Biology and Management of Spotted Wing *Drosophila* on Small and Stone Fruit

A USDA-NIFA Specialty Crop Research Initiative Project

A collaborative project among Oregon State University, Washington State University, University of California at Berkeley, University of California at Davis, USDA-ARS, USDA-NIFA, and the small and stone fruit industries of Oregon, Washington, and California.

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USDA United States Department of Agriculture National Institute of Food and Agriculture

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Evaluate genetic, biological and ecological parameters of *Drosophila suzukii.*

1.1 Conduct genomic studies

The genome characterization has been completed and analysis for *Drosophila suzukii* and construction of a portal that will allow researchers access to the genomic library is underway. Links to this portal will be made available on the project's website http://spottedwingflybase.oregonstate.edu/. Similar characterization and analysis of *D. melanogaster* is planned for use as a comparative tool.

1.2 Evaluate biological and environmental parameters

Currently traps are used to indicate whether adult *D. suzukii* are active in the field. Female *D. suzukii* captured in traps does not necessarily indicate females seeking fruits for oviposition. Traps simulate food sources; flies may not be reproductively active during winter or early spring. In order to assess the reproductive status of female flies, ovaries of about 200 trap-collected *D. suzukii* were compared to an established reference colony at the Mount Vernon Northwestern Washington Research and Extension Center. Observations allow researchers to identify viable or older, lesser quality eggs as well as undeveloped and degenerating ovaries.

Females collected from March through mid-May were not often good candidates for dissection; the small sample size renders description of reproductive potential during that period difficult. An abundance of viable eggs was observed from mid-May through September, coinciding with the fruiting season. A gradual shift was observed in the fall from a reproductively active population to an overwintering population with decreasing egg development. Degenerated ovaries were observed prior to winter but not in the spring, suggesting aging females

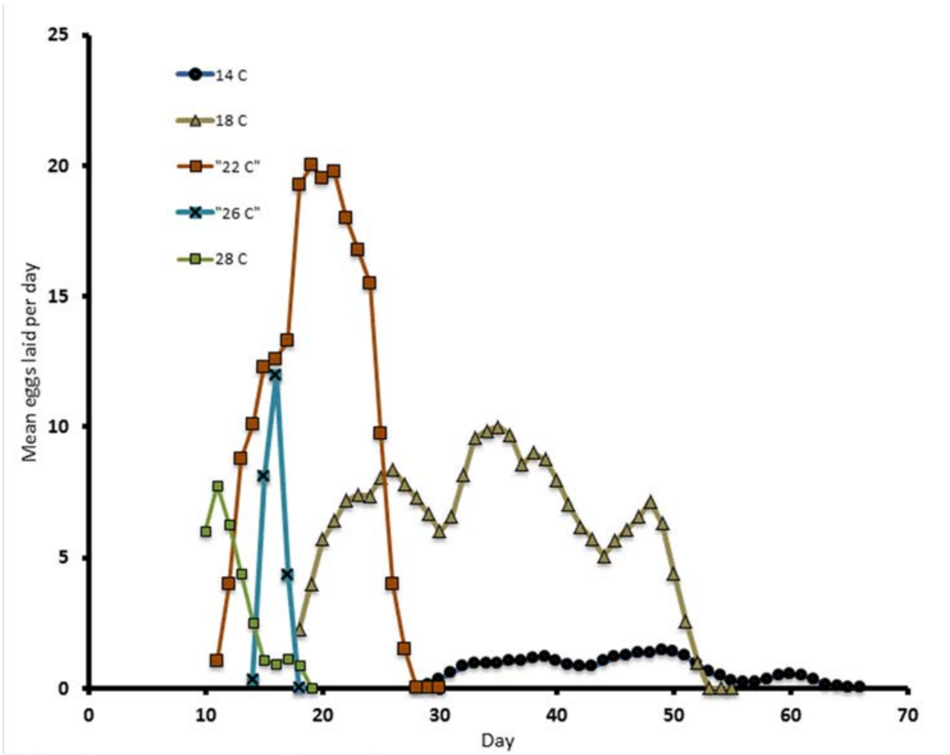

Figure 1. Mean *D. suzukii* egg production at five temperatures on 'Bing' cherry. Walton Lab, OSU.

are unlikely to survive the winter to play a founder role the following spring.

D. suzukii populations include females in varying states of ovarian development, making the population capable of quick recovery from insecticide applications and unseasonable weather events. These observations provide clues to likely age distribution and crop phenology, underscoring the critical need for timely insecticide applications to increase potential for economic management and to minimize the risk of resistance development in this reproductively agile fly. This work is ongoing and will better enable us to understand *D. suzukii* phenology and life history in the Pacific Northwest.

Temperature-related parameters: *D. suzukii* were reared in the lab on cherry and blueberry at seven temperatures and 16 h daily light exposure. Life stage, oviposition, and mortality for each replicate were recorded every 48 h for flies held at 10 and 14°C; and every 24 h for 22, 26, 28 and 30°C. Polynomial fitting allowed estimation of minimum, maximum and optimum development threshold temperatures. This work will ultimately help predict the population dynamics of *D. suzukii* as developmental rates vary with ambient (outdoor) temperatures.

Mean *D. suzukii* oviposition per day on cherry was recorded at only five of the seven listed temperatures (Figure 1). Egg-laying was relatively high at all temperatures directly after adult female emergence, followed by a gradual decline. Egg-laying started earlier at higher temperatures compared to lower temperatures. At cooler temperatures oviposition rates were lower but continued for longer periods than those of the higher temperatures. At optimal temperatures, *D. suzukii* oviposits in cherry at significantly higher rates than in blueberry, though as temperatures deviate from the optimal (18°C), rates in cherry are not

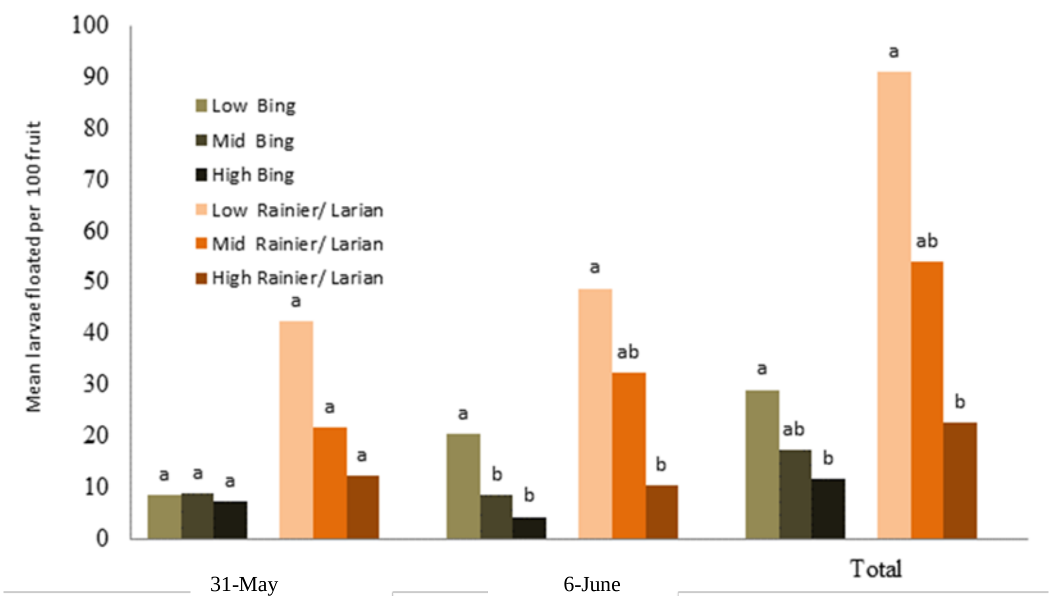

Figure 2. Cherry infestation by canopy height in the San Joaquin Valley, CA, 2011. Van Steenwyk Lab, UCB.

different from those in blueberry. An applied demography model, descriptive of an early season scenario, was run at 22°C. Populations remained low (lag phase) for 31 days and showed exponential rise (log phase) after 70 days. Such models are useful in estimating the potential pressure that can be exerted by *D. suzukii* reproductive populations. The *D. suzukii* population model displays life stages of whole populations, as well as relative population levels. These data may aid in forecasting when the damaging population stages may be present, as well as in identifying the level of pressure that may be considered injurious.

Evaluate *D. suzukii* behavior: Replicated fruit samples (100 fruits per height) were collected at three heights in the canopies of multiple cherry orchards in the San Joaquin Valley, CA. Heights were defined as low, <1.37 m; mid, 1.5-2.5 m; high, 2.6-3.8 m. Samples collected on May 31, 2011 were subjected to larval flotation extraction. Initial results showed no significant difference for larval infestation as a function of height; samples collected a week later were infested at significantly higher rates at

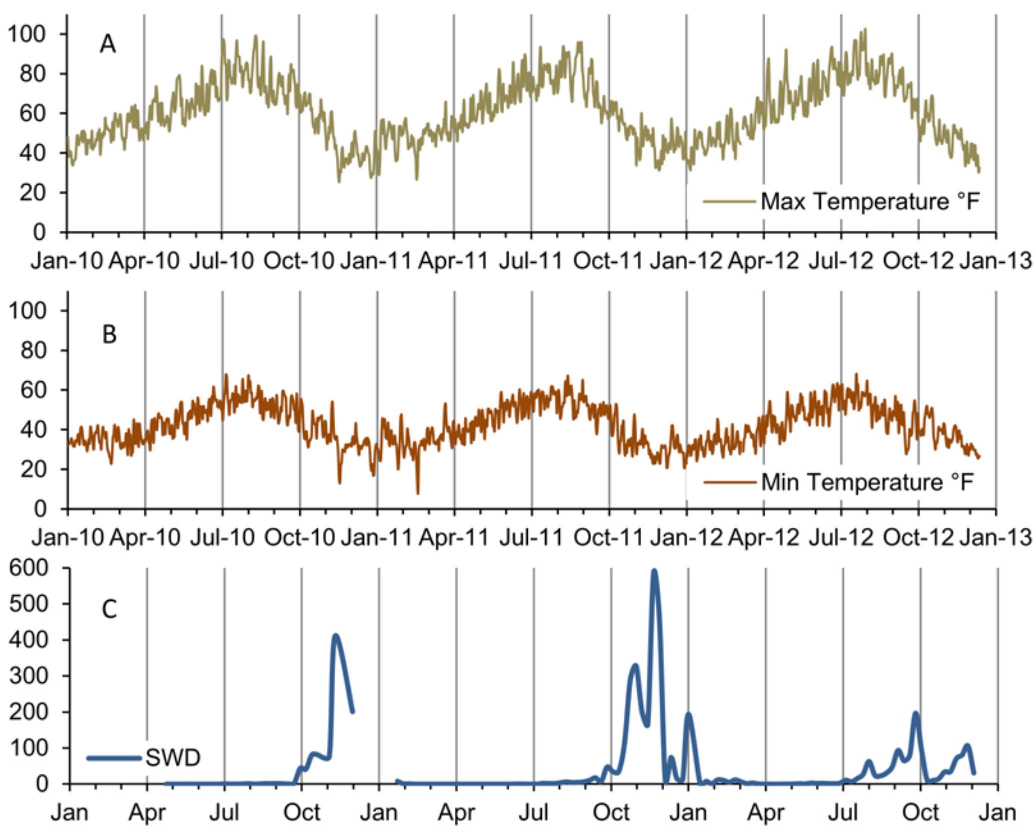

Figure 3. Average number of adult *D. suzukii* captured in apple cider vinegar (ACV) baited deli-cup traps per week and the corresponding maximum (max) and minimum (min) weekly temperatures (°F) from January 2010 to December 2012 in Hood River County, Oregon. (A) Weekly maximum temperature. (B) Weekly minimum temperature. (C) Average number of SWD adults captured per trap per week. Traps contained 10% NaCl Nov 2011 – Mar 2012 to inhibit freezing of ACV. Shearer Lab, OSU.

low heights compared to high heights. The study was repeated in 2012, with similar results (Figure 2).

Standard laboratory olfactometer studies were conducted on flies collected from a non-commercial, cultivated research setting in Watsonville, CA to determine whether habituated flies showed similar attraction to novel or familiar fruit odors. *D. suzukii* showed a preference for novel fruit odors. More research is necessary to validate this preference.

1.3 Determine seasonal phenology of *D. suzukii*

In the mid-Willamette Valley, winter survival of adult *D. suzukii* in field cages in semi-protected outdoor environments at ambient winter temperatures was studied during 2010-2012. Fifty adult females and 50 adult males were placed in each of 12 cages following acclimation at 10°C for 48 - 72 hr. Data suggested that a mean of 47% of the flies survived for 60 days, 36% for 100 days, 13% at 120 days, and less than 1% of adult *D. suzukii* survived fluctuating overwintering field conditions for 150 days. Zero flies survived to 180 days in the cages.

In Hood River County, OR, clear deli cups baited with apple cider vinegar (ACV) or ACV plus table salt (10% NaCl solution to prevent baits from freezing in the winter months) were used to monitor *D. suzukii* in a climate significantly colder than the Willamette Valley for the three years (2010 – 2012). Perhaps owing to a mild winter in 2012 as compared with the cold 2011 winter, *D. suzukii* were trapped earlier and in more places in the Mid-Columbia fruit production district in 2012. It also appears that a July, 2012 heat wave temporarily reduced fly activity. Analysis of flies captured in traps for the same years in Washington showed a consistent pattern of low fly activity January through late July, rising in mid-August, and peaking in October or November. In years with warmer winter conditions, fly counts were higher earlier in the season. Following an extreme cold snap in November 2010, 2011 was the anomalous year, with only 4 regions positive for *D. suzukii* by 1 August. By contrast, the majority of regions showed positive trapping in 2010 and 2012 by 1 August (Figure 3). The bulk of the Pacific Northwest cherry crop is harvested in June and July. Late fly emergence or buildup may provide an opportunity for temporal escape of early-ripening cultivars in many PNW cherry-producing regions.

1.4 Assess SWD plant preferences and determine stages of fruit susceptibility to larval infestation

In the Willamette Valley, fruits of field-collected wild and ornamental plants were examined in the lab for emergence of *D. suzukii.* Susceptibility of these plant species under laboratory conditions does not reliably correlate with susceptibility in commercial field settings. Thus, additional forced-choice laboratory trials were conducted in order to determine relative suitability and attractiveness for *D. suzukii*.

Tested plant species were assigned to one of three classifications based on results of the forced choice trials: i. plants that are not susceptible or attractive; ii. plants with eggs observed in the fruits, but with low levels of larval development; and iii. plants with eggs observed in the fruits and larval development at a sufficient level to suggest that they may be suitable and attractive to *D. suzukii* (Table 1).

Similar work is being conducted in the north San Joaquin Valley of California, but is not reported here.

Table 1. Potential attractiveness and susceptibility to *D. suzukii*

Not susceptible or attractive	Eggs laid: Low level of development	Development suggests potential susceptibility and attractiveness in the field
Chinese holly *Ilex cornuta*	Japanese aucuba *Aucuba japonica*	Salmonberry *Rubus spectabilis*
Japanese holly *Ilex crenata*	Parney's cotoneaster *Cotoneaster lacteus*	Indian strawberry *Duchesnea indica*
Japanese skimmia (white) *Skimmia japonica*	Heavenly bamboo *Nandina domestica*	Salal *Gaultheria shallon*
David's viburnum *Viburnum davidii*	Japanese skimmia (red) *Skimmia japonica*	Oregon grape *Mahonia aquifolium*
Bittersweet nightshade *Solanum dulcamara*	Portugese laurel *Prunus lusitanica*	Gooseberry *Ribes uva-crispa*
Beautyberry *Callicarpa americana*	Wild rose hips *Rosa spp.*	Hardy kiwi *Actinidia arguta*
Yeddo rhaphiolepis	Hawthorne *Crataegus spp.*	Redtwig dogwood *Cornus sanguinea*
	Gingko *Ginkgo biloba*	Cherry laurel *Prunus laurocerasus*
		American Elderberry *Sambucus canadensis*
		Pacific mountain ash *Fraxinus latifolia*
		Evergreen huckleberry *Vaccinium ovatum*
		Lingonberry *Vaccinium vitis-idaea*
		Sarcococca *Sarcococca spp.*
		Snowberry *Symphoricarpos spp.*

Lee Lab, USDA-ARS; Dreves Lab, OSU.

Develop management strategies to minimize infestation and reduce risk..

2.1 Optimize monitoring systems

Bait trials: In a 14-month study in the Willamette Valley, yeast-baited traps caught significantly more *D. suzukii* during the pre-harvest through post-harvest period in blueberries. It appears that yeast attracts more flies when the ambient temperature rises above 4.5°C. ACV appears to be the better attractant during cold winter months (Dreves Lab, OSU).

In Oregon, 17 organic compounds falling into four classes (alcohols, acids, acetates, esters) were tested in the lab for their attractiveness to *D. suzukii*. A trap containing a vial of the attractant and a soapy water control trap were placed in each cage of 200 mixed gender flies for a 24-hour period. The most attractive compounds in each class were subsequently tested in the field. One experiment for each class of compound was performed in two crops during peak fruit ripening. The six compounds most attractive in their respective classes were: methanol, ethanol,

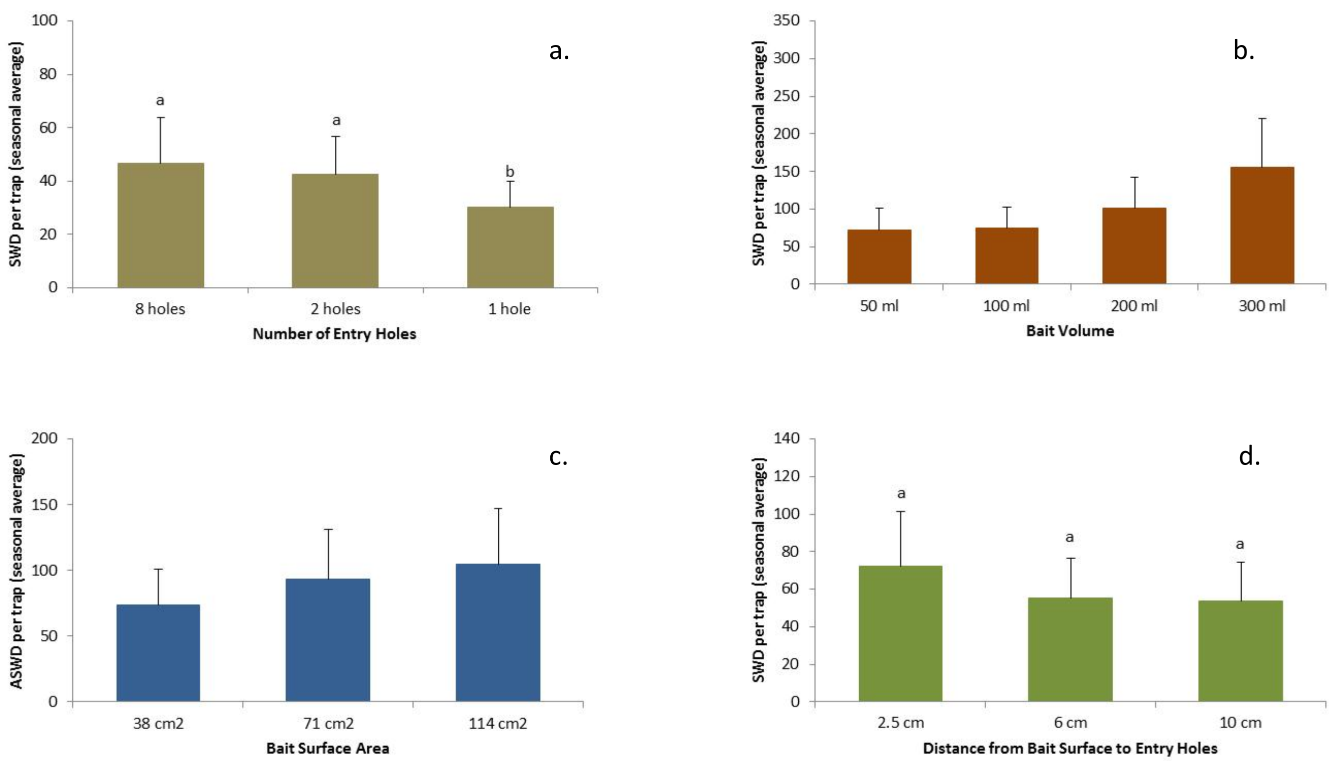

Figure 4. Four factors of trap design: Number of entry holes (a), bait volume (b), bait surface area (c), and headspace or distance from bait surface to entry holes (d). Fly capture increased with increasing number of entry points, increasing bait volume, and higher bait surface area. Headspace and surface area variance did not result in significant differences. Beers Lab, WSU.

Routine trap maintenance is an important component of any monitoring program.

acetic acid, ethyl acetate, phenethyl propionate and phenethyl butyrate were similar in their attraction in the field (Lee Lab, USDA-ARS). In California, ACV was augmented and tested with an assortment of organic volatiles including rosewater, raspberry extract, cane sugar, methyl anthranilate, and merlot wine. ACV was further augmented in a single trial with a combination all of those compounds. Merlot was significantly more attractive to *D. suzukii* than any of the others except for the combination bait; there was no difference between Merlot and the combination bait. Methyl anthranilate may repel *D. suzukii*. This work adds to previous work exploring whether compounds similar to those found in wine and vinegar are candidate bait ingredients for *D. suzukii* (VanSteenwyk Lab, UC Berkeley).

In Watsonville, CA, the efficacy of baits and relative seasonal attraction of *D. suzukii* among three raspberry varieties with sequential ripening dates were studied in hoop houses. Baits included apple cider vinegar (ACV), a yeast-sugar-water bait, and a water control. The yeast-sugar-water bait had begun to ferment before the traps were placed in the field. Larval infestation was monitored while fruit was present, and monthly vacuum samples of adults were collected. Females were more abundant in traps than males, and females were more strongly drawn to ACV than males at most time periods. The yeast lure captured slightly more flies overall, though both trap types showed similar trends.

<u>Trap trials:</u> Four factors in trap design were tested in Washington (Figure 4). These were i. number of entry points available to the fly; ii. bait volume; iii bait surface area; and iv. headspace. Fly capture increased with increasing number of entry points, greater bait volume and larger bait surface area. Headspace trials tested the distance from the bait surface to entry holes. No significant difference in fly captures was observed based on trap headspace. By contrast, researchers in Oregon and elsewhere found that smaller headspace correlated to higher trap count (Lee et. al). Traps with increased entry area in the form of mesh-covered holes on the sides of clear deli cups caught significantly more flies compared to standard fly entry points, and yellow and red cup traps caught more than white or clear traps. Work in Washington State confirmed the finding that trap color resulted in no significant difference in fly captures. Trap and bait optimization work is ongoing.

2.2 Develop and validate degree-day model and establish treatment thresholds

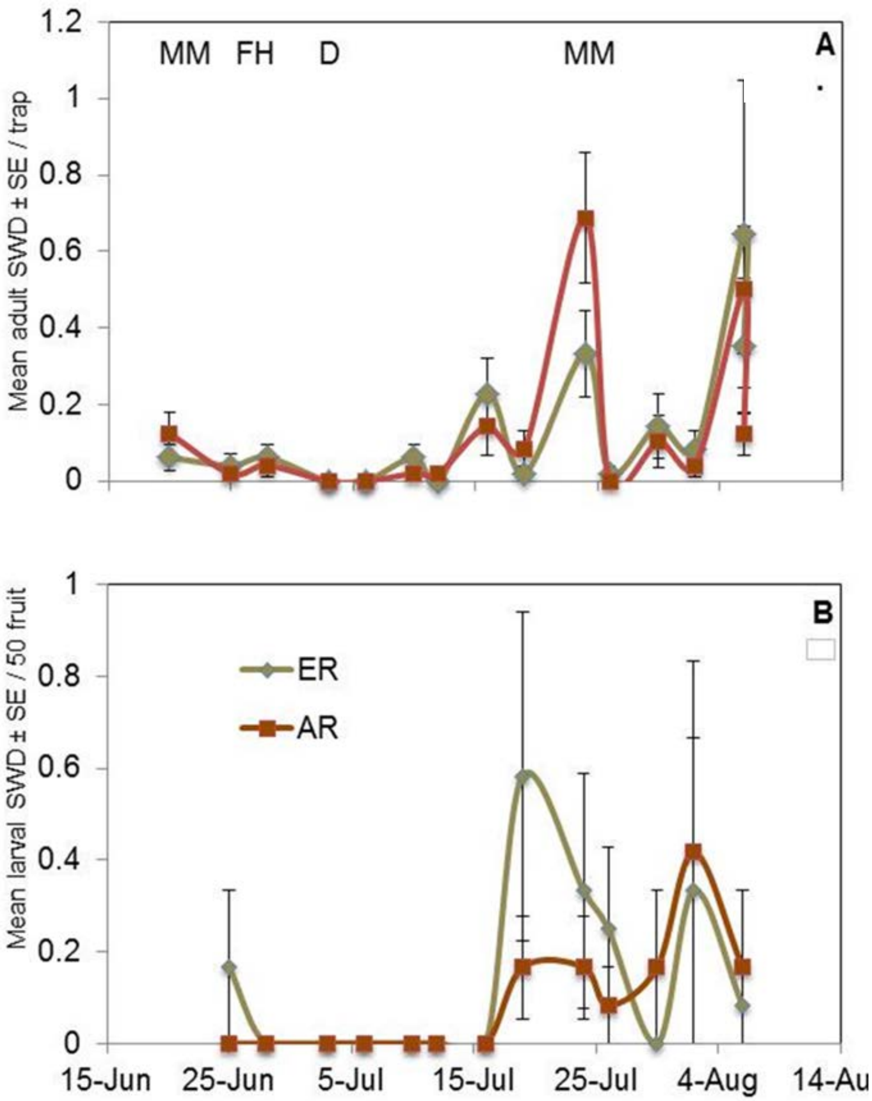

Figure 5. *D. suzukii* adult (A) and larval (B) mean larval abundance per 50 fruit on sampling dates for every row or alternate row pesticide applications. MM = Mustang Max application; D = Delegate application; FH = first harvest date; LH = last harvest date. Lee Lab, USDA-ARS.

The Integrated Plant Protection Center (IPPC) and the IPM Pest Information Platform for Extension and Education (PIPE) collaborate with this project and developed a series of synoptic incidence and risk maps along with degree-day (DD) summaries for *D. suzukii*. Phenology model predictions, using a *D. suzukii* DD clock and a winter survival index are supported by PIPE at Oregon State University.

2.3 Laboratory assays and field trials for chemical controls

__Alternate row sprays:__ Efficacy of reduced-pesticide alternatives was trialed in a conventional, commercial raspberry field. During each spray application, one side of each row was treated; during the next application, the other side was treated. Efficacy was determined by placing and collecting 50 fruit in each of three blocks. Fruit were subjected to larval flotation extraction. Similar numbers of *D. suzukii* were found in either treatment, indicating that alternate row sprays were as effective as every row sprays in managing *D. suzukii* (Figure 5).

Border sprays: Work in the Willamette Valley tested the degree to which flies from non-crop areas might migrate to crop areas. The hypothesis that invasion could be prevented by spraying a 15 m border swath was tested in conventional blueberry. Adult *D. suzukii* damage was similar in the border spray treatment compared to the full cover spray. Economic benefits of border spray included a 12-fold decrease in application time, a 70% reduction in spray area, and an 87% reduction in fruit knockdown compared to the full cover spray. In a complementary study, flies were marked with protein and later trapped to confirm movement from perimeter Himalayan blackberry into cultivated raspberry as the fruit ripened. Protein marking demonstrated that *D. suzukii* will move into the crop from Himalayan blackberries surrounding the commercial crop. Very little movement into wheat or grass was observed as opposed to increased movement toward the susceptible crop (Figure 6).

Pesticide residues: Pyrethroids Brigade, Danitol and Mustang Max provided good residual mortality (about 90%) for about 7 days on blueberry foliage. The organophosphate (OP) malathion, the spinosyn Delegate and the carbamate Lannate provided less residual protection, particularly at 7 and 14 days after treatment (DAT), on blueberry foliage in northwestern WA. This line of research will provide more realistic expectations for fruit protection given the stage of fruit maturity, cultivar, crop size, the export country's minimum residue levels (MRLs), preharvest interval (PHIs), and the number of applications per season for each of the insecticides (Figure 7).

Micro-sprinkler chemigation: A micro-sprinkler system using Netafim nozzles for fruit cooling was evaluated in the Willamette Valley to determine efficacy of a Mustang Max chemigation. First-season results showed promising residual and treatment levels compared to standard full-cover applications.

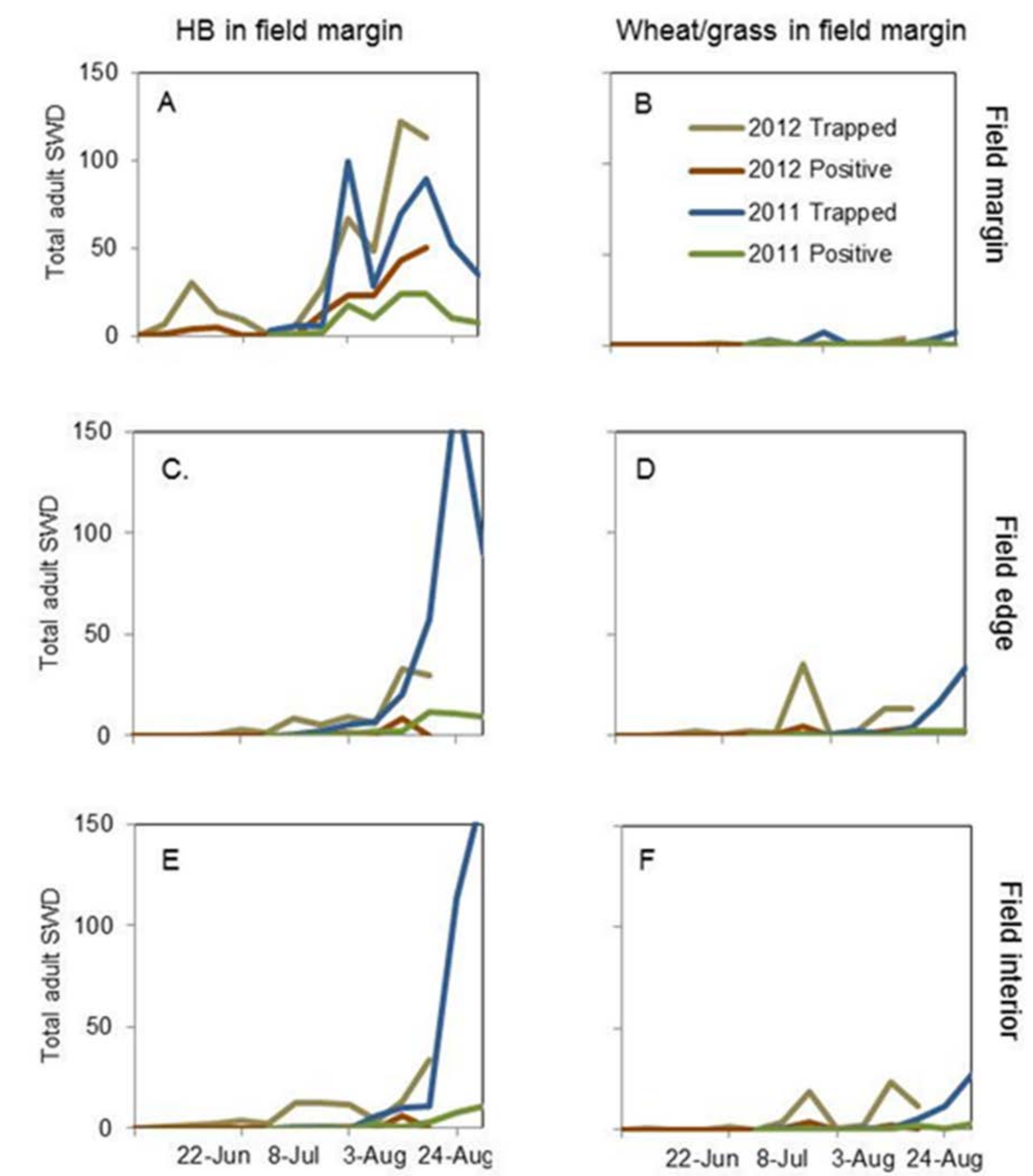

Figure 6. Abundance of protein marked *D. suzukii* adults visiting perimeter species from raspberry field. HB = Himalayan blackberry. Lee Lab, USDA-ARS.

Table 2. Efficacy of pesticides tested on cherry against *D. suzukii.*

Insecticide	Rate form./acre	Rating* Days after treatment 1	7	14-15
Diazinon 50WP	2-4 lb	E	F-G	F
Dimethoate 4E	2.75 pt	E	E	G
Malathion 57%	45 oz	G	P	P
Malathion 57%	90 oz	E	P	P
Malathion 8 Aquamul	5 pt	E	P	P
Malathion ULV	1 pt	G	P	P
Success 2SC	8 oz	E	F	P
Entrust 80WP	2.5 oz	E	F-G	P
Delegate 25WG	7 oz	E	G	F
Delegate 25WG	4.5 oz	E	F	P
Sevin XLR	4 qt	F-G	F	P-F
Sevin XLR	2 qt	F	F	P
Provado 1.6F	4 oz	P-F	P	P
Provado 1.6F	8 oz	F	P	P
Danitol 2.4 EC	10.7 oz	G	F	G
Danitol 2.4 EC	16 oz	E	G	G
Danitol 2.4 EC	21.3 oz	E	G	G
Warrior II	1.28 oz	F-G	F	F
Warrior II	2.56 oz	G	G	F
Mustang 1.5EC	4.3 oz	E	G	G
Baythroid XL	2.8 oz	E	G	G
Perm-Up 3.2EC	8 oz	F	F	P

*E = excellent, G = good, F = fair, and P = poor control.
Based on field-lab assays: VanSteenwyk, UCB; Shearer, OSU.

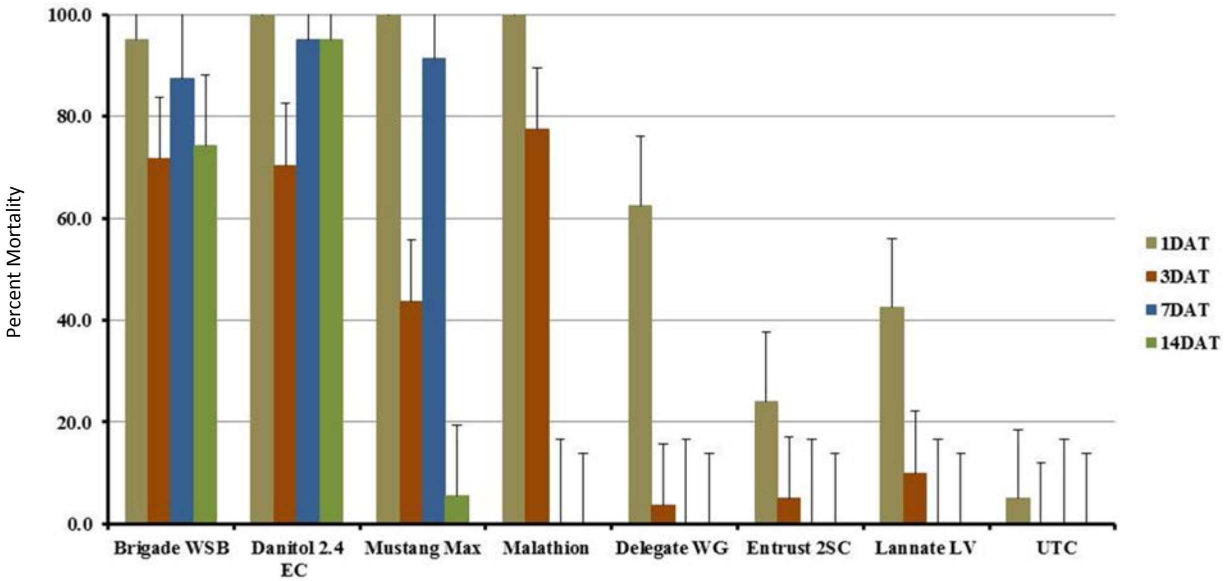

Figure 7: Efficacy of field-aged residues on *D. suzukii* on blueberry foliage, 2012. DAT = days after treatment; UTC = untreated control. Tanigoshi Lab, WSU.

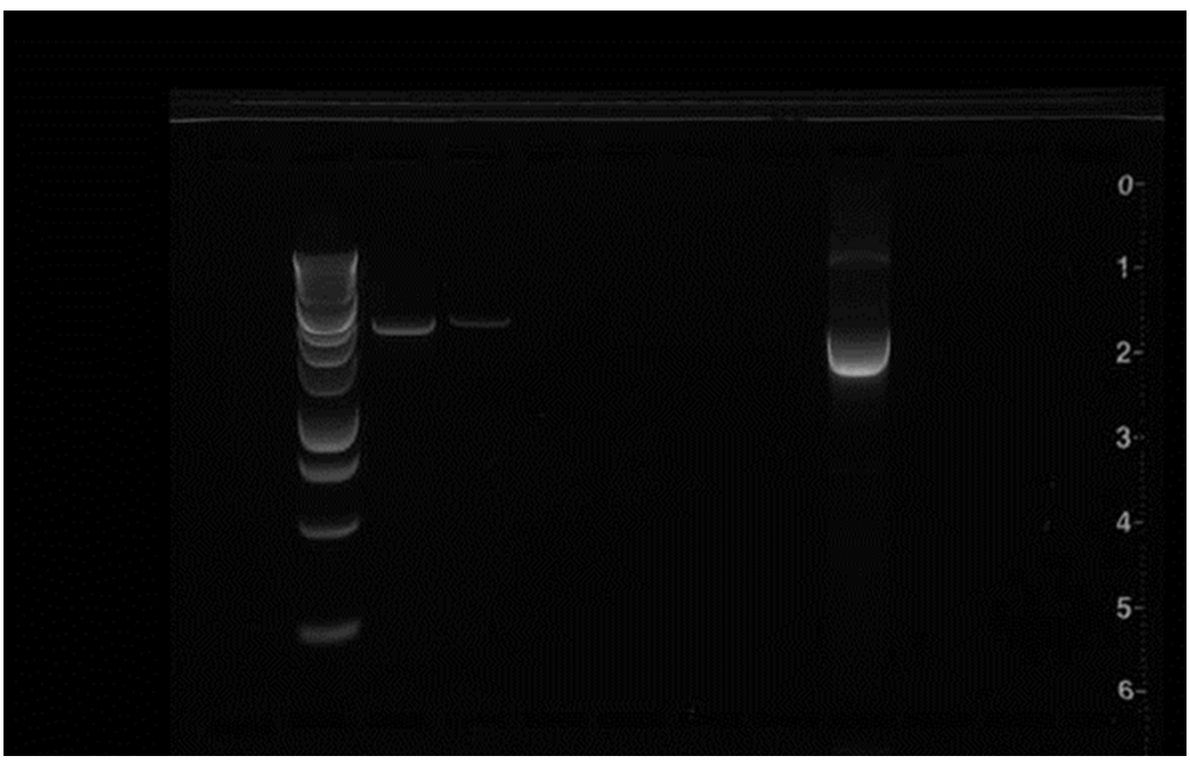

Figure 8. Gel electrophoresis with bright bands indicating successful amplification of Acetylcholinesterase (*AChE*) gene. Zalom Lab, UCD.

Chemical control trials: Assays were conducted in Oregon's Mid-Columbia region comparing the efficacy of products labeled for use on sweet cherry against *D. suzukii*. Field treated leaves and fruit were collected; flies were exposed for 24 or 48 hours to leaves at 1, 3, 7, 10, or 14 days after treatment (DAT) and for 24 hours to fruit at 1, 7, or 14 DAT. The pyrethroids Warrior and Danitol applied to foliage offered good control at either exposure or any DAT; there was no difference among the pyrethroids trialed. At 14 DAT, and with 24 hours exposure, these materials offered significantly better control than the spinosins (Delegate and Entrust), Malathion, a neonicotinoid (Belay) and carbaryl. The latter groups performed at statistically similar levels. By contrast, foliage efficacy trials at UC Berkeley using field-sprayed leaves indicated that Malathion consistently outperformed the pyrethoids Danitol and Lambda-Cy at 1 DAT on sweet cherry. At 7 DAT, a Lambda-Cy and Assail combination and Lambda-Cy alone outperformed Malathion at any rate and a Danitol-Belay combination (Table 2).

2.4 Determine propensity for insecticide resistance development

Work to determine likelihood of insecticide resistance development in *D. suzukii* is under way. Three compounds of interest that are regularly used by growers include zeta-cypermethrin, spinosad, and malathion. From the offspring of individuals surviving treatment with these compounds, regions of genes that are likely to mutate and confer resistance were studied for symptoms of resistance development. PCR primers have been designed for resistance gene target sites. One site that confers OP resistance has been identified in *D. melanogaster*; this site is highly conserved across many species. Researchers will determine whether OP resistant *D. suzukii* show genetic change at this site. This work contributes to management strategies of regional populations of *D. suzukii* prone to develop resistance to commonly used materials (Figure 8).

2.5 Survey for natural enemies for long-term biological control

The rove beetle *(Coleoptera: Staphylinidae)*, is a commercially available, ground dwelling generalist insect predator. Its potential to control *D. suzukii* infestations among fallen blueberry fruit was investigated. A lab assay placed two beetles and 2-5 infested berries on moist soil in 5-ounce containers. Mortality of *D. suzukii* larvae after 7 days was significantly higher than that of control treatments (Figure 9).

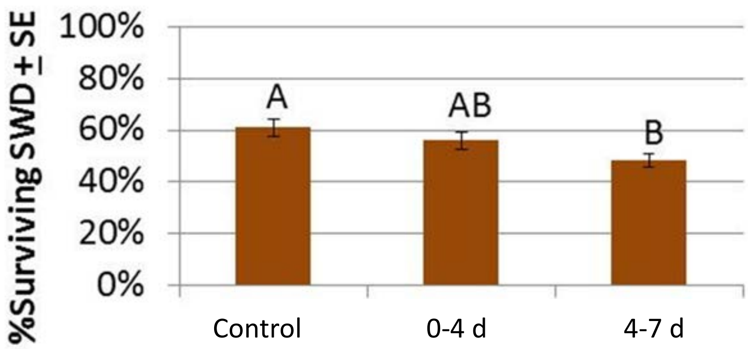

Figure 9. Percent SWD surviving in blueberries when rove beetles were introduced 0-4 d or 4-7 d post-infestation, and in an untreated control. Lee Lab, USDA-ARS.

A sampling method was developed to determine native parasitoid activity against *D. suzukii* using sentinel baits. Five bait media were used: an artificial medium (all weeks), intact blueberry, raspberry, and cherry fruits (when seasonally available), and banana slices (when no other fresh fruits were available). Baits were infested in the laboratory with *D. suzukii* and *D. melanogaster* larvae and exposed in the field for one-week periods from May through October. Bait traps were returned to the lab and observed for several weeks for parasitoid emergence. Two Hymenopteran species emerged from parasitized larvae: a Pteromalid, *Pachycrepoideus vindemmiae* (Rondani) and an unidentified Cynipid species. The generalist *P. vindemmiae* can utilize several Dipteran species as hosts and was the dominant parasitoid found on *D. suzukii* and *D. melanogaster*, representing 94% of the parasitoids identified in this trial. The

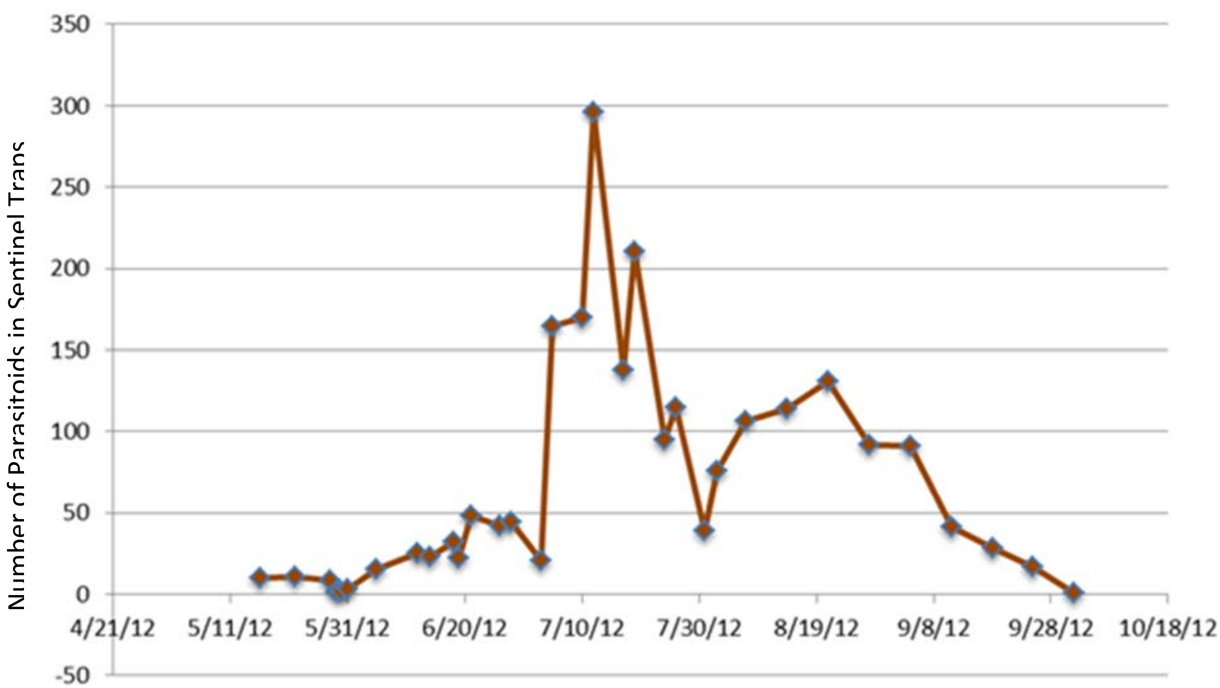

Figure 10. Seasonal abundance of parasitoids reared from host-baited sentinel traps from the Willamette Valley during 2012. Walton Lab, OSU.

Cynipid wasp made up the balance of parasitoids identified.

Parasitoid numbers in the traps increased with increasing *D. suzukii* numbers; a peak of 300 parasitoids were found on July 10, 2012. Sentinel traps successfully recovered parasitoids in all treatments, including unseeded artificial diet media. No-host traps recovered significantly lower parasitoid numbers compared to traps seeded with *D. suzukii* and *D. melanogaster* larvae. Low numbers of indigenous parasitoid species suggests foreign exploration for exotic natural enemies is necessary for biological control to be an effective IPM tool. This sampling method could also be used to discover viruses, bacteria, and fungi that may potentially impact *Drosophila* population growth (Figure 10).

Sentinel trap for discovery of *D. suzukii* parasitoids or microorganisms that prey on *D. suzukii.*

2.6 Sanitation and preventative practices

In an assay of larval survival in windfall blueberry in the Willamette Valley, *D. suzukii* adults emerged from fruit when exposed to outdoor summer conditions (temperatures ranged from 17.0 to 21.0°C, averaging 19.4°C), although the mean survival time decreased as length of exposure increased. In the field under conditions of heavy pest pressure, defined as more than 100 *D. suzukii* per trap per week, no oviposition was observed in windfall blueberry as long as fruit was plentiful in the canopy of the bush. Once availability of this preferred source declined, 2.5% of windfall fruits on average were positive for oviposition.

In a laboratory study of third instar larvae under a cold storage treatment, 'Earliblue' blueberries infested with non-acclimated larvae were held at 22°C for two days and then exposed to cold treatment at -1.1-1.7°C for 24, 48, 72, 96 and 168 hours. Emergence of adults from cold-stored fruit was observed at each exposure period. Fewer adults emerged from fruits held under longer exposures (Figure 11).

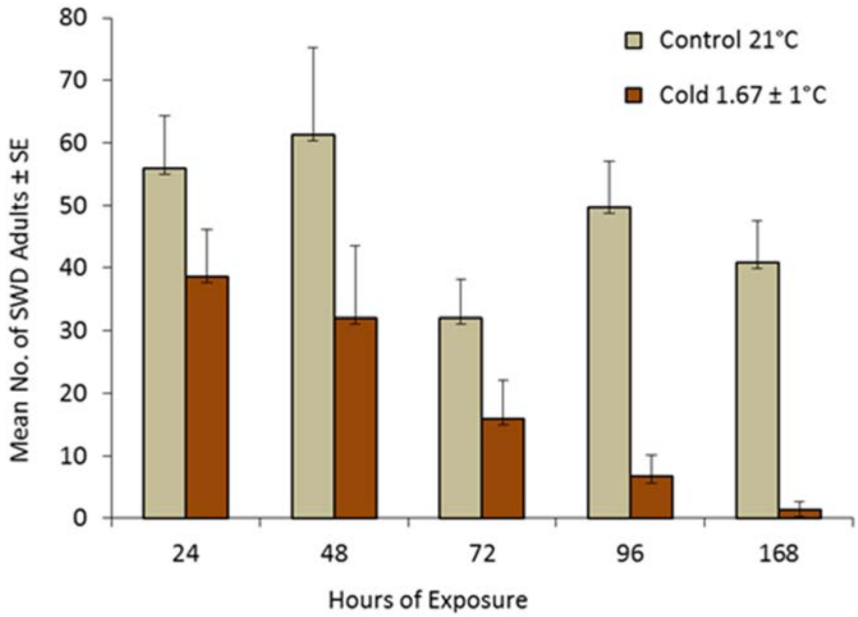

Figure 11. Mean number of developed adult D. suzukii from 2nd and 3rd instar *D. suzukii* larvae found in post-harvest 'EarliBlue' blueberries in relation to hours of exposure to cold or room temperature. Dreves Lab, OSU.

2.7 Economic analysis

Grant-related economic research from University of California Agriculture and Natural Resources models management costs including labor and pesticides, extra hired labor and packing plant rejections; optimal management is being compared to actual management. This work analyzes the extent to which growers implement recommended management practices, and captures how and why they deviate from them. An economic interpretation of deviation is that growers underestimate the risk of *D. suzukii* infestation of fruit crops. In Oregon, economic analysis follows a case-study approach to develop enterprise budgets. These economic models will permit growers to calculate the profitability and assess feasibility of conventional and integrated management scenarios, and account for different assumptions between typical large and small growers.

Measure awareness, impact and success.

3.1 Conduct annual stakeholder advisory panel meetings to review accomplishments and receive feedback and direction

The overall goal of these annual meetings is to network and increase project success by providing stakeholders with an opportunity to deliver feedback to researchers and correct the emphases within the original scope of work, according to industry need. The project evaluators gathered observational data at the November 9, 2012 meeting held in Portland, Oregon, which fell into three main categories.

Written communication: Project partners released several Extension publications addressing *D. suzukii* management in 2012. A publication was accepted in the Journal of Economic Entomology that compares trap types. Each state has developed websites or blogs, including real-time mapping and modeling products for producers.

Networking and verbal communication: Over the past year the advisory panel has observed greater collaboration among the project team members. They requested more information about overwintering behavior of *D. suzukii*. Such information would support funding requests to commodity groups for crop and local-area-specific research. Stakeholders perceive education of those growers of susceptible crops who believe their crop will not be impacted by *D. suzukii*, as an important task. These growers must be informed in order to develop management protocols so that they can produce marketable fruit without negatively impacting nearby fields. Social media were suggested as means to reach growers who do not participate in education programs.

Pest management concerns: In light of local levels of damage from *D. suzukii* in 2012, the advisory group hypothesized that greater concern will be documented in the 2013 survey results. Advisors further requested more information about modes of action, and which organically approved materials have been assayed. The failure of monitoring traps to attract flies in fields with infested fruit may fuel a lack of trust in the procedure. Other concerns included levels of infestation leaving packers with insufficient fruit, and fears of market backlash or undesirable publicity due to pesticide use in these crops with a reputation for healthfulness.

3.2 Evaluation tools that assess biological, economic and social impacts

Three Institutional Review Board approved tools are employed to assess perception of the biological, economic, and social impacts of *D. suzukii* within three commodity groups in Oregon: berries, stone fruits, and wine grapes (Table 3). Within each commodity group, packers and processors, growers, and participants in *D. suzukii*-related events are queried. The tools include: i. a confidential, annual grower survey; ii. a confidential, annual packer and processor survey; and iii. an “event questionnaire” for use at outreach events drawing mixed audiences.

Blueberry field day, July, 2012, OSU-North Willamette Research and Extension Center. Photo Credit: Bernadine Strik, Oregon

The confidential survey for growers, and the confidential survey for packers and processors, are distributed annually in March via US Mail (or, at stakeholder request, offered as on-line version) to their respective audiences for feedback on the previous growing season. The event tool is distributed at all *D. suzukii*-related educational events; respondents are anonymous and span a range of stakeholders. Data from all tools are submitted to the evaluation team for analysis and interpretation. Findings are presented at subsequent stakeholder advisory meetings.

This most recent evaluation indicated that stakeholders heard about SWD from Extension, field consultants, and at workshops. Their most trusted sources of information are personal observations, field personnel, conferences and other educational events, and the Internet. Although stakeholders do not attribute economic loss to *D. suzukii*, they do feel “concerned” to “very concerned” about the pest, and their greatest concerns are increased use of pesticides, loss of income or markets, and increased costs. They want more information from websites, educational events, and statewide monitoring. The principle actions they are willing to do include observing, monitoring, adjusting their management practices, and working with researchers.

The stakeholder concerns are a clear message to project participants to continue to work closely with Extension field faculty to actively promote the survey tools as a means of improving response rate. Project leadership and the stakeholder advisory group have repeatedly emphasized the importance of managing the message while gathering information. Data gathered by the evaluation team is shared carefully and the institution and a stakeholder panel screen highly sensitive data before it they are made available to the public. Table 3 provides a summary of specific lessons learned from the Oregon evaluation products.

Table 3. Impacts of *D. suzukii*, by commodity grouping. Packer/processor survey results, and grower survey results, 2011.

PACKER-PROCESSOR survey results			
	Stone Fruit (cherry)	Berries (blueberry, raspberry, strawberry)	Wine Grape
Perceived economic loss[1]	2009: 17% 2010: 0% 2011: 0%	2009: 53% 2010: 40% 2011: 46%	2009: 0% 2010: 0% 2011: 0%
Greatest concerns	Regulations placed on fruit Loss of market Increased pesticide use	Increased pesticide use Potential for market loss Increased costs	Wine quality Cost of controls Reduced yield
Actions taken	Conduct visual inspections Work with researchers Monitor and report	Conduct visual inspections Adjust management practices Work with researchers	Monitor and report Conduct visual inspections Adjust management practices
GROWER survey results			
Perceived economic loss	2009: 3% 2010: 3% 2011: 7%	2009: 7% 2010: 10% 2011: 26%	2009: 4% 2010: 4% 2011: 0%
Greatest concerns	Loss of market Increased pesticide use Increased costs	Increased pesticide use Loss of income Loss of market	Wine quality Increased pesticide use Reduced yields
Actions taken	Adjust management practices Conduct visual inspections Monitor and report	Conduct visual inspections Adjust management practices Monitor and report/Work with researchers (tie)	Monitor and report Conduct visual inspections Work with researchers

[1]These perceived losses are related to increased management costs to produce commercial market quality fruit intended for the local market. Conway Lab, OSU.

Synthesize existing and new information and provide real-time support.

4.1 Organize and schedule outreach and education interactions

Local, regional, and national outreach events are important educational activities for the research partners. In 2012, these included more than 100 presentations, including field days, to growers and home gardeners, and more than 50 presentations to academic peers, some of them international. The federal government of Mexico requested and supported a face-to-face research review for their berry industry. With this support, the project leveraged multiple Spanish-language resources from existing documents for project stakeholders.

4.2 Create informational materials

Each of the land-grant institutions funded by this project has an active website dedicated to communicating research findings, resources, and news about *D. suzukii* to the public. As findings accumulate, are reviewed, and published, grant-funded outputs are made available through sector-appropriate venues. Some informational materials are extremely focused in their audience and content, for example a photo document comparing late instar larvae of western cherry fruit fly with those of *D. suzukii*; this work addresses a very specific need of the western cherry industry. Others, such as UC Davis' *Landscape Pest Identification Cards*[1] or OSU's *Flies in Space*, support Extension learning activities. Print formats such as the *Blueberry 2013 Pest Management Guide for the Willamette Valley*[2] or the *PNW Insect Management Handbook*[3] are regularly revised to include strategic management of *D. suzukii* and other emerging pests. Outreach is also conducted through webinars, presentations to audiences of all descriptions, and volunteers who assist with many research- and outreach-related tasks.

4.3 Develop real-time online information, networking tools, and forums

The project website is a primary outreach tool for University of California, Oregon State University and Washington State University. In eastern Washington, a regional trapping program reports to cherry growers on *D. suzukii* seasonal phenology, distribution and first regional capture. An online map shows the placement of 330 traps that were deployed from the Canadian border to the Oregon border; color-coding of trap symbols indicates *D. suzukii* captures per trap. An accompanying

[1] http://anrcatalog.ucdavis.edu/LawnGarden/3513.aspx
[2] http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/36828/em8538.pdf
[3] http://uspest.org/pnw/insects

table summarizes the current year trap history by region. The first capture in a region is the recommended action threshold for growers; growers in the affected region are alerted by email distribution. Users can graph the entire database, or filter by region and crop.

The IPPC and PIPE collaborate with this project to support a series of synoptic incidence and risk maps along with degree-day summaries for *D. suzukii.* Phenology model predictions, mapping of regional relative abundance, a *D. suzukii* DD clock, and a winter survival tool including heat effects are supported by these groups at Oregon State University. The collaborative multi-state Northwest Berry and Grape Information Network provides users with real-time mapping access to trap counts by crop at the county level. Weekly and biweekly historical data can be retrieved by crop. In the Willamette Valley, Peerbolt Crop Management continues to update the scouting database; posts regional weekly updates, which are also distributed to growers, packers and distributors by email.

Appendix 1: Contributors by Objective

Objective		Contributor, affiliation[4], study subject
Objective 1: Evaluate genetic, biological and ecological parameters of SWD.		
Objective 1.1	Conduct Genomic studies to assess origin and propensity for adaptation to different climates	Begun, David; UC Davis, generic study
Objective 1.2	Evaluate biological and environmental parameters for survival, population growth, overwintering, life cycle and habits	Brown, Preston; OSU, stone fruit, generic study Dreves, Amy; OSU, all fruit, generic study Lee, Jana; USDA-ARS, small and stone fruit, generic study Shearer, Peter W.; OSU, stone fruit, generic study Walton, Vaughn; OSU small fruit, grape, generic study
Objective 1.3	Determine seasonal phenology of SWD	Beers, Elizabeth H.; WSU, stone fruit Bolda, Mark; UCANR, small fruit Caprile, Janet; UCANR, stone fruit Castagnoli, Steven; OSU, small and stone fruit Coats, William; UCANR, stone fruit Dreves, Amy; OSU, all fruit, generic study Grant Joseph; UCANR, stone fruit Hamby, Kelly; UC Davis, small and stone fruit Lee, Jana; USDA-ARS, small and stone fruit, generic study Long, Lynn; OSU, stone fruit Shearer, Peter W.; OSU, stone fruit, generic study

[4] OSU = Oregon State University; UC Berkeley = University of California, Berkeley; UCANR = University of California Agriculture and Natural Resources; UC Davis = University of California, Davis; USDA-ARS = United States Department of Agriculture, Agricultural Research Service; WSU = Washington State University.

		Tanigoshi, Lynell; WSU, small fruit van Steenwyk, Robert; UC Berkeley, stone fruit Walsh, Douglas; WSU, grape Walton, Vaughn; OSU, small fruit, grape, generic study Zalom, Frank; UC Davis, small and stone fruit, generic study
Objective 1.4	Assess SWD plant preferences in the lab and in the field, and determine stages of fruit susceptibility to larval infestation	Lee, Jana; USDA-ARS, small and stone fruit, generic study Walsh, Douglas; WSU, grape
Objective 2: Develop a management strategy to minimize infestation and reduce risk		
Objective 2.1	Optimize monitoring systems for early detection, trapping, and assessing damage	Beers, Elizabeth H.; WSU, stone fruit Caprile, Janet; UCANR, stone fruit Dreves, Amy; OSU, all fruit, generic study Walsh, Douglas; WSU, grape
Objective 2.2	Develop regional mapping of degree day accumulation for SWD combining field and lab studies; establish economic thresholds	Dreves, Amy; OSU, all fruit, generic study Lee, Jana; USDA-ARS, small and stone fruit, generic study Walton, Vaughn; OSU, small fruit, grape, generic study
Objective 2.3	Conduct laboratory assays and replicated field trials for chemical controls	Beers, Elizabeth H.; WSU, stone fruit Bolda, Mark; UCANR, small fruit Shearer, Peter W.; OSU, stone fruit, generic study Tanigoshi, Lynell; WSU, small fruit van Steenwyk, Robert; UC Berkeley, stone fruit
Objective 2.4	Determine propensity for insecticide resistance development	Begun, David; UC Davis, generic study Hamby, Kelly; UC Davis, small and stone fruit Zalom, Frank; UC Davis, small and stone fruit, generic study
Objective 2.5	Initiate local field survey for natural enemies in agroecosystems, home gardens and wildlands, and long-term biological control	Brown, Preston; OSU, stone fruit, generic study Dreves, Amy; OSU, all fruit, generic study Lee, Jana; USDA-ARS, small and stone fruit, generic study Miller, Jeffrey; OSU, generic study Shearer, Peter W.; OSU, stone fruit, generic study Walton, Vaughn; OSU small fruit, grape, generic study
Objective 2.6	Conduct area-wide sanitation and preventative practices	Bolda, Mark; UCANR, small fruit Caprile, Janet; UCANR, stone fruit Coats, William; UCANR, stone fruit Dreves, Amy; OSU, all fruit, generic study Tanigoshi, Lynell; WSU, small fruit Yang, Wei; OSU, small fruit Zalom, Frank; UC Davis, small and stone fruit, generic study
Objective 2.7	Complete economic analysis regarding performance of examined management alternatives.	Bolda, Mark; UCANR, small fruit Goodhue, Rachael, UC Davis, generic study Seavert, Clark; OSU, generic study Strik, Bernadine; OSU, small fruit
Objective 3:	Measure awareness, impact and success	Conway, Flaxen; OSU Halbleib, Mary; OSU
Objective 4: Synthesize existing and new information and provide real-time support to growers, IPM practitioners, industry and community		

Objective 4.1	Organize and schedule training interactions with growers, IPM practitioners, industry and community	Bolda, Mark; UCANR, small fruit Brewer, Linda; OSU Caprile, Janet; UCANR, stone fruit Castagnoli, Steven; OSU, small and stone fruit Dreves, Amy; OSU, all fruit, generic study Long, Lynn; OSU, stone fruit Murray, Todd; WSU, small and stone fruit Strik, Bernadine; OSU, small fruit Tanigoshi, Lynell; WSU, small fruit van Steenwyk, Robert; UC Berkeley, stone fruit Walsh, Douglas; WSU, grape Yang, Wei; OSU, small fruit Zalom, Frank; UC Davis, small and stone fruit, generic study
Objective 4.2	Create informational materials	Beers, Elizabeth H.; WSU, stone fruit Bolda, Mark; UCANR, small fruit Caprile, Janet; UCANR, stone fruit Castagnoli, Steven; OSU, small and stone fruit Defrancesco, Joseph; OSU, small fruit Dreves, Amy; OSU, all fruit, generic study Gerdeman, Beverly, WSU; small fruit Long, Lynn; OSU, stone fruit Shearer, Peter W.; OSU, stone fruit, generic study Strik, Bernadine; OSU, small fruit Tanigoshi, Lynell; WSU, small fruit van Steenwyk, Robert; UC Berkeley, stone fruit Walsh, Douglas; WSU, grape Walton, Vaughn; OSU, small fruit, grape, generic study Yang, Wei; OSU, small fruit
Objective 4.3	Develop real-time interactive online web-based information and networking tools and forums allowing rapid learning and response	Dreves, Amy; OSU, all fruit, generic study Peerbolt, Thomas; Peerbolt Crop Management, small fruit Yang, Wei; OSU, small fruit