesh (226 μ) paint strainer (AES Industries, Plant City, FL) to remove insects from the solution. Using a dissecting microscope (Leica EZ4W, Leica Microsystems, Buffalo Grove, IL), *D. suzukii* was identified, sexed, and counted to obtain the total number of *D. suzukii*. The date of first *D. suzukii* catch for each trap was noted.

Lure age study. In 2016 and 2017, a lure aging study was conducted at the University of Minnesota Rosemount Research and Outreach Center in Rosemount, Minnesota, USA. The Scentry trap and lure system was used to assess the impact of lure age on weekly trap catch of *D. suzukii*. Traps contained 90 ml water, with one drop of soap to break surface tension. The two treatments for this study consisted of lures being changed every 2 and 6 wk, with three replicates each. In both years, traps were set up on the 23 June and attached to the top of metals stakes at 1 m high within 8 m of a fall raspberry crop, adjacent to a tree line; each trap was spaced approximately 8 m apart.

Once traps were deployed, the contents of the traps were collected, and drowning solution was refreshed on a weekly basis until 25 August in 2016 and 21 August in 2017. Each week, all trap samples were collected in individual 118-ml jars and transported to the laboratory for processing. Trap samples were filtered through a medium nylon mesh paint strainer to remove insects from the drowning solution. Using a dissecting microscope, *D. suzukii* were identified, sexed, and counted to obtain the total number of *D. suzukii*.

Temporal activity studies. All experiments were conducted in southeastern Minnesota in Houston Co. (43°31′ N, 91°42′ W) on a commercial berry farm. *Drosophila suzukii* traps from Scentry, baited with Scentry lures, and containing a drowning solution (90 ml water plus a drop of liquid dishwashing soap) were used to monitor *D. suzukii* adult activity. Traps were hung on metal t-posts 1 m above the ground within the canopy and near fruit clusters of summer-bearing black raspberries (cultivar ‘Jewel’), and in a mixed planting of half-high and highbush blueberries (*Vaccinium* spp., primary cultivars ‘Northland’, ‘Saint Cloud’, ‘Patriot’, and ‘Duke’).

To assess adult *D. suzukii* activity, hourly sampling was conducted. In 2017, hourly trap sampling occurred from 17 to 20 July and in 2018 from 8 to 11 August. Treatment was assigned to the hourly sample time, and days were considered replicates. In 2017, there were 17 treatments starting at 6:00 a.m. and continuing until 10:00 p.m. the same day, with the overnight period of 10:00 p.m. to 6:00 a.m. the next day being a cumulative sample. In 2018, there were 10 hourly treatments from 6:00 a.m. to 10:00 p.m. and 6:00 a.m. to 10:00 p.m., with the two periods from 10:00 p.m. to 6:00 a.m. and 10:00 p.m. to 6:00 a.m. being cumulative samples due to minimal adult activity the previous year. Trapping was initiated by placing three traps, spaced 12 m apart, hung on metal t-posts in each crop at 10:00 p.m. (CST, 17 July 2017; 8 August 2018) and remained there until 6:00 a.m. the following day. Hourly sampling began at 6:00 a.m. (18 July 2017; 9 August 2018) and followed the

Table 1. Comparison of mean ± SEM weekly trap catch of adult *D. suzukii* for Scentry and Trece monitoring systems in Minnesota.*

Year	Location	Scentry (mean ± SEM)	Trece (mean ± SEM)	*F* Value	*P* Value	df
2016	Rosemount	255.06 ± 135.03	41.79 ± 28.41	20.09	<0.0001	1,4
2016	Forest Lake	833.03 ± 79.34	332.31 ± 326.00	3.93	0.05	1,4
2017	Rosemount	26.44 ± 17.15	33.46 ± 23.69	0.61	0.44	1,6
2017	Forest Lake	15.27 ± 3.06	15.56 ± 9.16	0.29	0.59	1,6

* ANOVA results for means within each row reflect analysis conducted on transformed data (square root), tested for $P = 0.05$; untransformed means presented.

schedule as described above. Hourly sampling was repeated for a total of 3 consecutive days in both crops. During each sample period, the trap was quickly removed from its post, placed in a 7.6-L resealable bag, and another trap was immediately hung in its place. After all new traps were placed, the trap contents from the previous hour were emptied into vials and stored in a refrigerator (2.7°C) until the *D. suzukii* could be counted and sexed.

Data analyses. To assess differences in trap catch on a weekly basis, for both monitoring systems throughout the growing season, analysis of variance (ANOVA) was used for the total trap catch across treatments and replicates. A square root transformation was applied to all count data. Transformed data were used for analyses, with a least significant difference (LSD) test to obtain mean separations, untransformed means are presented (R Core Team 2017). To determine the difference in trap catch on a weekly basis for lure age comparisons throughout the growing season, data were analyzed using ANOVA for the total trap catch across treatments and replicates. Hourly mean trap catch data used to determine temporal activity were analyzed using ANOVA with hour as treatment and days as replicates. A square root transformation was applied to all count data. Transformed data were used for analyses, with a protected least significant difference (LSD) test to obtain mean separations; untransformed means are presented (R Core Team 2017).

Results

Trap comparison study. In 2016 at Rosemount, we observed a significant difference ($P < 0.05$) between the weekly *D. suzukii* catch of Scentry (255.06 ±163.96) and Trece (41.79 ± 34.50) traps during a high-density year (Table 1). However, in 2017, with lower population pressure, we did not find a significant difference between trapping systems ($P > 0.05$) for mean weekly trap catch (Scentry, 26.44 ± 17.15; Trece, 33.45 ± 28.69; Table 1). Although the Scentry monitoring system detected the presence of *D. suzukii* a week earlier than the Trece system in Rosemount (Table 2), there was no difference in 2017, where both traps caught the first *D. suzukii* on 12 June (Table 2).

Table 2. Date of first catch in Scentry and Trece traps for female and male adult *D. suzukii* from traps in Rosemont and Forest Lake, Minnesota, 2016 and 2017.

		Scentry		Trece	
Year	Location	Female	Male	Female	Male
2016	Rosemount	13 Jun*	20 Jun	20 Jun	20 Jun
2016	Forest Lake	13 Jun*	27 Jun	27 Jun*	5 Jul
2017	Rosemount	12 Jun*	19 Jun	12 Jun*	19 Jun
2017	Forest Lake	10 Jul	3 Jul*	19 Jun*	3 Jul

* Earliest date of catch for each location and trap type.

Field trials conducted at Forest Lake in 2016, demonstrated significant differences ($P < 0.05$) for the mean weekly *D. suzukii* trap catch between trapping systems (Table 1). In 2016, *D. suzukii* trap catch for Scentry averaged 833.03 ± 790.34 and Trece averaged 332.31 ± 326. In 2017, *D. suzukii* trap catch for Scentry averaged 15.27 ± 3.06, whereas Trece averaged 15.56 ± 9.16 in 2017 (Table 1). In 2016, first trap catches in Scentry traps were 2 wk earlier than Trece on 13 June (Table 2). However, in 2017, first trap catch in Trece was 2 wk earlier than Scentry on 19 June (Table 2).

Date of first trap catch was further characterized by sex (Table 2). With two exceptions, Trece traps in 2016 at Rosemount and Scentry traps in 2017 at Forest Lake, female *D. suzukii* were caught first each season, typically 1–2 wk earlier than male *D. suzukii* (Table 2). Typical dates of first catch were in mid-June, with 13 June and 12 June the earliest dates of first catch in 2016 and 2017, respectively.

In 2016 and 2017 at the Rosemount location, both Trece and Scentry monitoring systems had similar patterns in their cumulative fly catch throughout the season (Fig. 1, A–D). For the Forest Lake location in both 2016 and 2017, we also observed similar patterns for cumulative flies captured when comparing Trece and Scentry monitoring systems (Fig. 2, A–D). Proportion of flies caught that were female, across trap type, years, and locations, indicated that the majority of flies caught were females and that the proportion rarely fell below 50% with the exception of Forest Lake monitoring systems in 2016 (Figs. 1 and 2, A–D).

Lure age study. In both 2016 and 2017, there were no significant differences (2016, $F = 1.11$; df = 1; $P = 0.30$; 2017, $F = 0.01$, df = 1, $P = 0.93$) in weekly trap catch between the 2-wk (2016, 239.44 ± 216.29; 2017, 108.67 ± 58.70) and 6-wk (2016, 156.33 ± 122.75; 2017, 107.04 ± 65.43) lure age using the Scentry monitoring system (Fig. 3).

Temporal activity studies. Adult fly activity results in both 2017 and 2018 indicated that female flies are very active, often reaching 100% of flies caught in Minnesota raspberry and blueberry fields (Fig. 4, A–D) using Scentry traps. Female fly activity was generally highest in the evening hours between 5:00 and 10:00 p.m., with the exception of blueberries in 2017 (Fig. 4B). Cumulative trap catch for male and female flies in 2017 exceeded 75% after 5:00 p.m. By contrast, only 10% and

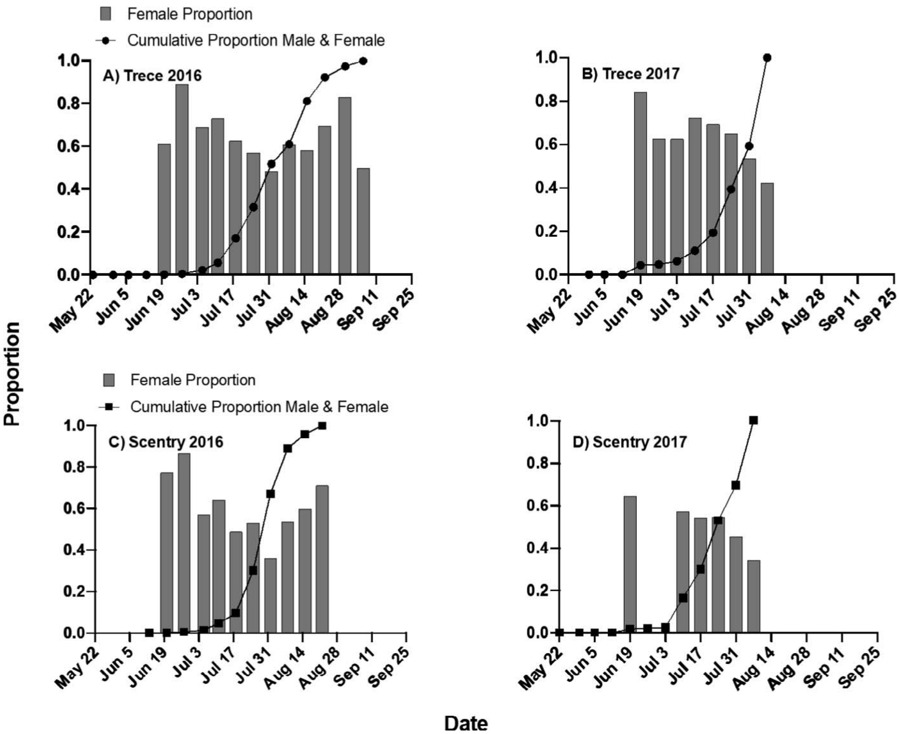

Fig. 1. Cumulative proportion of *D. suzukii* adults (lines) and proportion of female *D. suzukii* adults (bars) in weekly trap collection using Trece traps in 2016 (A) and 2017 (B) and Scentry traps in 2016 (C) and 2017 (D), Rosemount, MN, USA.

16% of flies were caught between 10:00 a.m. and 6:00 p.m. in raspberries and blueberries, respectively, in 2017, whereas 10%–12% of the flies were caught between 6:00 and 10:00 a.m. (Fig 4, A, B). Less than 1% of flies were captured between 10:00 p.m. and 6:00 a.m. in 2017 in either crop. This trend was similar in 2018 with no flies caught from 10:00 p.m. to 6:00 a.m. and less than 1% of flies captured from 10:00 a.m. to 6:00 p.m. (Fig. 4, C, D). However, in 2018 with much lower fly populations, 26%–47% of flies were captured from 6:00 to 10:00 a.m., which still accounts for more than 50% of flies being caught in the 6:00 to 10:00 p.m. time interval. In general, mean fly catch/hour peaked at 8:00 p.m. each day, with the exception of the raspberries in 2018 (Fig. 4C), where the daily peak occurred at 7:00 a.m., with 8:00 p.m. as the next highest trap catch of the day. In 2017, significantly higher trap catch occurred for raspberries ($F = 2.72$, df $= 18, 32$, $P = 0.007$) and blueberries ($F = 3.69$, df $= 18, 32$, $P = 0.001$) for the evening hours of 5:00 to 10:00 p.m. compared with the morning hours (Fig 4, A, B). However, with lower fly populations in 2018, the 7:00 a.m. time period was not significantly different from the peak evening catch at 8:00 p.m. that occurred in both crops. Both the 7:00 a.m. and 8:00 p.m. catches were significantly higher than all other time

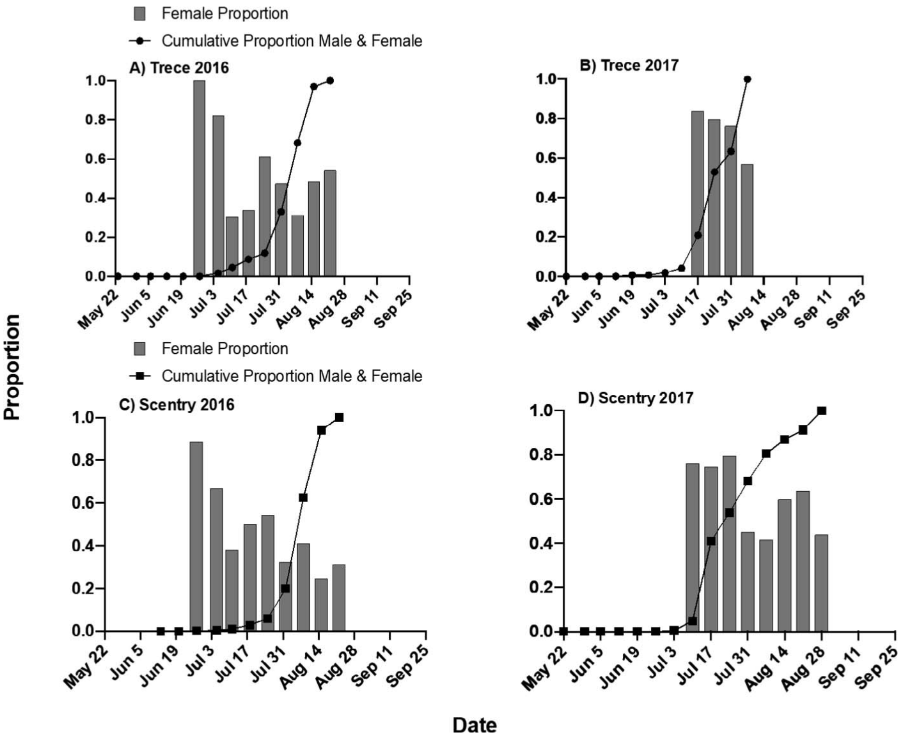

Fig. 2. Cumulative proportion of *D. suzukii* adults (lines) and proportion of female *D. suzukii* adults (bars) in weekly trap collection using Trece traps in 2016 (A) and 2017 (B) and Scentry traps in 2016 (C) and 2017 (D), Forest Lake, MN, USA.

intervals in raspberries ($F = 4.51$, df = 11, 18, $P = 0.002$) and blueberries ($F = 3.34$, df = 11, 18, $P = 0.011$) throughout the day (Fig. 4, C, D).

Discussion

The results of these studies provide new insights regarding the operational value of baited trapping systems for *D. suzukii* that will be useful toward improving IPM programs for this invasive species. At Rosemount, the 2016 field studies for trap type comparison showed a significant difference ($P < 0.05$) in the mean number of *D. suzukii* trapped, but only at high densities. The Scentry trap and lure system detected *D. suzukii* a week sooner than that of Trece and reflected higher pest pressure throughout the season (Table 1). In 2017, at Rosemount, there was no significant difference in either the weekly trap catches or the date of first detection of *D. suzukii* between trapping systems (Table1). The Forest Lake location did not demonstrate any significant differences either year (Table 1); however, at this site, increased variability was evident in the date of first trap catch between the 2 yr (Table 2). These data demonstrate that, although mean trap catch and date of first

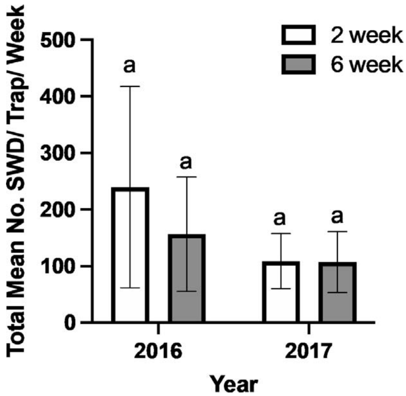

Fig. 3. Total mean adult *D. suzukii* trap catch for lures replaced every 2 or 6 wk, in 2016 and 2017, Rosemount, MN, USA. Traps were monitored weekly from 30 Jun to 25 Aug in 2016 and from 26 Jun to 21 Aug in 2017. No significant differences (2016, $F = 1.11$, df = 1, $P = 0.30$; 2017, $F = 0.01$, df = 1, $P = 0.93$) in weekly trap catch between the 2-wk (2016, 239.44 ± 216.29; 2017, 108.67 ± 58.70) and 6-wk (2016, 156.33 ± 122.75; 2017, 107.04 ± 65.43) lure age using the Scentry monitoring system.

catch can vary by year and location, overall, Scentry traps provided earlier indications of *D. suzukii* activity than Trece.

In an effort to further improve trapping options for IPM use, we examined how lure age affected how often lures need to be changed to minimize cost and maintain efficacy. Therefore, we designed a study to determine whether Scentry lures remain effective in the field for 6 versus 2 wk to potentially minimize monitoring costs for this specific monitoring system. Current recommendations for lure age are 4–6 wk. In both 2016 and 2017, we observed no significant differences ($P > 0.05$) in mean weekly trap catches of *D. suzukii* adults for either lure age. These data confirm that lures for the Scentry trap should be able to remain in the field for up to 6 wk before replacement, resulting in less maintenance and reduced costs to growers and crop consultants. Because lure age should not be an issue when first placed in the field, date of first catch should not be affected as long as lures are placed in the field within a reasonable time period before *D. suzukii* activity is expected, including late May to early June for most Minnesota locations. Future studies to evaluate possible impacts of lure age for the Trece system would be beneficial.

As noted by Asplen et al. (2015) correlations between population levels of *D. suzukii* in traps and berry infestations in a given fruit crop have not been fully determined. Currently, there are no established economic thresholds for *D. suzukii* in fruit crops grown in the midwest United States, but trapping results at both local farm and regional levels provide valuable information to growers (Hutchison et al. 2019). The main value of monitoring adult populations includes tracking dates of first catch, whether populations are increasing or decreasing, and to estimate overall population pressure during periods of peak crop susceptibility (Asplen et al.

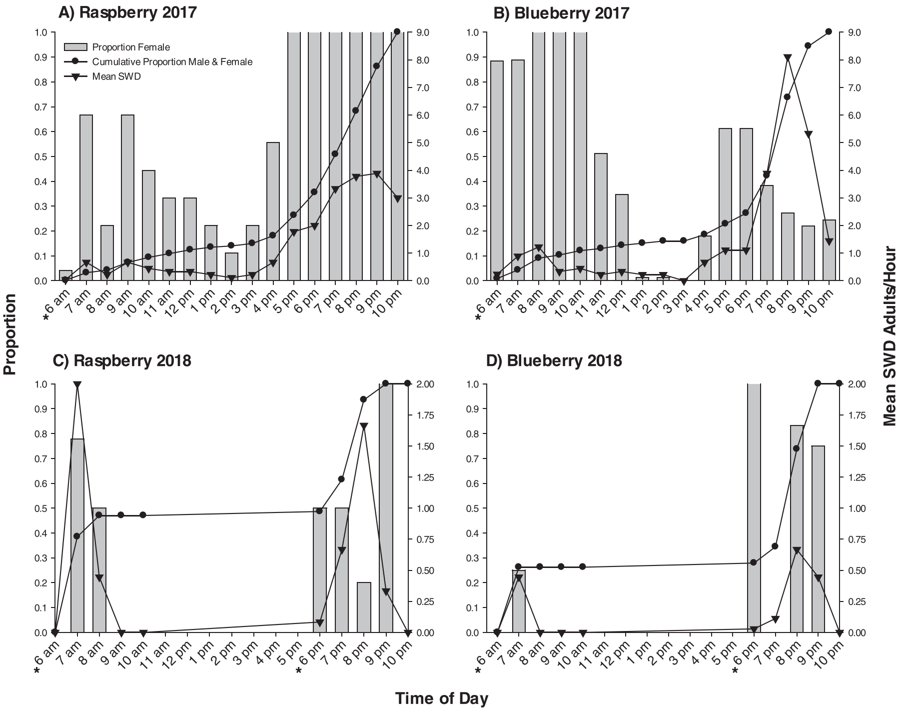

Fig. 4. Hourly *D. suzukii* trap catch, proportion female (gray bars), cumulative proportion total catch (circles), and mean catch (triangles) in summer-bearing raspberries from 16 July 2017 to 19 July 17 (A) and 8 August 2018 to 11 August 2018 (C) and blueberries from 16 July 2017 to 19 July 2017 (B) and 8 August 2018 to 11 August 2018 (D). In 2017 (A and B), 6:00 a.m. trap catch represents *D. suzukii* caught between 10:00 p.m. and 6:00 a.m. In 2018 (C and D), 6:00 a.m. trap catch represents *D. suzukii* caught between 10:00 p.m. and 6:00 a.m. and 6:00 p.m. trap catch represents *D. suzukii* caught between 10:00 a.m. and 6:00 p.m., Mabel, MN, USA.

2015, Cini et al. 2012). That said, because trap catch of adults may only represent a small-to-moderate proportion of a local fly population (Tochen et al. 2014), trap catch for this species continues to be a relative indicator of population trends (Southwood and Henderson 2000). Although several growers in Minnesota have evaluated various ACV trap designs for mass trapping purposes, the trap efficiencies observed to date suggest this is not practical for open-field production systems (El-Sayed et al. 2006). With this in mind, the current goal of the *D. suzukii* traps is to monitor adult populations as a guide for growers and crop consultants in developing and implementing IPM strategies.

From an operational perspective, decisions regarding the type of trap to use for monitoring *D. suzukii*, should also be based on experience with trap logistics, ease of use, and initial investment for growers. Trece uses a drowning solution of ACV and soap, whereas the Scentry only requires use of tap water and soap. With tap water being more readily available and having a lower cost than ACV, this allows growers to maintain a monitoring system at a lower cost. Moreover, although Trece lure age was not tested in the lure age study, the results for the Scentry lure age suggests a less frequent replacement interval that further reduces the cost of establishing and maintaining this monitoring system. Based on this justification of trap choice, we also chose to use Scentry traps to evaluate temporal activity.

Temporal activity studies revealed a crepuscular activity pattern by *D. suzukii* (Fig. 4, A-D). With peak daily trap catch highest during early morning (6:00. to 10:00 a.m, CST) and late evening (6:00 to 10:00 p.m.), it is clear that knowledge of temporal activity may be very useful in guiding management activities for *D. suzukii*. These results are also similar to what Evans et al. (2017) reported in Georgia, USA, a recent report in North Carolina, USA (Swoboda-Bhattari and Burrack 2020), and the results of Jaffe and Guédot (2019) in Wisconsin, USA. Also, Shaw et al. (2018) recently reported a similar diel periodicity to *D. suzukii* oviposition activity and demonstrated the underlying circadian clock mechanism. Because our data provide similar adult activity periods for both blueberry and raspberry, the results indicate that any possible confounding effects of fruit volatiles from each berry species did not appear to impact the crepuscular timing of trap catch. Temporal activity of flies becomes critical as current management options, such as insecticides, primarily target adults. Because adult feeding is minimal on the crop, and oviposition behavior may provide limited residue exposure to female flies, achieving direct insecticidal contact with flies should improve efficacy. As flies appear to be most active around 8:00 p.m. in both raspberry and blueberry (Fig. 4, A-D), applying insecticides in the evening may prove to be advantageous. In addition, insecticide applications during evening hours may assist in avoiding times when pollinators are active in berry crops (Jaffe and Guédot 2019) and can minimize nontarget impacts of insecticide use (Njoroge et al. 2004).

These studies provide additional insight into the utility of two *D. suzukii* monitoring systems, with improved four-component lures that are commercially available to growers, and new data confirming the diel periodicity of adult captures in traps under midwestern US conditions. In summary, we found that both trapping systems have value in Minnesota and are useful in alerting growers of the need to begin monitoring crops more closely and initiating management tactics that currently rely primarily on insecticide use (Hutchison et al. 2019). Moreover, given the knowledge of the tendency for *D. suzukii* to exhibit a crepuscular activity pattern, management activity focused on the evening hours, just prior to dusk, may be most beneficial for increasing insecticidal contact with flies, as well as minimizing contact with foraging pollinators (Hutchison et al. 2019, Jaffe and Guédot 2019). With the many challenges this invasive species poses with its short generation time, high fecundity, and lack of effective control methods, it is important to continue working toward multiple management strategies that can better assist growers and crop consultants in managing *D. suzukii*.

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