FINAL PROJECT REPORT

Project Title: Environmental predictors of *Drosophila suzukii* abundance in cherry orchards

PI: Dalila Rendon, Postdoctoral research associate.
Organization: Oregon State University. Mid-Columbia Agricultural Research and Extension Center, Hood River.
Telephone: (503)6797690
Email: Dalila.rendon@oregonstate.edu

Co-PI: Vaughn Walton, Professor.
Organization: Oregon State University, Department of Horticulture
Telephone: (541)7404149
Email: Vaughn.walton@oregonstate.edu

Collaborators: Gabriella Boyer, MCAREC
Steve Castagnoli, Director, MCAREC.
Orchard owners in Hood River and Wasco counties
U.S Forest Service, Mt. Hood national forest.

Total Project Request: **Year 1 (2018):** $20,305 **Year 2 (2019):** No funds requested

Other funding sources: Genomic work for identification of small-nucleotide polymorphisms to characterize subpopulations of SWD will be done in Dr. Chiu's laboratory in UC Davis, and this work is covered by a current NIFA-SCRI grant.

Budget 1

Organization Name: OSU-MCAREC **Contract Administrator**: L.J. Koong
Telephone: (541)7374866 **Email address:** l.j.koong@oregonstate.edu

Item	**2018**
Wages[1]	$14,400
Benefits[2]	$1,400
Supplies[3]	$2,365
Travel[4]	$2,140
Total	$20,305

[1]Wages: 800hr for a Biological Science Tech. at $18.00/hr (20 hrs per week for 40 weeks, 0.5 FTE), 3% salary increase for year 2.
[2]Benefits: 10% of the wage.
[3]Supplies: Traps, lures, containers, insect cages, colony bottles, fly diet. HOBO temperature dataloggers and reader, software license for analysis of ecological data (CANOCO). License renewals and replacement for lost/broken dataloggers for year 2.
[4]Travel: Weekly travel to orchards and forest sites (~100 miles) for 40 weeks at $0.535 per mile

No funds will be requested from WTFRC for this project for 2019

ORIGINAL OBJECTIVES

1) To determine environmental predictors of SWD occurrence and fecundity such as altitude, monthly temperatures, host plant phenology, presence of pollinator refuges, and level of urbanization in cherry orchards and unmanaged areas.
2) To provide an improved risk assessment tool to improve the efficacy/accuracy of scheduling and frequency of insecticide applications in cherry orchards based on annual environmental and site variability.

The primary objective of this proposal was to determine the dispersal capabilities of SWD in no-agricultural areas where the pest is known to thrive. This projects falls within the research priority topic “SWD: Predicting location and intensity of infestations”. We conducted this work in the Mt Hood National Forest, and rural/urban areas of Hood River and Wasco counties.

This study also aimed to help identify single nucleotide polymorphism (SNP) markers that can be used to develop genotyping assays to examine dispersal between geographical sites. SNP genotyping should be able to shed light on the origin of these flies early in the growing season to answer the following questions: Did they migrate from warmer low-elevation areas? Or are they overwintering populations from the previous season?

Together, an analysis of environmental variables and the identification of SNP markers will help pinpoint wild sink-and-source sites, i.e., spots where SWD can overwinter and then migrate from agricultural areas to wild unmanaged areas, and determine when SWD is most likely to be found in these areas.

SIGNIFICANT FINDINGS

- We found that environmental predictors of SWD abundance vary depending on winter temperatures. In years with cold winters, degree days (DD) accumulated at the end of the spring equinox (June 20), along with average maximum temperature during winter, and accumulated precipitation during winter were the strongest predictors of total SWD collected in June. In years with mild winters, site setting (urban/agricultural/forest) and winter precipitation were the best (but still weak) predictors of SWD abundance.
- Tracking winter temperatures (for example, number of days with minimum temperatures below 23F) are an important tool for making early spray management decisions. However, there is still a lot of unexplained variability in the data, and environmental predictors do not provide clear thresholds.
- Live traps were not effective as monitoring tools. In general we found more abundance of SWD in forest sites compared to orchards, but it is not clear whether elevation or host fruit had an effect.
- SWD was reared from wild hosts such as huckleberries and thimbleberries.
- Future molecular work can help disentangle whether forest and orchard populations are isolated, or migrate between sites.

RESULTS AND DISCUSSION

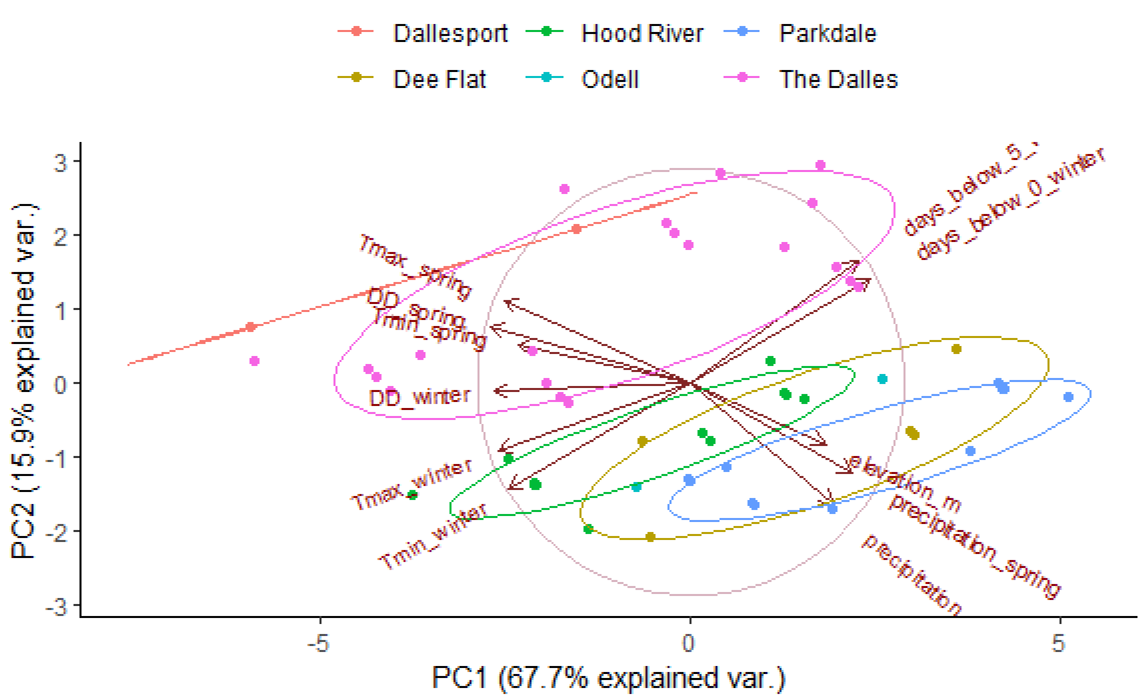
1) Which environmental factors best predict the total number of SWD trapped in various areas in Hood River and Wasco counties during 2017 and 2018?

To answer this question, we used the data from the trap network deployed by OSU extension in 2017 and 2018 in Hood River and Wasco counties. As an assessment of risk infestation, the response variable selected was total number of SWD collected in each trap during June of each year.
For each trap, we selected the nearest weather station from the U.S pest website (http://uspest.org/cgi-bin/ddmodel.us?sta=E9560&mdt=ins&spp=swd&cal=S1&tlow=50&thi=88&stm=1&std=1&styr=18&enm=9&end=20&cel=0&fcast=1&spyr=0&shd=1&mkt=0&mkg=1&ipc=1&evnts=3)
From each weather station, we extracted the following information:

- Average minimum temperature during winter solstice
- Average maximum temperature during winter solstice
- Average minimum temperature during spring equinox
- Average maximum temperature during spring equinox
- Total number of days with temperatures below 23F (-5°C) during winter solstice
- Total number of days with temperatures below 32F (0°C) during winter solstice
- Degree-days (DD) accumulated at the end of winter solstice (on March 20, using lower threshold of 50F, 10°C)
- Degree-days (DD) accumulated at the end of spring equinox (on June 20, using lower threshold of 50F, 10°C)
- Total precipitation during winter solstice
- Total precipitation during spring equinox
- Elevation

To reduce the number of environmental variables that might be correlated, we performed a principal component analysis (PCA). This tells us how each variable is associated with each other, visualized by location (Hood River / Odell / Parkdale / The Dalles / Dallesport / Mosier).

Figure 1. Biplot of principal component analysis of environmental variables.



In this case, the first two components explain 83% of the variation (PC1 + PC2, Fig. 1). Variables that point in similar (or directly opposite directions) are highly correlated, and therefore redundant. For instance, Tmax_winter (average maximum temperature during winter solstice) is positively correlated with Tmin_winter (average minimum temperature during winter solstice), and inversely correlated with number of days below freezing, and number of days below 23F. In case of highly correlated variables, it is more adequate to choose ones that have higher loadings on the first principal component.

Table 1. Loadings of each variable on principal components.

	Tmin_winter	**Tmax_winter**	**Tmin_spring**	**Tmax_spring**
PC1	-0.3146984	-0.3296766	-0.2972291	-0.3205501
PC2	-0.3806404	-0.2416034	0.133411	0.2904705
	days_below_5_winter	**days_below_0_winter**	**DD_winter**	**DD_spring**
PC1	0.2881748	0.3088001	-0.3361714	-0.3434887
PC2	0.4302847	0.3631645	-0.031987	0.1935672
	precipitation_winter	**precipitation_spring**	**elevation_m**	
PC1	0.2467444	0.2771615	0.2325543	
PC2	-0.432349	-0.3223878	-0.2195105	

After determining the loadings of each variable in the PCA, we selected a smaller number of variables to build a general linear model (GLM) that best predicted abundance of SWD collected during the month of June. In this case, we selected the environmental variables "average maximum temperature during winter solstice", "precipitation during winter solstice" and "degree-days accumulated during spring equinox".

In addition to the weather data extracted from the stations, we also selected the following categorical variables from each trap site:

- Fruit host (cherry / blackberry / peach)
- Setting (agricultural / urban / forest)
- Management (managed / unmanaged)
- Lure type (Apple cider vinegar ACV / ACV+ Trece commercial lure).

Using the Akaike criterion information (AIC) on environmental and categorical variables, we built the model that best described the abundance of SWD collected in June by dropping variables that did not contribute to data fit. Data was analyzed separately for 2018 and 2017. Due to the high number of traps without SWD in 2017, we used a zero-inflated Poisson model, and for 2018, we used a general linear model.

For 2017, the best model was:
Total SWD June = 0.037(DD spring) + 0.009(precipitation winter) – 2.76(Tmax_winter) – 5.87.
The strongest predictor in this model was DD spring ($p = 0.04$)

For 2018, the best model was:
Total SWD June = 8.79(setting forest) + 0.85(setting urban) + 0.009(precipitation_winter) +3.10
However, all these variables were weak predictors and there is a lot of unexplained variability.

Why were the models so different in 2017 and 2018?

Let’s have a look at the relationship between the predictors and SWD (Figure 2). There is a clear separation between 2017 and 2018 data in variables such as mean minimum and maximum temperatures during winter (2017 having lower values, Fig. 2a, b), and number of days below 23F in winter (more days in 2017, Fig. 2e). This suggests that, in years with cold winters, the best predictor of SWD abundance was degree days (DD) accumulated during the spring equinox (until June 21, Fig. 2h). But in years with milder winters, the accumulation of DD will not be a reliable predictor of SWD abundance, and instead, the spatial setting (urban/ forest / agricultural, Fig 2n) and the precipitation during winter (Fig. 2i) can better predict where SWD will be more abundant.

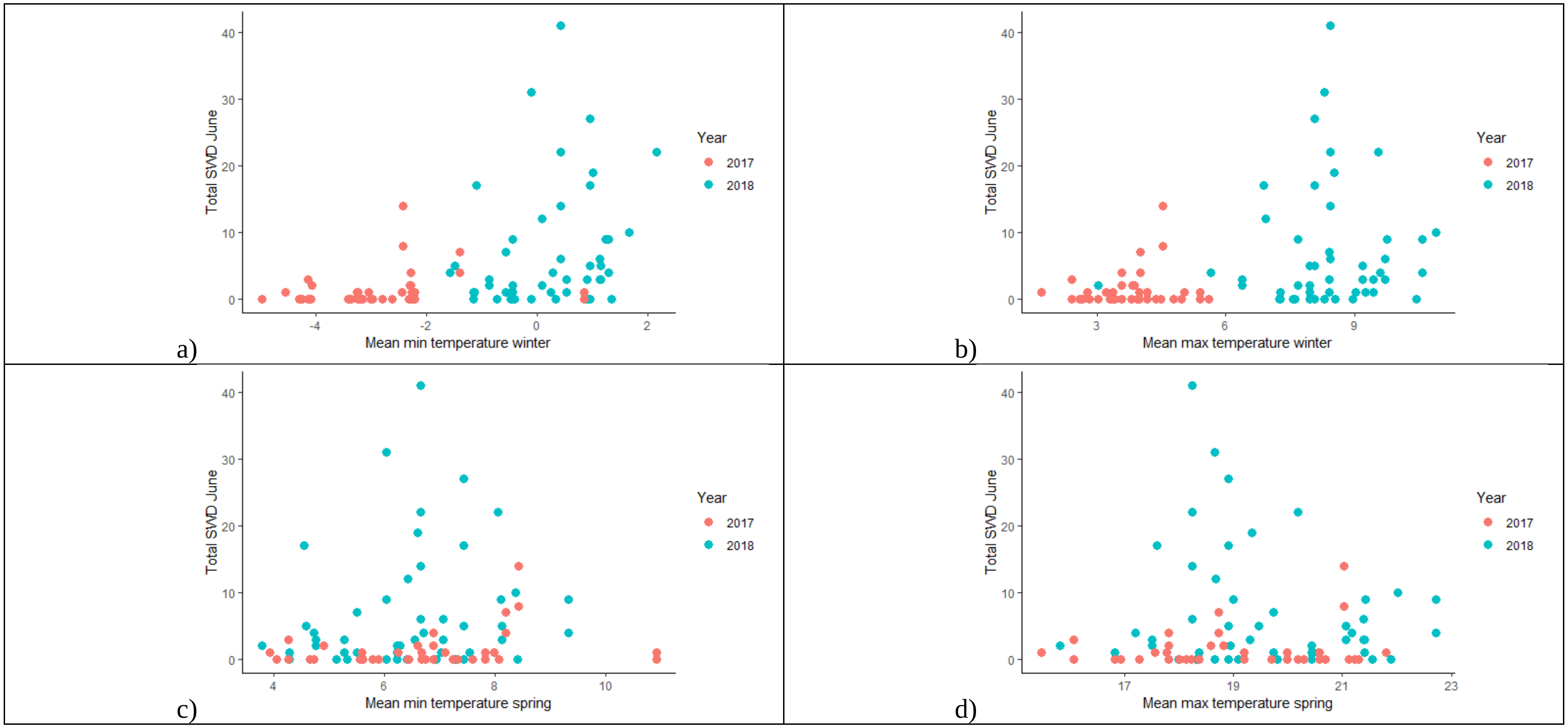
A predictor that is easy to track in terms of quantifying how cold a winter is as it progresses is number of days below 23F. There was a clear cut difference between both years; across the region in 2017 there were at least 12 days below 23F in winter, while in 2018, there were some sites with zero days below 23F in winter. As winter progresses, the low temperatures can be tracked in local weather stations, and once there are more than ~10 days with temperatures below 23F, then DD accumulated in spring will be more important in predicting SWD abundance.

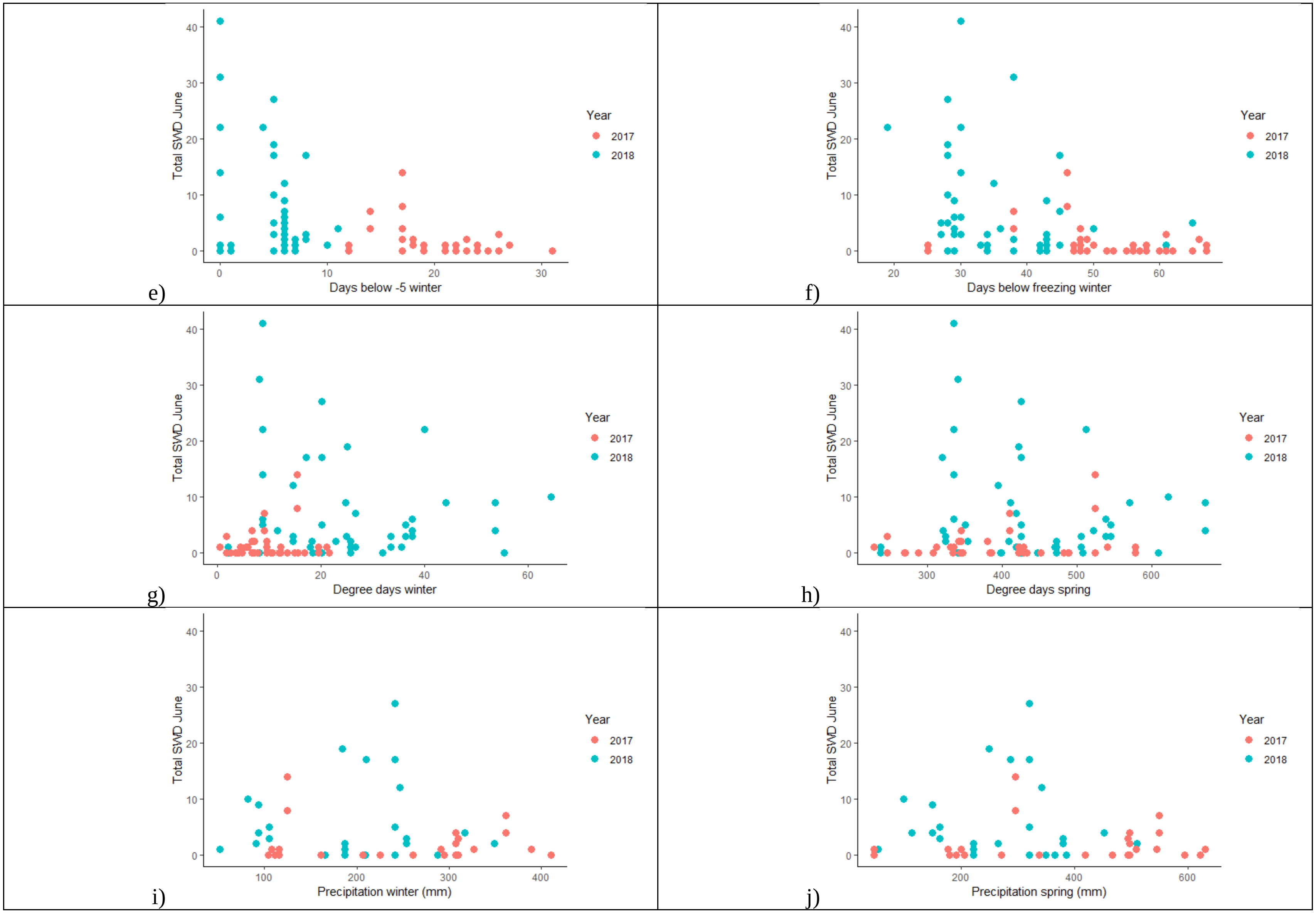
There is not a clear-cut threshold on how spring DD can affect SWD abundance in cold years, or winter precipitation in mild years. After a cold winter, sites with less than 400DD accumulated by the end of the spring equinox (~ 20 June), will likely have very low occurrence of SWD. After a mild winter, sites with more than ~7in (200mm) of rain accumulated during winter solstice (until March 20), or sites near forested areas may be at higher risk of SWD infestation. It is important to emphasize that there is still a lot of variation unaccounted for that none of these variables can predict, so there is inherent risk in relying on these models.

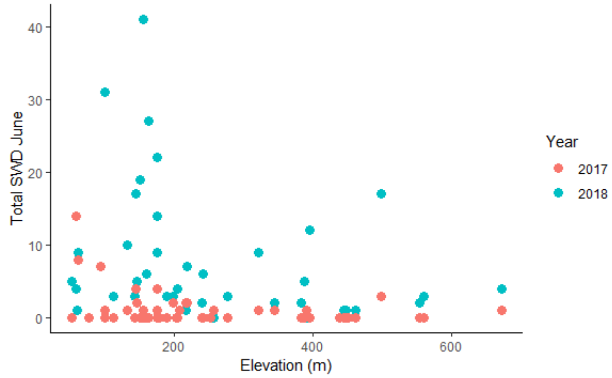
Implications for SWD management

This study highlights the importance of keeping track of environmental conditions when assessing risk of SWD infestations. We found that in years with cold winters, it could be possible to skip early insecticide sprays, and it is important to keep track of DD accumulation during spring to make application decisions. In years with milder winters, DD accumulation during spring becomes an unreliable predictor for SWD abundance.

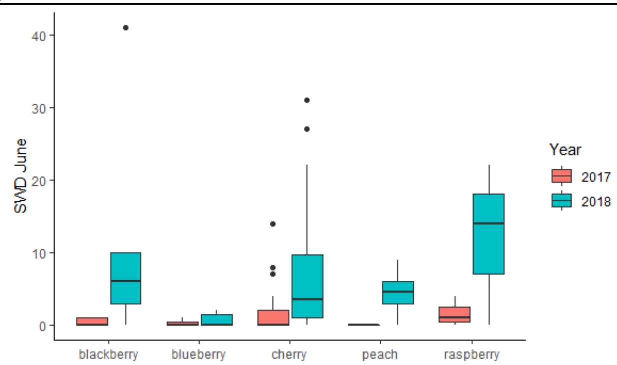
Figure 2. Environmental and categorical variables plotted against total number of SWD collected in June in 2017 and 2018 in Hood River and Wasco counties.



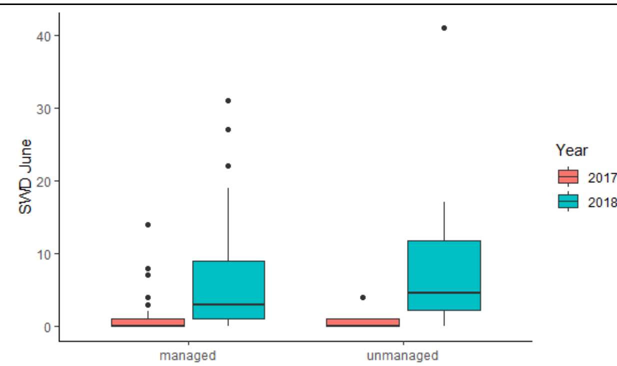

e)
Total SWD June
Days below -5 winter
Year
2017
2018
f)
Total SWD June
Days below freezing winter
Year
2017
2018
g)
Total SWD June
Degree days winter
Year
2017
2018
h)
Total SWD June
Degree days spring
Year
2017
2018
i)
Total SWD June
Precipitation winter (mm)
Year
2017
2018
j)
Total SWD June
Precipitation spring (mm)
Year
2017
2018


Total SWD June
0
10
20
30
40
200
400
600
Elevation (m)
Year
2017
2018

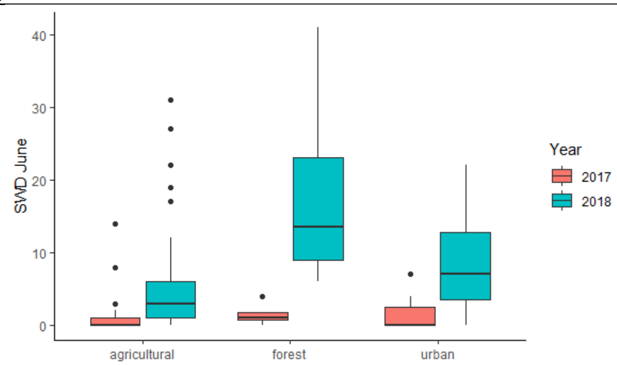
k)


SWD June
0
10
20
30
40
blackberry
blueberry
cherry
peach
raspberry
Year
2017
2018

l)


SWD June
0
10
20
30
40
managed
unmanaged
Year
2017
2018

m)


SWD June
0
10
20
30
40
agricultural
forest
urban
Year
2017
2018

n)

2) Which environmental factors best describe the abundance of SWD in unmanaged forest areas (Mt. Hood national forest)?

To collect in Mt. Hood national forest we deployed live traps at 9 sites on the northern and southern slope during summer. We measured the following variables:

- Elevation
- Fruit host (huckleberry / thimbleberry / native blackberry)
- Average maximum temperature during summer solstice
- Average minimum temperature during summer solstice

Additionally, we collected ripening fruit from each site at various times during the summer, and reared SWD from them. We also measured brix from each fruit, to determine if there was a relationship between brix and fruit infestation.

To be able to collect live flies for SNP molecular analysis, the traps used for the forest sites were different from the traps used in the Hood River/ Wasco trapping network, and did not have a drowning solution. We had tested these traps previously in 2016, but this year, we found that these traps were not very effective to collect SWD. As a result, many sites had low or zero catch, and we were not able to perform analyses to select the best predictive variables. The data presented here is only descriptive, and summarizes what we found in orchard and forest areas with live traps (Table 2). Data from live traps should not be used for monitoring or analysis purposes.

Table 2. Total SWD caught in live traps between 27 June and 17 Oct 2018 in various forest and orchard sites.

Elevation (ft)	**Setting**	**Total SWD traps**
292	Orchard	0
394	Orchard	0
528	Orchard	0
643	Orchard	0
669	Orchard	0
758	Orchard	0
761	Orchard	2
810	Orchard	0
866	Orchard	2
909	Orchard	8
925	Orchard	1
1089	Orchard	0
1204	Orchard	0
1263	Orchard	0
1483	Orchard	3
1486	Orchard	1
1732	Orchard	0
1880	Forest	2
2008	Orchard	0

2024	Forest	2
2028	Forest	2
2211	Orchard	2
2618	Forest	0
3025	Forest	50
3196	Forest	10
3563	Forest	3
3957	Forest	0
4518	Forest	0
4669	Forest	2

We reared SWD from huckleberry (*Vaccunium ovalifolium*) and thimbleberry (*Rubus parviflorus*) collected from Mt. Hood NF. There was no relationship between location or fruit brix on the number of SWD reared from forest berries.

Female flies collected alive in these traps during 2018 will be sent to UC Davis for SNP analysis.

EXECUTIVE SUMMARY

We aimed to identify which environmental factors best predict the total number of SWD trapped in various areas in Hood River and Wasco counties during 2017 and 2018. To answer this question, we used the data from the trap network deployed by OSU extension in 2017 and 2018 in Hood River and Wasco counties. As an assessment of risk infestation, the response variable selected was total number of SWD collected in each trap during June of each year. For each trap, we selected the nearest weather station from the U.S pest website. From each weather station, we extracted multiple environmental variables.

After performing a principal component analysis to eliminate redundant variables, we selected three environmental predictor variables: 1) “average maximum temperature during winter solstice”, 2) “precipitation during winter solstice” and 3) “degree-days accumulated during spring equinox”. Additionally, we selected the following categorical variables:

- Fruit host (cherry / blackberry / peach)
- Setting (agricultural / urban / forest)
- Management (managed / unmanaged)
- Lure type (Apple cider vinegar ACV / ACV+ Trece commercial lure).

The models that best described SWD collected during June varied by year. In 2017, the best predictors were DD accumulated at the end of spring equinox, mean maximum temperature during winter solstice, and cumulative winter precipitation. In 2018, environmental predictors were weak, but the best ones were setting (forest/agricultural/urban), and cumulative winter precipitation.

The difference between predictors in both years is likely due to differences in winter temperatures. For instance, there was a clear cut difference in number of days below 23F between 2017 and 2018. In years with cold winters, DD spring accumulation can provide information about SWD in late spring/early summer, but in years with milder winters, DD spring is not a reliable predictor.

Keeping track of winter temperatures in local weather stations as winter progresses is a useful tool to estimate which environmental predictors will become important to predict SWD abundance. We recommend taking note of how many days below 23F have occurred, and then keeping track of spring DD. There is not a clear-cut threshold on how spring DD can affect SWD abundance in cold years, or winter precipitation in mild years. After a cold winter, sites with less than 400DD accumulated by the end of the spring equinox (~ 20 June), will likely have very low occurrence of SWD. After a mild winter, sites with more than ~7in (200mm) of rain accumulated during winter solstice (until March 20), or sites near forested areas may be at higher risk of SWD infestation. It is important to emphasize that there is still a lot of variation unaccounted for that none of these variables can predict, so there is inherent risk in relying on these models.

We used live traps in some forest and orchard sites to be able to preserve flies for molecular analyses, but live trapping was very inefficient and unreliable for monitoring and analysis. It is unclear whether flies migrate between these sites; future molecular SNP analyses can help determine whether these are separate populations.