



Brief Report

Seasonal Population of *Drosophila suzukii* (Diptera: Drosophilidae) and Pesticide Use Pattern after Its Invasion in Caneberry Crops in Pennsylvania (USA)

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Abstract: *Drosophila suzukii* (Diptera: Drosophilidae) is a major invasive pest of caneberries (e.g., blackberries and raspberries) and other thin-skinned fruit crops. In recent years, it has been reported as an economically important fruit pest in many countries. In caneberries, the timely detection and management of invasive insect pests such as *D. suzukii* is important to maintain profitability and avoid fruit export restriction. Invasions by such new pest species in commercial crop production often changes pesticide use patterns and frequency as growers try to control pest populations on their farms. In this study, we examined the seasonal population of *D. suzukii* and pesticide use patterns before and after *D. suzukii* invasion in primocane-fruited raspberry and florican-fruited blackberry crop production in Pennsylvania. The results of seasonal monitoring conducted over two years showed higher populations of *D. suzukii* fruit flies during the settle period. The evaluation of crop-specific pesticide programs showed an increase in pesticide use frequency compared to the crop season before *D. suzukii* invasion in the blackberry planting. Similarly, over a five-fold increase in pesticide application was recorded in the raspberry planting in the year following invasion. The implications of increased pesticide use patterns in blackberry and raspberry production are discussed.

Keywords: fruit insect pest; pest population; cherry drosophila; spotted wing drosophila; population monitoring; pesticides



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1. Introduction

Drosophila suzukii (Matsumura, 1931) (Diptera: Drosophilidae) is an economically important invasive insect pest of small and stone fruit crops in the United States [1,2]. *D. suzukii*, commonly known as the cherry drosophila or spotted wing drosophila, has a wide range of hosts [3,4], and is considered a primary pest in several economically important crops [5,6]. Unlike many other fruit fly species, *D. suzukii* females possess long sclerotized and serrated ovipositor [7,8] and directly oviposit into undamaged ripe as well as ripening fruits of various host species, mainly thin-skinned fruits, such as blackberries (*Rubus* spp.), blueberries (*Vaccinium* spp.), cherries (*Prunus* spp.), grapes (*Vitis* spp.), peach (*Prunus persica* (L.) Batsch), strawberry (*Fragaria* × *ananassa* Duchesne), red raspberry (*Rubus idaeus* L.), black raspberry (*Rubus occidentalis* L.), plum (*Prunus domestica* L.) and apricot (*Prunus armeniaca* L.) [9–13]. Damage is caused by *D. suzukii* females while inserting eggs into fruits and by three larval instars (after egg hatch) feeding inside the host fruits while they are ripening [9,14]. If not managed in a timely fashion, *D. suzukii* has the potential to cause severe economic losses in berries and other fruit crops [5,6,15–17]. In

particular, losses in small fruit crops such as blackberries, raspberries, and cherries are estimated to total over USD 850 million in the western fruit-growing states of the USA (viz., California, Oregon, and Washington) alone [8,18].

Invasion by new insect pests such as *D. suzukii* in crop production usually results in economic losses to growers, and these losses could be severe depending on the degree of invasion, pest species and crop type [15,19–21], as well as grower's responses to invasion [22]. New invasive pests are more difficult to manage in the early stages of invasion as there is a lack of information related to pest bioecology (in newly invaded areas), host range and damage potential to agricultural crops. Pest management in the initial period of invasion becomes more challenging, as no registered pesticides are available to growers for immediate use in controlling the pest population. In such scenarios, certain pesticide products may be granted approval for emergency use against new invasive pests. In the case of *D. suzukii*, during the early years of invasion, fruit growers had limited pest control options: primarily a few registered broad-spectrum insecticides (such as zeta-cypermethrin and spinetoram) that were granted emergency-use approval for *D. suzukii* management in small fruit and berry crops in different states of the USA. Some of these pesticides had been evaluated for their effectiveness against *D. suzukii* in different fruit crops [23–27]. However, the successful control of *D. suzukii* with pesticide chemicals depends on several factors, including choice of pesticide, active ingredient, application timing, residual properties, and spray coverage [28]. The frequent application of insecticidal chemicals increases the cost of production in fruit and other specialty crops [29], and may also pose the increasing risk of environmental contamination. This also increases the likelihood of resistance developing in the target pest population, since few available insecticide chemistries are repetitively applied throughout the season to control the invasive pest. This is especially true for pests that have many generations in a season, such as mites and psyllas in tree fruit, and this is most likely true for *D. suzukii* in the mid-Atlantic region, which has several generations in a season. The frequent application of pesticides may also have non-target effects on beneficial species such as pollinators and insect and mite species that help with the biological control of arthropod pests in the farmscape. Therefore, understanding how pesticide use patterns change due to the invasion of new pests and how growers' normal pest-management strategies are disrupted is important for maintaining the overall environment health of agricultural farms. In this context, the main objective of this study was to determine the seasonal occurrence of *D. suzukii* during the initial period of invasion and evaluate the crop-specific pesticide use patterns before and after its invasion in commercial caneberry crop production in a Pennsylvania farm where we first found *D. suzukii* in 2011.

2. Materials and Methods

This study was conducted on a 3-acre berry farm of Adams County, Pennsylvania (USA) that grows a mix of cultivars of floricane-fruiting blackberries and primocane-fruiting raspberries. As a part of a state-wide *D. suzukii* and invasive pest-monitoring program with the Pennsylvania Department of Agriculture, we conducted weekly monitoring for *D. suzukii* fruit flies for two growing seasons (2011 and 2012) and additionally compared on-farm pesticide use patterns that were changed by the arrival of this invasive insect pest in raspberry and blackberry production.

2.1. Seasonal Monitoring of *D. suzukii* Population

Weekly monitoring of *D. suzukii* fruit flies was conducted. Monitoring traps were constructed by modifying clear plastic containers (1 L) by drilling 8–10 small holes (approx. 10 mm in diameter) around the container surface near the lid. Two of the holes were used to connect a wire-tie to place the traps. In all traps, apple cider vinegar (ACV, diluted with water to 5% acidity) was used as the primary lure and bait material. ACV is known to attract drosophilid flies including *D. suzukii* in traps [30]. Each trap contained ~200–250 mL of ACV (Great Value Apple Cider Vinegar, store brand, Walmart Stores, Inc., Bentonville, AR, USA). Population-monitoring traps ($n = 4$ in first year, $n = 8$ in second year) were

placed in the trellis, approx. 1.2 m above the ground and approx. 7 m apart. At the time of weekly sample collection, a fine mesh strainer was used to collect insects from the trap container. These samples were immediately preserved in ethanol (70%) and transported to an entomology laboratory at the Penn State Fruit Research and Extension Center (Biglerville, PA, USA) for species identification. All collected specimens were identified, following the procedure described by Kikkawa and Peng [31], and Bock and Wheeler [32]. In the first year, weekly sampling was started in June and continued through October. Monitoring was stopped in October due to adverse weather conditions that affected the crop field. In the second year, weekly sampling using the same type of traps began on May 1 and continued until the first week of November. The mean number of male *D. suzukii* adults per trap was determined for each year. Weekly average temperature during the sampling period was also recorded from a weather station at the Penn State Fruit Research and Extension Center located approximately 1 km away.

2.2. Pesticide Use Pattern

Pesticide spray applications were recorded for the three years (before, during and after documented *D. suzukii* invasion) of the study farm. These spray records were compared to assess the pesticide use changes caused by pest invasion. From pesticide records, information related to primary target pests, pesticide active ingredients and the application dates and spray amounts were compared for each year.

3. Results and Discussion

Drosophila suzukii arrival in the study farm was confirmed by weekly trap captures. During the year when *D. suzukii* invasion occurred, spotted wing drosophila males capture per trap was higher in the traps placed in raspberry planting (Figure 1). The first capture was in traps collected on 19 September, and *D. suzukii* population in terms of trap capture peaked around 5 October in both crops. Thereafter, numbers decreased towards the end of the sampling month, when the average weekly temperature started declining. However, the weekly capture per trap was still over 200 *D. suzukii* adults in blackberry and over 250 *D. suzukii* adults in fall raspberry through mid-October (Figure 1). Dropped and decaying raspberry fruits were a potential breeding ground for late-season *D. suzukii* populations [33]. These crops were close enough to each other that raspberry fruit produced during this time likely supported the populations in both crops. In addition, fruits from wild host plants (such as mulberry and wild berries) surrounding fruit plantings could support off-season population in fruit farms [34] and may have caused the increase in the pest population. Moreover, this was the first crop season of *D. suzukii* invasion in the study farm and little was known about which pesticides were effective at controlling the fruit fly at that time. Other factors contributing to a high *D. suzukii* population could be that spray-application techniques resulted in a less thorough spray-coverage of the crop canopy, which is considered important while attempting to control pests with insecticides.

During the second year (i.e., the year after invasion), fewer *D. suzukii* males were captured during the summer months compared to the fall (Figure 2). The ability to prevent populations from rising as quickly following initial capture as compared to the previous year is likely due to the application of more effective pesticides and better spray coverage with pesticides. Pesticide application was discontinued in the late September, and monitoring traps showed higher capture rates starting in October in both crops. This could be due to a late-season population spike resulting from breeding in dropped fruits or non-crop host species. *Drosophila suzukii* trap capture rate peaked towards the end of October and the first week of November, which is likely due to no pesticide applications being made during the end of the crop season and the cessation of commercial harvesting leaving unsprayed late developing berries on the plants. There are several other factors that might have caused a late spike in the *D. suzukii* population. One was the presence of non-crop habitats in adjacent landscape [35]. In another study, we found a similar late-season higher *D. suzukii* population trend in small fruit crops when monitored using Pherocon *D. suzukii* Dual-Lure

(Trécé Inc., Adair, OK, USA) [36]. The late-season occurrence of *D. suzukii* in various fruit crops has been reported from regions abroad, as well [37,38]. Monitoring traps in this study also caught another newly invasive species of Drosophilidae, *Zaprionus indianus* Gupta, 1970, and many other fruit flies and other dipterans during sampling. Representing an invasive species in this region, *Z. indianus* was also discovered in Pennsylvania at around the same time when *D. suzukii* populations started to spread across the state [39]. Several species of sap beetles (Nitidulidae) and several species of proctotrupid wasps of the genera of *Brachyserphus*, *Cryptoserphus*, and *Exallonyx* that are thought to be parasitic on Nitidulidae were also found in large numbers. Staphylinidae larvae that were also found in traps could have been drawn to the ACV like the fruit flies or possibly from a mating pheromone from the beetle hosts.

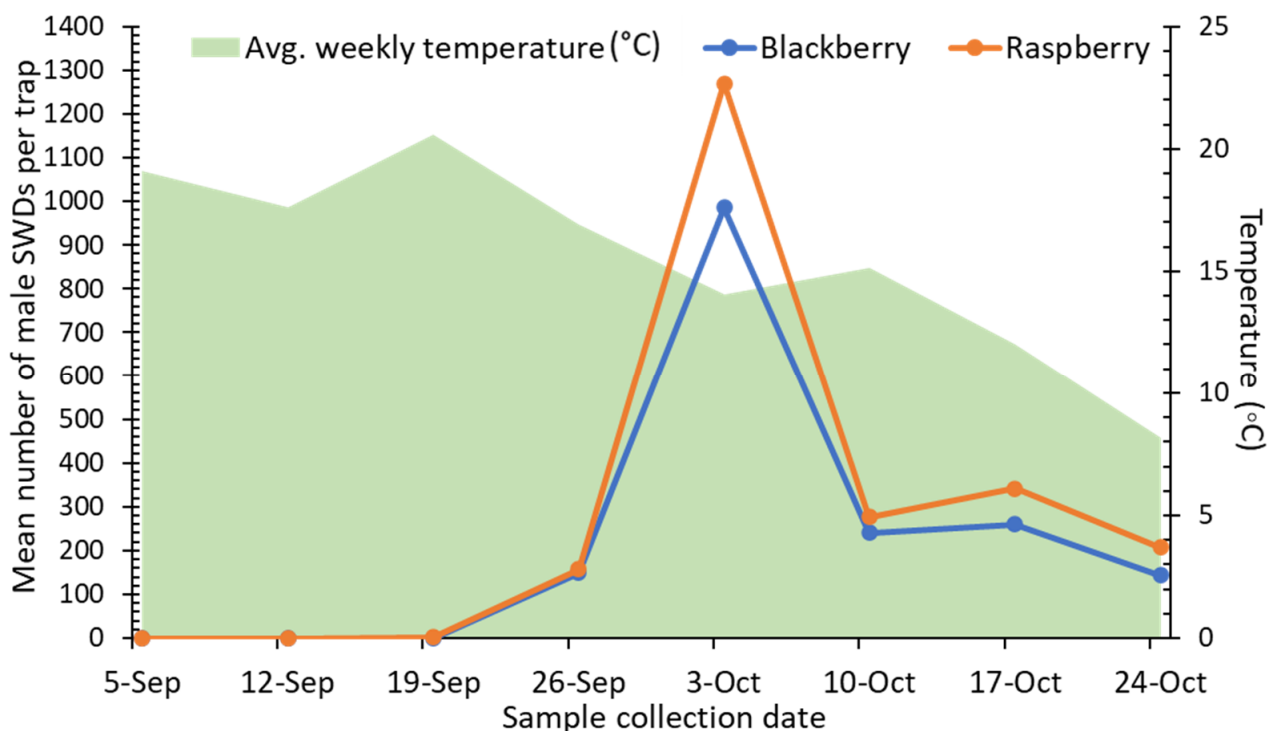


Figure 1. Seasonal occurrence of *D. suzukii* (spotted wing drosophila, SWD) in terms of mean weekly captures in ACV traps deployed in raspberry and blackberry plantings in Adams County, PA (USA) during the first year of invasion.

In this study, a comparison of pesticide spray records revealed four additional insecticide sprays that were applied to control *D. suzukii* in the blackberry planting in the year after spotted wing drosophila invasion compared to the year before its invasion (Table 1). Similarly, in the raspberry planting, 17 additional sprays (i.e., over fivefold than normal year) were applied to control the *D. suzukii* population (Table 2). These findings show that the pesticide use pattern could significantly change after the invasion of exotic pests. The spray records of the commercial berry farm for the year before *D. suzukii* invasion reveal fewer sprays of insecticides that were applied to manage common blackberry and raspberry pests in this region. During the first year of study/crop season, *D. suzukii* was found for the first time on the study site [40] after blackberry harvest was complete, and during harvest of the fall raspberry crop. As a result, the study site lost most of its late-season raspberry crop due to a lack of effective control by insecticides that were not optimal for control of this new pest (i.e., acetamiprid) and due to heavy rains from a hurricane. However, in the following crop season, we worked with the growers to start earlier monitoring of *D. suzukii* and helped to revise their control program with more optimal insecticide choices to better control *D. suzukii*, combined with improved spray-application coverage due to the use of better spray-application equipment. Cultural practices that were also successfully adopted

included improving spray coverage by increasing the summer pruning of new non-bearing cane growth at the base of the plants and improving sanitation by reducing the number of dropped or unpicked berries during and after the commercial picking season. Economically viable production of blackberry and raspberry crops was restored in the second year due the effectiveness of the *D. suzukii* insecticide program.

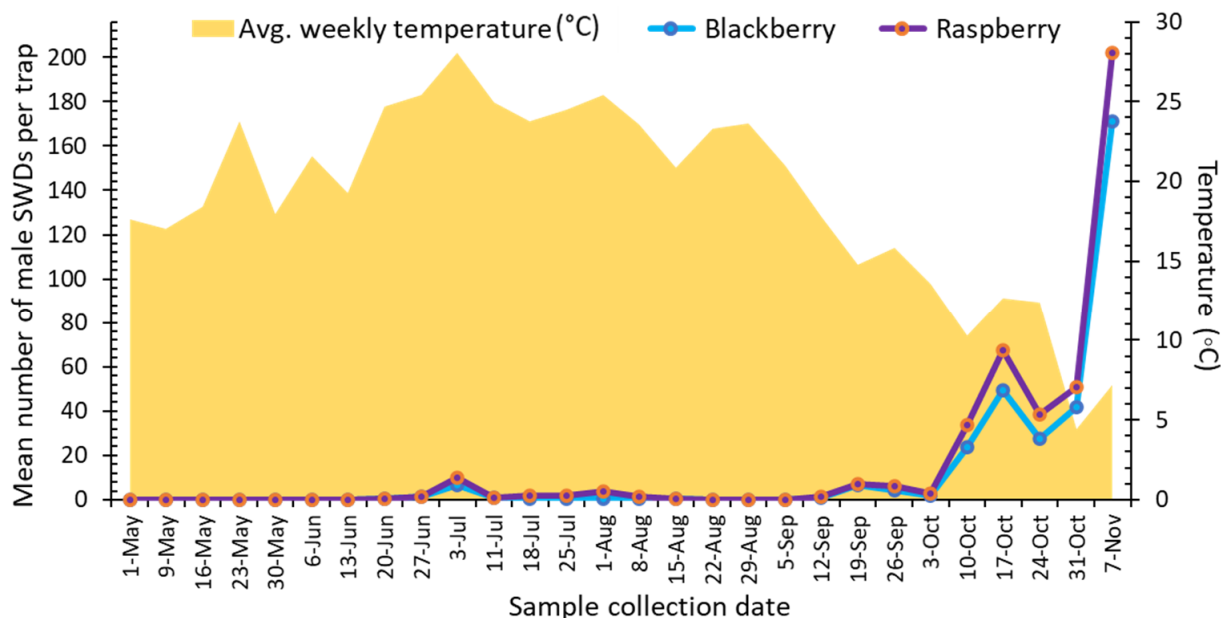


Figure 2. Seasonal occurrence of *D. suzukii* (spotted wing drosophila, SWD) in terms of mean weekly captures in ACV traps deployed in raspberry and blackberry plantings after invasion in Adams County, PA, USA.

Table 1. Changes in the pesticide use in blackberry production from the growing seasons before, during and after *D. suzukii* invasion in Adams County, PA (USA).

Date	Primary Target Pest	Pesticide	Active Ingredient	Amount (L)/Hectare
Before invasion				
3-Apr	RCB	Brigade WSB	bifenthrin	1.161
25-May	LH	Malathion 57EC	malathion	1.754
30-Jun	LH	Malathion 57EC	malathion	1.754
17-Jul	JB	Assail 30 SG	acetamiprid	0.328
During invasion				
16-Jul	TPB	Assail 30 SG	acetamiprid	0.328
20-Aug	BMSB, TPB, OSI	Assail 30 SG	acetamiprid	0.328
After invasion				
23-Mar	RCB	Altacor	chlorantraniliprole	0.328
13-Apr	RCB	Altacor	chlorantraniliprole	0.328
9-Jun	LH	Malathion 57EC	malathion	
10-Jun	LH	Assail 30 SG	acetamiprid	0.328
9-Jul	SWD	Brigade WSB	bifenthrin	1.168
16-Jul	SWD	Delegate 25WG	spinetoram	0.365
21-Jul	SWD	Mustang Max	zeta-cypermethrin	0.291
28-Jul	SWD	Delegate 25WG	spinetoram	0.365

RCB = raspberry crown borer, LH = leafhopper, JB = Japanese beetle, TPB = tarnished plant bug, BMSB = brown marmorated stink bug, OSI = other sucking insects, and SWD = spotted wing drosophila.

Prior to *D. suzukii* arrival in various fruit-growing regions in the United States, stone fruits and berry crops received fewer insecticide applications throughout the growing season [41–43]. In many states of the USA, the presence of *D. suzukii* as a primary pest

of small fruits and berry crops has caused growers to revise their existing pesticide spray programs and pest-management practices. As a result, growers have increased pesticide application (i.e., number of pesticide sprays) during the crop season in small fruits and berry farms [29]. Difficulties in effectively controlling *D. suzukii* invasion in small fruit crop farms in this region, as in this case, also resulted in an increased use of broad-spectrum pesticides and a decrease in organic production, and more farms need to be analyzed in this direction. Considering the strict quarantine policies adopted in recent years, multiple pre-harvest insecticide applications are recommended for *D. suzukii* control in cherry orchards [18]. The insecticides primarily used to control *D. suzukii* are broad-spectrum, and generally affect other non-target beneficial species used in conservation biocontrol in the farmscape. Therefore, there is a crucial need to develop alternative and cultural control tactics to effectively manage this pest. Cultural control practices such as the use of early maturing cultivars, exclusion netting, pruning, removal of cull fruits from plantings, and post-harvest cold storage are now used to manage *D. suzukii* in small fruits and berry crops [44].

Table 2. Changes in pesticide use in raspberry production from the growing seasons before, during and after *D. suzukii* invasion in Adams County, PA (USA).

Date	Primary Target Pest	Pesticide	Active Ingredient	Amount (L)/Hectare
Before invasion				
25-May	LH	Malathion 57EC	malathion	1.101
12-Jun	LH	Carbaryl 4L	carbaryl	2.347
30-Jun	LH, OSI	Malathion 57EC	malathion	1.754
During invasion				
11-Jun	LH	Assail 30 SG	acetamiprid	0.328
18-Jun	LH	Malathion 57EC	malathion	1.754
5-Jul	JB	Sevin 4F	carbaryl	3.508
13-Jul	JB	Sevin 4F	carbaryl	3.508
20-Aug	BMSB, TPB, OSI	Assail 30 SG	acetamiprid	0.328
After invasion				
31-May	LH	Malathion 57EC	malathion	1.168
10-Jun	LH	Malathion 57EC	malathion	1.168
26-Jun	LH/JB	Assail 30 SG	acetamiprid	0.328
9-Jul	SWD	Brigade WSB	bifenthrin	1.168
16-Jul	SWD	Delegate™ 25WG	spinetoram	0.365
21-Jul	SWD	Mustang Max	zeta-cypermethrin	0.291
28-Jul	SWD	Delegate™ 25WG	spinetoram	0.365
3-Aug	SWD	Entrust	spinosad	0.108
4-Aug	SWD	Mustang Max	zeta-cypermethrin	0.291
8-Aug	SWD	Entrust	spinosad	0.108
12-Aug	SWD	Delegate™ 25WG	spinetoram	0.365
15-Aug	SWD	Entrust	spinosad	0.108
18-Aug	SWD	Mustang Max	zeta-cypermethrin	0.291
25-Aug	SWD	Delegate™ 25WG	spinetoram	0.365
29-Aug	SWD	Entrust	spinosad	0.145
1-Sep	SWD	Mustang Max	zeta-cypermethrin	0.291
5-Sep	SWD	Entrust	spinosad	0.145
8-Sep	SWD	Delegate™ 25WG	spinetoram	0.365
15-Sep	SWD	Delegate™ 25WG	spinetoram	0.437
23-Sep	SWD	Mustang Max	zeta-cypermethrin	0.365

RCB = raspberry crown borer, LH = leafhopper, JB = Japanese beetle, TPB = tarnished plant bug, BMSB = brown marmorated stink bug, OSI = other sucking insects, SWD = spotted wing drosophila.

Pesticides are an integral part of *D. suzukii* management strategy as this pest has potential to cause severe economic losses. Considerable yield loss in raspberries had been reported by fruit growers from Minnesota, USA [45]. Prior to the *D. suzukii* invasion, small fruits and berry crops received far fewer applications of insecticides throughout the crop season [43]. In many states of the USA, *D. suzukii* is the primary pest of small

fruits and berries, and considering the low pest tolerance in the fresh produce market, its timely and effective management is essential. Therefore, additional *D. suzukii* specific pre-harvest insecticide applications are recommended in some small fruits [18]. The frequent application of insecticide to achieve *D. suzukii* control is complicated in diversified fruit farms, where multiple pickings and u-pick operations necessitate the use of pesticides with short re-entry and pre-harvest intervals. With crops such as primocane-fruiting raspberries that have extended fruiting periods, insecticide-based control measures overlap with the continual bloom that occurs throughout the season and the impact of sprays on pollinators is an important consideration. Pesticides targeted for *D. suzukii* control may also affect populations of natural arthropod enemies [46]. Therefore, such non-target impacts of frequent insecticide applications to manage invasive pest species in crops (where pollinators and beneficial species are commonly found) needs to be studied in the future. In small and diversified farms in Pennsylvania, growers generally rely on wild bee species for pollination services [47]. Minimizing the exposure of these pollinator species to insecticides is crucial to maintaining overall ecosystem sustainability. Innovative ways of applying pesticides in combination with *D. suzukii* baits or bait sprays [48], such as an attract-and-kill formulation [49,50], or using oviposition antagonist chemicals [51], phenology models to predict *D. suzukii* populations [52], and careful pesticide timing, could be helpful in minimizing insecticide use in various fruit crops. Developing an *D. suzukii* management plan under the newly evolving framework of integrated pest and pollinator management (IPPM) [53–56] by combining selective methods of applying pesticides, the selection of less-pollinator toxic pesticides, as well as the readjusting the spray timing, may reduce the potential risk of pesticide exposure to pollinator communities in farm landscape. A similar framework could also be developed for other non-target arthropod species (e.g., species that help in biological control such as parasitoids and predators) that are usually present in fruit farms, and could provide important ecosystem services by regulating pest populations [57].

4. Conclusions

In this study, a season-long monitoring of *D. suzukii* in blackberry and raspberry fruit crops in Pennsylvania (USA) showed higher populations during the invasion period compared to previous crop season. Consequently, pesticide use patterns in these fruit crops changed from one year to another as several additional pesticide chemical sprays were applied to protect fruit crops from *D. suzukii* infestation. These findings are important in understanding how fruit growers' normal pest management strategies could be disrupted due to the arrival of an invasive insect pest on their fruit farms. Additional pesticide sprays may also have non-target effects on beneficial pollinators (such as bees and birds) that are usually present during crop season in the farm landscape. Therefore, there is an indispensable need to assess the potential environmental risk of such increased on-farm pesticide use in future studies.

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