Final Report: Evaluating the Impacts of Border Vegetation Patterns on Multifunctional Biodiversity and Crop Production in Washington Blueberry

Principal Investigator(s) and Cooperator(s):

- Lisa DeVetter (PI; Assistant Professor, Dept. Horticulture at WSU)
- Dr. Beverly Gerdeman (Co-PI; Assistant Research Professor, Dept. Entomology at WSU)
- Dr. Bill Snyder (Co-PI; Professor, formerly in the Dept. of Entomology at WSU and now at the University of Georgia)
- Dr. Matt Arrington (Co-PI; PhD Student in Dept. of Hort. with DeVetter; now employed at Plenty)
- Dr. Hollis Spitler (Project Assistant; Agricultural Technician, Dept. of Entomology at WSU)

Abstract

Herbaceous flowering or woody plant borders are controversial in commercial blueberry (*Vaccinium corymbosum*) production. Border vegetation has the potential to increase populations of native pollinators and beneficial insects and birds that feed on key blueberry pests, such as spotted wing drosophila (*Drosophila suzukii*; SWD); however, they may also draw pollinators away from the crop, serve as overwintering and/or refugia sites for SWD, and increase populations of wild birds that feed on fruit and transmit foodborne pathogens. The objective of this project was to explore the impacts of border vegetation adjacent to commercial blueberry fields on multifunctional biodiversity, with an emphasis on pollination services, populations of beneficial and pest insect and bird species, and crop production. The hypothesis is that vegetation adjacent to blueberry plantings will increase multifunctional biodiversity and associated benefits, which will be measured as increased pollinator activity, increased populations of beneficial insects and insect-eating birds (with the potential for biocontrol), and enhanced crop productivity relative to plantings without adjacent border vegetation. However, we also hypothesize that adjacent vegetation will provide refugia for SWD and problematic birds (i.e. species that predate on fruit or transmit food-borne pathogens) that may limit the benefits of border vegetation. We tested our hypotheses in 2017 by comparing pollination services, populations of beneficial and pest insect and wild bird species, and production attributes of blueberry grown with or without adjacent border vegetation on 9 commercial farms in northwest Washington. Our border vegetation treatments include: 1) Control (no vegetation adjacent to the site); 2) Woody perennial vegetation [mixture of woody perennial species including Cedar (*Cedrus* sp.) and Arborvitae (*Thuja* sp.)]; and; 3) Herbaceous vegetation [mixture of monocots (e.g., *Poa* sp. and quackgrass (*Elymus* sp) and broadleaves (E.g., *Taraxacum officinale*)]. There were no differences in pollinator abundance, flower visitation rates, or estimated yield and fruit quality across the treatments. Different species of insects and arachnids were collected during a 16-week period using an insect vacuum and apple cider vinegar traps. Virtually no SWD were recovered and populations of all arthropod species declined in the border vegetation after a pesticide application. Yellow sticky cards used to monitor the movement of beneficial and pest insect species suggest there are no differences in their in-field populations by treatment. However, there were overall greater populations of both pest and beneficial insects in the border vegetation relative to in the blueberry field. Habitat-based point-counts were used to evaluate how border vegetation influenced populations of wild bird species. Pest species were observed in all treatments and densities of birds increased with decreasing distance to our border vegetation treatment. Data from this project show that our evaluated border treatments have small to negligible impacts on our measured variables and we did not detect any clear multifunctional benefits associated with our different border vegetation treatments.

Project Description

Washington State is a national leader in highbush blueberry production, producing 117 million pounds valued at $114 million dollars in 2017 (USDA 2018). Despite the industry's success, improving pollination and fruit set of highbush blueberry is a shared goal among growers in Washington State. Pollination is particularly challenging for western Washington growers, where cool and rainy climactic conditions during the bloom time are unfavorable for pollination by honey bees. DeVetter et al. (2016) demonstrated honey bee densities in western Washington are below the recommendations of 4-8 honey bees/bush, showing inadequate pollination is a constraint to achieving maximum yields and productivity (Isaacs et al. 2016).

Previous research has shown hedgerows and flower strips can promote pollination in blueberry by increasing pollinator richness and abundance (Blaauw and Isaacs 2014, Garibaldi et al. 2014). Blaauw and Isaacs (2014) compared blueberry fields adjacent to established wildflower plantings to those adjacent to mowed grass borders in Michigan. They observed an increase in the abundance of wild bees and syrphid flies, while honey bee populations were the same between wildflower and grass borders. Furthermore, fruit set, berry weight, and seed number per berry were greater among plants adjacent to wildflowers, which led to increased yield and revenue that exceeded the cost of wildflower establishment and maintenance. Blaauw and Isaacs (2015) also demonstrated wildflower plantings increased the abundance of natural enemies, including predaceous arthropods. These findings suggest similar benefits on pollination and biocontrol may be achieved through border vegetation in Washington blueberry fields.

Despite these positive findings, there is concern regarding the potential negative aspects of border vegetation on blueberry production. Arborvitae (*Thuja* sp.) is a popular hedgerow species bordering blueberry fields in western Washington and functions to prevent pesticide drift onto adjacent properties. The primary insect pest targeted by spray programs is SWD, a direct pest whereby larvae feed on developing fruit. Infestations of SWD lead to unsellable fruit or fruit that is downgraded based on poor quality. SWD will overwinter in evergreen vegetation (Caprile et al. 2016) and have been recovered by co-PI Gerdeman in arborvitae, raising concern that border vegetation may serve as overwintering sites for SWD and encourage their establishment. Additionally, native flowering plants bordering blueberry fields may supplement SWD nutrition, enhancing establishment and increasing pest populations earlier in the season. Laboratory studies by Tochen et al. (2016) determined access to flowering cherries and blueberries boosted nutrient levels with the potential to increase SWD survivorship.

Another concern is that border vegetation could provide habitat and increase populations of birds that feed on and damage blueberries, as well as transmit foodborne pathogens (e.g. human-pathogenic strains of *E. coli* and Salmonella) when they defecate in fields (Nielsen et al. 2004). Conversely, border vegetation could increase habitat for insectivorous birds that contribute to biological control of pest insects, and of raptors (e.g. hawks and falcons) that kill pest birds (Symondson et al. 2002).

Evidence from previous studies suggests that border vegetation can increase blueberry yields by promoting pollination and biocontrol. However, there may be negative aspects that reduce crop yields, fruit quality, and endanger food safety. Our project sought to generate data that will begin to elucidate the impacts current border vegetation has on these multifunctional aspects of blueberry production in western Washington.

Our BIOAg-funded project has allowed us to collect one year of data and we have observed some important trends in the pollinator, arthropod, and avian data. Overall, evaluated border treatments had small to negligible impacts on the measured variables and no clear multifunctional benefits were detected. SWD populations were low in 2017, so we are unable to determine how border vegetation impacts SWD specifically. However, populations of other species of insects and arachnids followed an important trend whereby they decreased shortly after on-farm insecticide applications for SWD. Insect biodiversity was also low and likely influenced by SWD insecticide applications. Our project shows current insecticide applications appear to drive insect populations and diversity in the field and may limit the benefits of border vegetation treatments. However, boarders with early-blooming flowers that coincide with blueberry's bloom time and when insecticide applications are reduced should be evaluated for their potential to enhance pollination services. We are currently wrapping up this project and publishing papers, but have been and plan to continue perusal of other project funding using our BIOAg data.

OUTPUTS

- Overview of Work Completed and in Progress:

  We collected all field data in 2017 and results from avian fecal samples are being analyzed. They will be completed by March 2019. Smith and DeVetter will write a paper summarizing the results from the avian fecal samples. We have also been assessing sticky card data in 2018. Results from our field study have been analyzed and a manuscript summarizing our findings will be submitted to the *Canadian Entomologist* in Dec. 2018 or Jan. 2019.

  Current project information has been extended to the Washington blueberry industry via a presentation at the Small Fruit Conference on Nov. 2017. An extension newsletter article summarizing year-one results was prepared and published in the WSU *Whatcom Ag Monthly* in April 2018 (https://extension.wsu.edu/wam/how-border-vegetation-impacts-pollination-and-insect-and-bird-species-abundance-on-washington-blueberry-farms/). Results were also briefly reviewed at the 2018 Small Fruit Conference during the Pollinator Workshop co-organized by DeVetter.

- Methods, Results, and Discussion (discussion for final reports only):

  Nine commercial field sites were identified in Whatcom and Skagit counties in 2017 and used for the study. Sites included the cultivars 'Duke', 'Draper', and 'Liberty' and were assigned one of the following three treatments, which each treatment replicated three times (nine sites total; **Fig. 1**):

  1) Control [no vegetation adjacent to the site other than monoculture fields of blueberry, red raspberry (*Rubus idaeus*), or potato (*Solanum tuberosum*); any grass adjacent to the site was mowed regularly];
  2) Woody perennial vegetation [Mixture of woody perennial species including Cedar (*Cedrus* sp.) and Arborvitae (*Thuja* sp.)]; and
  3) Herbaceous vegetation [mixture of monocots (e.g. *Poa* sp. and quackgrass (*Elymus* sp.) and broadleaves (E.g. *Taraxacum officinale*).

Assessments were made on how border vegetation treatments impacted: 1) pollinator activity and abundance; 2) populations of beneficial, neutral, and/or pest insect and arachnid species; 3) populations of bird species that predate on fruit, provide biological control from frugivorous avian species and/or pest insect species, or have the potential to vector food borne pathogens; and 4) blueberry productivity. Below is a description of how these data were collected in 2017.

Pollinator activity. Pollinator activity was measured during the bloom period in April/May of 2017, as described by Courcelles et al. (2013). Three 100-m transects proceeding down a row were established and ten bushes 10 m apart from each other were identified and tagged per transect so that they could be re-measured throughout the experiment (30 bushes total per site). Transects began at the natural edge of a field and proceeded towards the interior of the planting. Pollinator activity was measured at each site from 1000 HR to 1600 hr and when weather conditions were conducive to their activity (> 13 °C, with low wind, full-to-partial sun), which minimizes artificial differences due to environmental effects and makes data more comparable. Pollinator activity was measured when plants were in 15-100% bloom. These data were collected by counting the number of flower visitations per tagged bush within one-minute intervals, repeated three times per day for three days. Both pollinator species and relative abundances were also recorded during pollinator visitation counts.

Figure 1 Border vegetation treatments adjacent to highbush blueberry plantings include: 1) Control (furthest left); 2) Herbaceous vegetation (center); and 3) Woody perennial vegetation (furthest right). Photos by DeVetter.

Populations of beneficial, neutral, and/or pest insect and arachnid species. Between 12 May and 31 Aug. 2017, three replicate sites representing each vegetation type were sampled weekly using a D-vac vacuum insect net (Model-122). Weekly sampling consisted of 30 seconds of vacuuming per replicate location. Samples were placed into plastic bags, transported to WSU NWREC laboratory, and placed in the freezer. After 24 hours, samples were sorted into beneficial arthropods and pests, identified, and results were tallied and recorded (**Tables 1 and 2**). In total,144 total D-vac samples were collected and sorted.

Table 1. Beneficial Arthropods from Each Border Vegetation Type

Beneficials	Control	Perennial	Herbaceous
Parasitic wasps	785	212	1142
Spiders	97	237	162
Rove beetles	91	15	134
Lacewings	89	100	80
Ground beetles	31	62	26

Table 2. Total Pests Collected from Each Vegetation Border Type			
Pests	Control	Perennial	Herbaceous
Aphids	622	227	685
Thrips	327	173	558

In addition, apple cider vinegar traps were placed at each replicate border site and replaced with fresh vinegar as needed during the 16-week period in order to measure populations of SWD, which are attracted to vinegar and other products of alcoholic fermentation. We also placed yellow sticky cards (7 x 12 cm) at strategic locations in the field (along the rows at 9, 18, and 27 m; sticky surface was perpendicular to the row orientation) and borders at each of the 9 fields to provide additional information on movement of both pests and beneficial arthropods into and out of the blueberry field sites. These cards were placed out in fields at 15% blueberry bloom and sampled every 2 weeks until harvest depending on the volume of the catch. These data allowed us to capture changes in insect and arachnid population diversity and abundance as a function of different borders over time.

Avian assessments. During ripening and near harvest (July-Aug. 2017), wild bird identification and estimated abundances were obtained using a habitat-based point-count protocol (Huff et al. 2000). Counts were made from sunrise (~0500) to 0900 HR and repeated twice per field. For each census we observed birds at 2-10 points in each blueberry field, with number of locations varying depending on field size. Each point encompassed a 50 m radius and were 100 m apart. At each selected point, we identified the number of individual bird species seen or heard during a 10 minute period following the Farnsworth Removal method. Observations both within and beyond the 50 m radius were recorded. We focused our observations on species that are known to be present in northwestern Washington blueberry fields and predate on fruit. In addition, we included species that have the potential to feed on insects or deter frugivorous birds (e.g. raptors).

During this same time period, nets were placed in blueberry fields and fecal samples were collected from trapped birds. Birds were released after trapping. Fecal samples were taken to the Snyder lab to determine insects in the diet through extracting and sequencing prey DNA and the presence of human pathogens using 16s RNA sequencing. Data from these samples are pending and should be available March 2019.

Plant productivity. Select yield components, including berry number/bush, estimated yield, and berry mass were measured in order to evaluate the effects of border vegetation on crop productivity. Average seed number per berry was also be determined, as number of healthy, fertile seeds (> 1.7 mm in length) is indicative of fertilization and can serve as a proxy for effective pollination.

Data analysis. Pollination and plant (fruit set, estimated yield, berry mass, and seed number) data were analyzed in R-studio Version 2.15.3 (R Development Core Team; R Foundation for Statistical Computing, Vienna, Austria) statistical platform using the '*cran*', '*agricolae*' '*lme4*' and '*ggplot*' statistical packages (RStudio, 2015). We used generalized linear mixed models (GLMMs) to analyze the effect of border treatment on total wild bird density and the density of five focal bird species. We further investigated the impact of distance to closest semi-natural or natural habitat on total wild bird density using GLMMs. We measured Euclidean distance from each survey point center to nearest natural/semi-natural habitat using ArcGIS v. 10.2. We used treatment as a fixed effect for total and focal species density and distance to natural habitat as a fixed effect for total density. Point nested within farm was treated as a random effect to account for repeated visits and Poisson error distributions were utilized. GLMMs were performed in the lme4 package in Program R (Bates et al. 2015). We a priori selected 7 species but did not have enough observations to model European Starling (*Sturnus vulgarus)* or crow (*Corvis* spp.) density. Diet guilds were classified following Wilman et al. (2014) and food pathogen reservoirs were determined by searching the UGSG Wildlife Health Information Sharing Partnership Event Reporting System (WHISPers) and searching the ISI Web of Science database.

- RESULTS

Pollinator activity. No significant difference was observed in honey bee (*Apis mellifera*) foraging activity during optimal foraging conditions between hives at different sites. This indicates that the colony size and health of stocked honey bee hives were uniform across sites during bloom. No treatment differences were observed for pollinator activity by honey bees or other bee species (primarily *Bombus* spp.) across the treatment sites (*P*-value= 0.8212 and 0.6615, respectively).

Populations of beneficial, neutral, and/or pest insect and arachnid species. No SWD were collected using either sampling method. This aligns with low populations of SWD reported in Western Washington and by Skagit County Extension in 2017. Overall, SWD populations in 2017 were the lowest since they first invaded the state in 2009. Therefore, no investigations into SWD reproductive status were able to be conducted.

Total numbers of arthropods collected from the herbaceous and control borders were very similar (40% and 35%, respectively) and together represented 75% of the total number of arthropods collected. The perennial sites exhibited the lowest total arthropods collected during 2017 at 25%. Aphids and thrips were the most commonly collected pests while parasitic wasps and spiders represented the largest percentage of beneficial arthropods collected using the D-vac (**Fig. 2**).

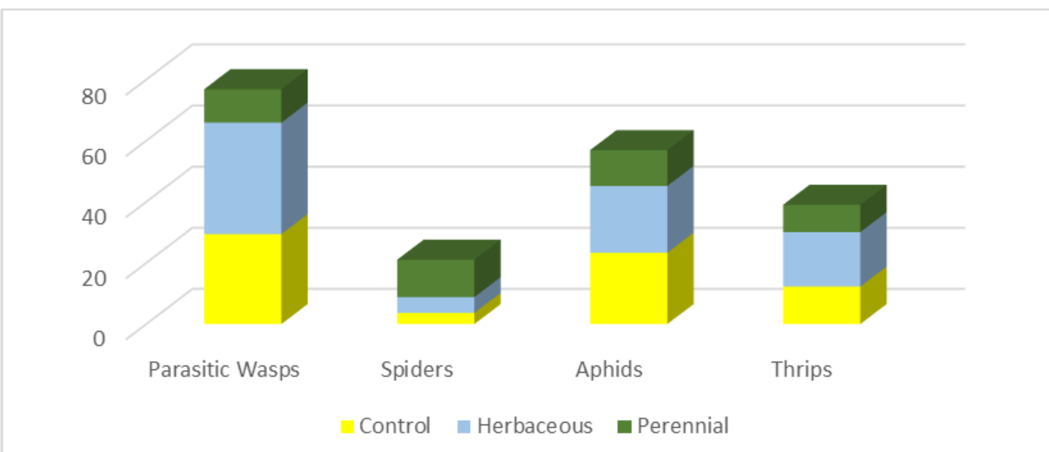

Figure 2. Arthropod diversity based on D-vac samples from all border replicates. Y-axis represents total number of observed arthropods. Figure by Gerdeman and Spitler.

Numbers of parasitic wasps aligned with border vegetation diversity, with herbaceous borders exhibiting 1.45-fold increase over the control border and a 5.4-fold increase over that of the perennial border (**Fig. 3**). Presence of nectar producing flowers boosts oviposition of parasitic wasps and the herbaceous vegetation border was most likely to have flowers and nectar present. On the other hand, spiders were more common in the woody perennial border but do not partake on nectar or pollen and do not require supplemental sources and are only restricted by presence of prey. Although not included in the tables, a group of mites, the Oribatida were present in large numbers; 515 in the control, 300 in the herbaceous, and 825 in the perennial sites. Oribatids are fungivores and will feed on algae and lichen. Perennial sites, while not particularly diverse, provide a perfect substrate for growth of algae and lichen. The high numbers of Oribatids could provide food for the spiders. Thrips feed on pollen and were more numerous in the herbaceous borders where chance of flowers with pollen (including grasses) would be greatest. Overall the herbaceous borders exhibited 1.17-fold greater numbers of arthropods than the control borders and 1.61-fold greater than the perennial borders. Basically, we observed the more diverse the border vegetation, the greater the increase in the numbers of arthropods present.

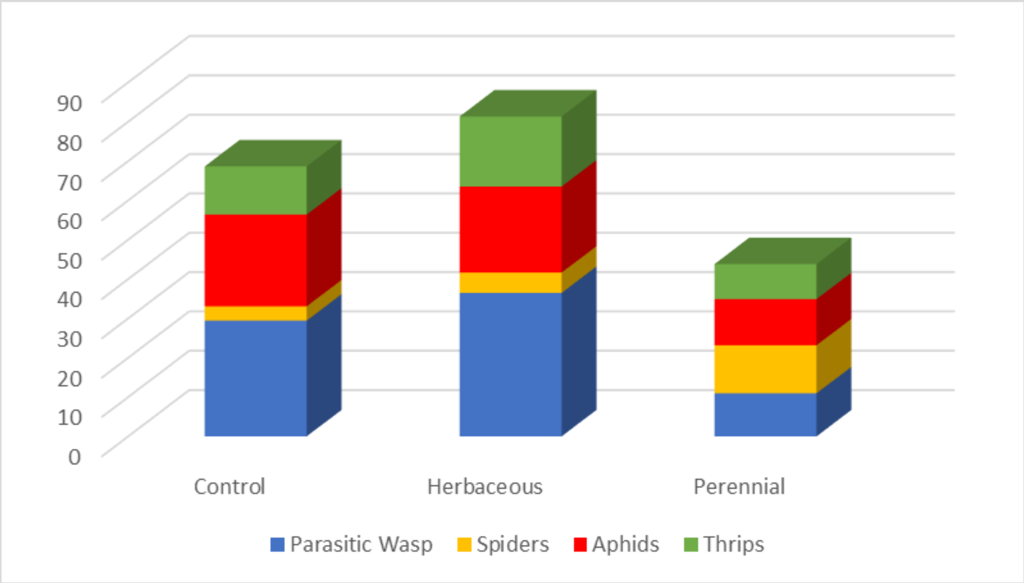

Figure 3. Border site diversity and correlation with insect diversity. Y-axis represents total number of observed arthropods. Figure by Gerdeman and Spitler.

Total numbers of insects collected were low when sampling began in mid-May until mid-June for all 3 border types (**Figs. 4-6**). A lag time between increasing hours of light and temperatures and first population peaks is expected and by mid-June, insect populations show a sharp increase in numbers. Despite the three different blueberry cultivars: 'Duke' (early season), 'Draper'(mid-season), and 'Liberty' (mid-late season) planted adjacent to the border sites, the study did not detect any cultivar-specific differences in pests, beneficials, or timing of their appearance despite variations in ripening of the berries. The increase in insect populations observed in mid-June across all 3 cultivars suggests very little benefit is derived from implementing a particular type of border. The weekly fluctuations observed in arthropod populations after mid-June most likely are responses to the weekly SWD insecticide applications, which begin when blueberries begin to ripen (data not presented). Despite lack of SWD in the blueberry fields or borders, growers are reluctant to reduce their weekly calendar SWD management programs due to the industry zero policy for SWD larvae in fruit. Totals and numbers of aphids and their parasitoid wasps where closely aligned.

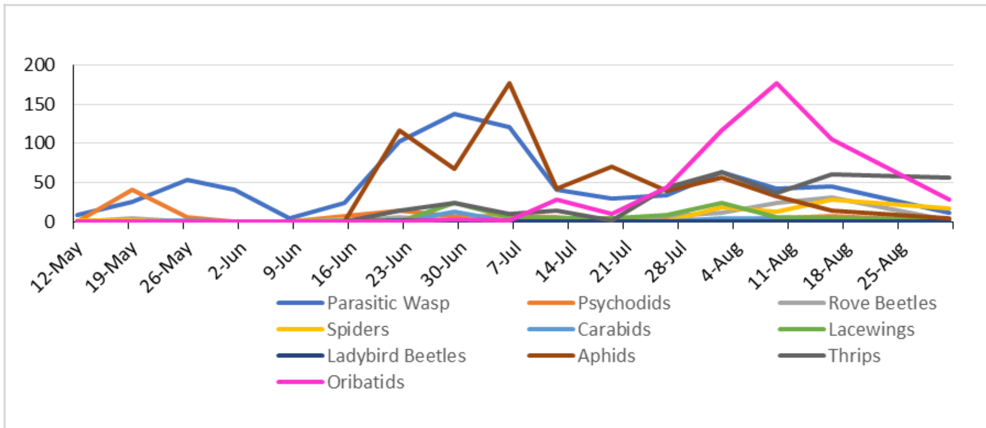

Figure 4. Seasonality of arthropods at the control sites. Y-axis represents total number of observed arthropods. Figure by Gerdeman and Spitler.

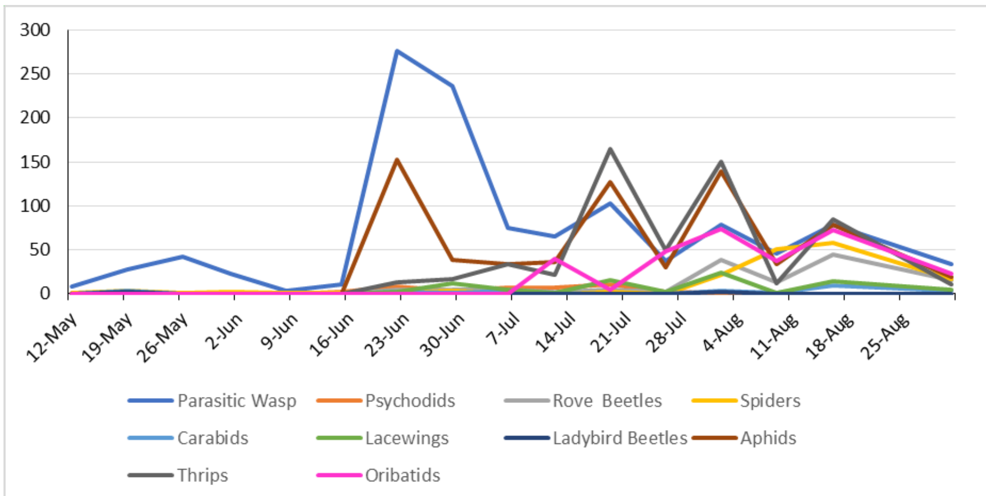

Figure 5. Seasonality of arthropods collected from the herbaceous border sites. Y-axis represents total number of observed arthropods. Figure by Gerdeman and Spitler.

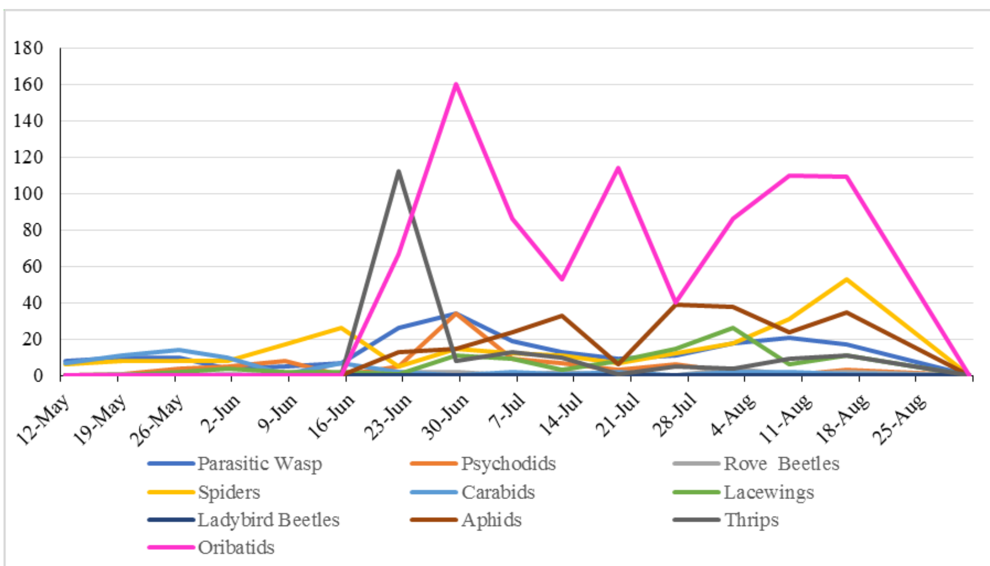

Figure 6. Seasonality of arthropods collected from the perennial border sites. Y-axis represents total number of observed arthropods. Figure by Gerdeman and Spitler.

We assessed the yellow sticky card data and have focused on evaluating border impacts on aphids and parasitic wasp populations, which are pest and beneficial insects, respectively. We did not see a significant difference in the populations of these two insects by treatment, so data were pooled and compared between the field ("in-plot") and in the border ("hedge") (**Fig. 7**). We observed greater populations of both aphids and parasitic wasps in the border vegetation in contrast to within the field. We also observed populations increased from our early sampling time point in May to our later sampling time point in July.

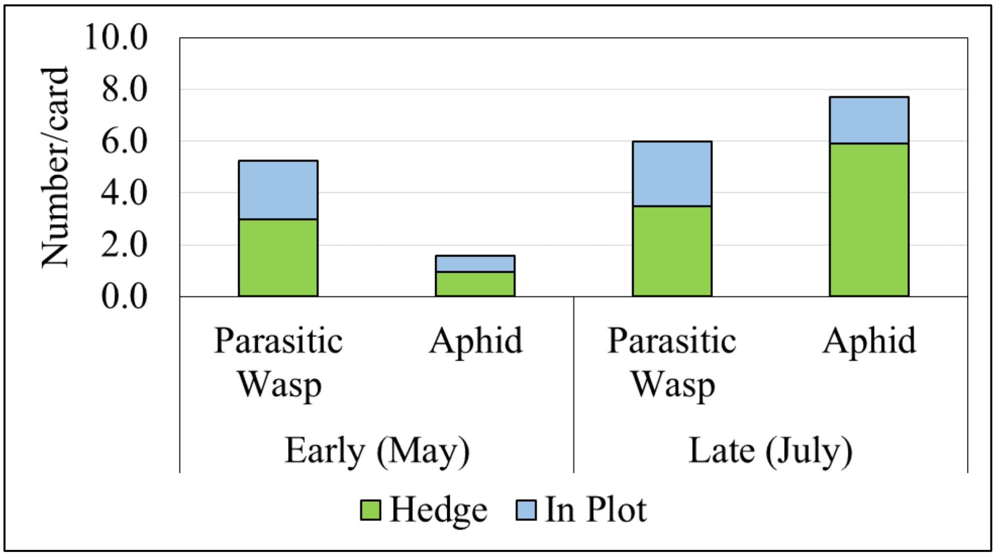

Figure 7. Populations of parasitic wasps (beneficial) and aphids (pest) in vegetative borders ("hedge") and within blueberry fields ("in-plot") in May and July 2017. Figure by Arrington and DeVetter.

<u>*Avian assessments.*</u> A list of the identified species and their corresponding abbreviation is provided in **Table 3**. Border vegetation increased total wild bird density and impacted all focal species densities (**Table 4; Fig. 8A**). Control sites had the highest total wild bird density. Barn Swallows had the highest densities in the control sites that lacked border vegetation, while White-crowned Sparrows had the lowest densities in the control sites. Total wild bird density was inversely related to distance to natural/semi-natural habitat (P = 0.02; **Fig. 8B**). Fecal data are pending and will be ready by March 2019.

Table 3. Bird species, common name, and species code in northwest Washington blueberry fields, 2017.

Species	Common name	Bird species code
Corus brachyrhynchos	American crow	AMCR
Turdus migratorius	American robin	AMRO
Bombycilla cedrorum	Cedar waxwing	CEWA
Haemorhous mexicanus	House finch	HOFI
Zonotrichia leucophrys	White-crowned sparrow	WHCR
Hirundo rustica	Barn swallow	BASW

Table 4. Generalized linear mixed effects models analyzing effects of border vegetation on focal species density wild birds in blueberry. Significance levels are given below the table. Control sites were used as the reference group. Data are presented as coefficient estimate (SE).

Species	Control	Herbaceous	Perennial
Total wild bird density	1.43 (0.14) ***	0.18 (0.19)	0.31 (0.22)
American Robin (*Turdus migratorius)*	-0.58 (0.80)	-1.61 (1.12)	-2.47 (1.13) *
Barn Swallow (*Hirundo rustica)*	-0.59 (0.63)	-3.16 (1.16) **	-2.47 (0.92) **
Cedar Waxwing (*Bombycilla cedrorum)*	-1.14 (0.72)	-0.65 (0.84)	-2.84 (1.26) *
House Finch (*Haemorhous mexicanus)*	0.42 (0.38)	-1.20 (0.50) *	-0.55 (0.47)
White-crowned Sparrow (*Zonotrichia leucophrys)*	-3.69 (1.36) **	1.93 (1.41)	2.70 (1.40)

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

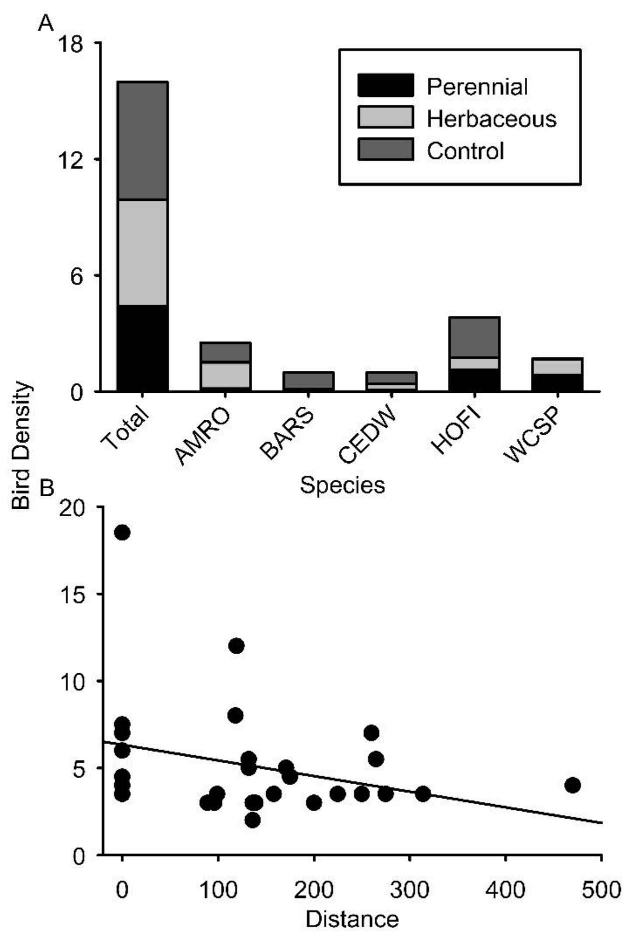

Figure 8. Wild bird density per 50 m radius survey point surveyed on 9 blueberry farms in Whatcom County, WA in 2016. **A**, Total wild bird density and density of 5 focal species by treatment type (AMRO = American Robin, BARS = Barn Swallow, CEDW = Cedar Waxwing, HOFI = House Finch, WCSP = White-crowned Sparrow) and **B**, Total wild bird density versus distance to closest semi-natural habitat type such as hedge or forest plot. Figure by Smith.

Plant productivity. No differences were observed across treatments for fruit set, estimated yield, berry weight, and seed number (**Table 5**).

Table 5. Fruit set, estimated yield, berry mass, and seed number of highbush blueberry grown adjacent to different border habitats, 2017.

Treatment	Fruit set (%)	Estimated yield (kg/plant)	Berry mass (g/berry)	Seed number (no./berry)
Control	85	2.5	1.3	38
Perennial	83	2.5	1.4	32
Herbaceous	86	3	1.3	34
P-value	NS	NS	NS	NS

- Discussion

The year in which the study was conducted was highly unusual given the absence of SWD. Thus, we are not able to specifically conclude how border vegetation impacts SWD. However, we observed few differences in all our other measured variables and declines in arthropod populations coincided with insecticide applications. Thus, in-field management practices, namely insecticide applications for SWD, appear to be driving arthropod diversity, not border vegetation habitat. Despite these results, we did observe slightly greater arthropod diversity in our herbaceous border habitat treatment (**Table 1, Figs. 2-3**). This mirrors work by Blaauw and Isaacs (2014 and 2015) in Michigan where they found diverse border habitats results in a greater arthropod diversity and in their case, a greater number of beneficial arthropods than pests. However, we did not see a significant or impactful increase in pollinator species regardless of border treatment and populations of arthropods that could provide biocontrol could not be sustained in the field given the intensity of insecticide applications.

Blaauw and Isaacs (2014 and 2015) used purposeful plantings of flowering plants in their studies, whereas we used pre-existing borders that serve to minimize pesticide drift, provide riparian buffers, serve as windbreaks, deter trespassers, and/or were naturally present and not cultivated by the growers. The use of multi-species flowering borders with bloom that coincides with blueberry's bloom may impact pollinator species diversity and abundance and the subsequent pollination services they perform. The species in our borders had few flowering plants that overlapped with blueberry. Identifying flowering species that can be planted in or adjacent to commercial fields and coincide with blueberry's bloom is challenging given current planting densities, the intensity of commercial practices, and blueberry's very early bloom period. Interestingly, the perennial borders in our study represent the least diverse habitat and function as drift control and provide a screen to deter trespassing and illegal picking.

We observed six bird species that we selected a priori that prior research suggests are beneficial insectivores, beneficial carnivores, or crop pests and were known to be common in the study region (**Table 3**). Barn Swallows had the highest densities in control sites without border vegetation, which is unsurprising given its known preference for open foraging areas (Brown and Brown, 1999). The Barn Swallow diet is almost exclusively flying insects, including Hemipterans and Lepidopterans (Bael, 1918). The only frugivore in the study, the Cedar Waxwing, had the lowest densities in sites with perennial border vegetation. This was surprising given the known association of Cedar Waxwings with trees and shrubs (Witmer et al., 2014), but is likely attributed to bird deterrence mechanisms used on the farms (cannons and “bird scarers”). This matches with DeVetter’s observations, who saw few incidences of bird damage in all fields and widespread use of bird deterrence mechanisms. Only a few crows and Red-tailed Hawks were observed across the sites, precluding statistical analyses, and surprisingly, no European Starlings were observed in 2017 within survey plots. Starlings are known to damage fruit crops and reach high densities in agricultural systems (Somers and Morris, 2002), but are also known to exhibit large seasonal and annual fluctuations in flock size and habitat usage (Fischel and Caccamise, 1985). Blueberry growers regularly report problems with European Starlings, so we may have simply not observed them given our sampling method and their tendency to exhibit seasonal fluctuations.

We observed higher total wild bird densities as distance to border habitat decreased, consistent with prior research (Maas et al. 2015; Boesing et al., 2017). Boesing et al. (2017) describes links with increased avian mediated pest control services with decreasing proximity to natural habitat. Yet, other researchers have shown fruit damage increases towards the edges of plots (Somers and Morris, 2002). In order to elucidate the net effects of wild birds on blueberry yields, more data is needed on wild bird diet and net yield when birds are excluded. Omnivorous bird species may provide a benefit early in the season through natural pest control services when chicks demand large quantities of protein-rich insects in the diet, but damage crops later in the season after fruit set. Further, though we found evidence for all focal species to harbor deadly human enteric pathogens (Morishita et al., 1999; Gorski et al., 2011), it is unclear how great a risk each poses to food safety of blueberries because few data exist to generate robust risk assessments.

- Publications, Handouts, Other Text & Web Products:
    - DeVetter, L.W., B. Gerdeman, M. Arrington, H. Spitler, B. Snyder, and O. Smith. 2018. How Border vegetation impacts pollination and insect and bird species abundance on Washington blueberry farms. WSU Whatcom Ag Monthly. < https://extension.wsu.edu/wam/how-border-vegetation-impacts-pollination-and-insect-and-bird-species-abundance-on-washington-blueberry-farms/>.
    - DeVetter, L.W., M. Arrington, B. Gerdeman, H. Spitler, O. Smith, and W. Snyder. 2019. Border vegetation has few impacts on multifunctional biodiversity and crop production in commercial blueberry. Canadian Entomologist. *In preparation*.
    - Smith, O., L.W. DeVetter, and W. Snyder. 2019. Analysis of avian fecal samples from Washington blueberry fields. *In preparation*.
- Outreach & Education Activities:
    - DeVetter, L.W. (presenter), B. Gerdeman, M. Arrington, H. Spitler (co-presenter), B. Snyder, and O. Smith. 2017. Evaluating the impacts of border vegetation patterns on multifunctional biodiversity and crop production in Washington blueberry. Washington Small Fruit Conference. Lynden, WA.

IMPACTS

- Short-Term: This project provided quantitative data on the impacts of non-flowering border vegetation on multifunctional biodiversity and crop yield/quality in commercial blueberry production systems in Washington. We have shared this information with growers through established outreach mechanisms.
- Intermediate-Term: The current practice among blueberry growers is to establish border vegetation to mitigate drift from pesticide applications next to sensitive areas and to provide a riparian buffer for the protection of waterways. These practices are often viewed as regulatory necessities. Seldom do growers mention or realize the potential for border vegetation to improve pollination and biocontrol, or to conversely worsen pest

problems by harboring pest insects and frugivorous birds. Our intermediate-term goal is to pursue federal-competitive funding to further study and describe ways to maximize benefits, and minimize any harms, resulting from border plantings alongside blueberry fields. To date, however, our preliminary results have not supported the conclusion of any impact (positive or negative) of border vegetation on our measured variables. Flowering borders that are intentionally established for pollination services and with a bloom that overlaps with blueberry may result in more positive findings and should be investigated. However, there are constraints with regards to integrating these into commercial blueberry production. Locations to install flowering borders will need to be identified and managed, which growers may be reluctant to do. Additionally, our data suggests that there is the potential that regular pesticide applications could limit the benefits of these flowering borders.

- Long-Term: Blueberry productivity in western Washington is lower on a per area basis compared to eastern Washington. Much of this has been attributed to constraints during pollination, which could be improved through more resilient pollination systems. Insect pest pressure from SWD is also more severe in western Washington, resulting in regular insecticide applications. Over time, border vegetation that shows a detectable benefit may lead to more resilient pollination systems due to increased biodiversity from adjacent vegetative borders, which may increase yields. Beneficial insects and birds may also be better conserved, which may lessen SWD infestations and lead to reduced pesticide applications. Growers' perception of border vegetation may also be enhanced to encompass how they impact pollination services, biocontrol, and crop productivity. However, the potential insect-mediated benefits may be lost if growers maintain their robust insecticide programs, as we observed declines in insect populations in our study that coincided with insecticide application. Improved integrated pest management (IPM) for SWD may help reduce the need for these insecticide applications.

Additional funding applied for / secured

We collaborated with Catherine Lindell at Michigan State University and applied to the USDA CPPM program in 2018. The title of the grant was: "Cultural management practices as influences on services and disservices provided by birds in fruit crops". We were unsuccessful, but plan to re-apply in 2019.

Graduate students funded

- This project provided salary for Matt Arrington during the Fall 2017 semester. This project also supported Weixin Gan, MS student studying blueberry pollination in the DeVetter lab, who assisted Arrington with data collection and analysis.
- We also worked very closely with Olivia Smith, PhD student in Dr. Snyder's lab, and she provided the essential avian expertise for this project.

Recommendations for future research

Data from this project show that our evaluated border treatments have small to negligible impacts on our measured variables and we did not detect any clear multifunctional benefits associated with our different border vegetation treatments. Until growers reduce weekly SWD insecticide applications, we feel the costs of border modifications would not be cost effective and border modifications are not recommended for Washington blueberry growers at this time. The exception to this is for borders used for drift control, provision of a screen, riparian buffer, or windbreak, or if flowering plants are established to obtain certification for pollinator protection. This certification is starting to be encouraged by certain fruit buyers but is not common practice.

More diverse flowering borders with a bloom period that overlaps with blueberry may provide pollinator benefits and we will continue to look for funding opportunities to study this. However, the greater need is for improved IPM for SWD that would lead to a reduction in insecticide applications, as our data highly suggests that these insecticide applications drive populations of insects and other arthropods in the field. While we did observe greater total wild bird densities with decreasing distance to natural habitat, more research is needed to determine if this has a net effect on biocontrol and blueberry yields.

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