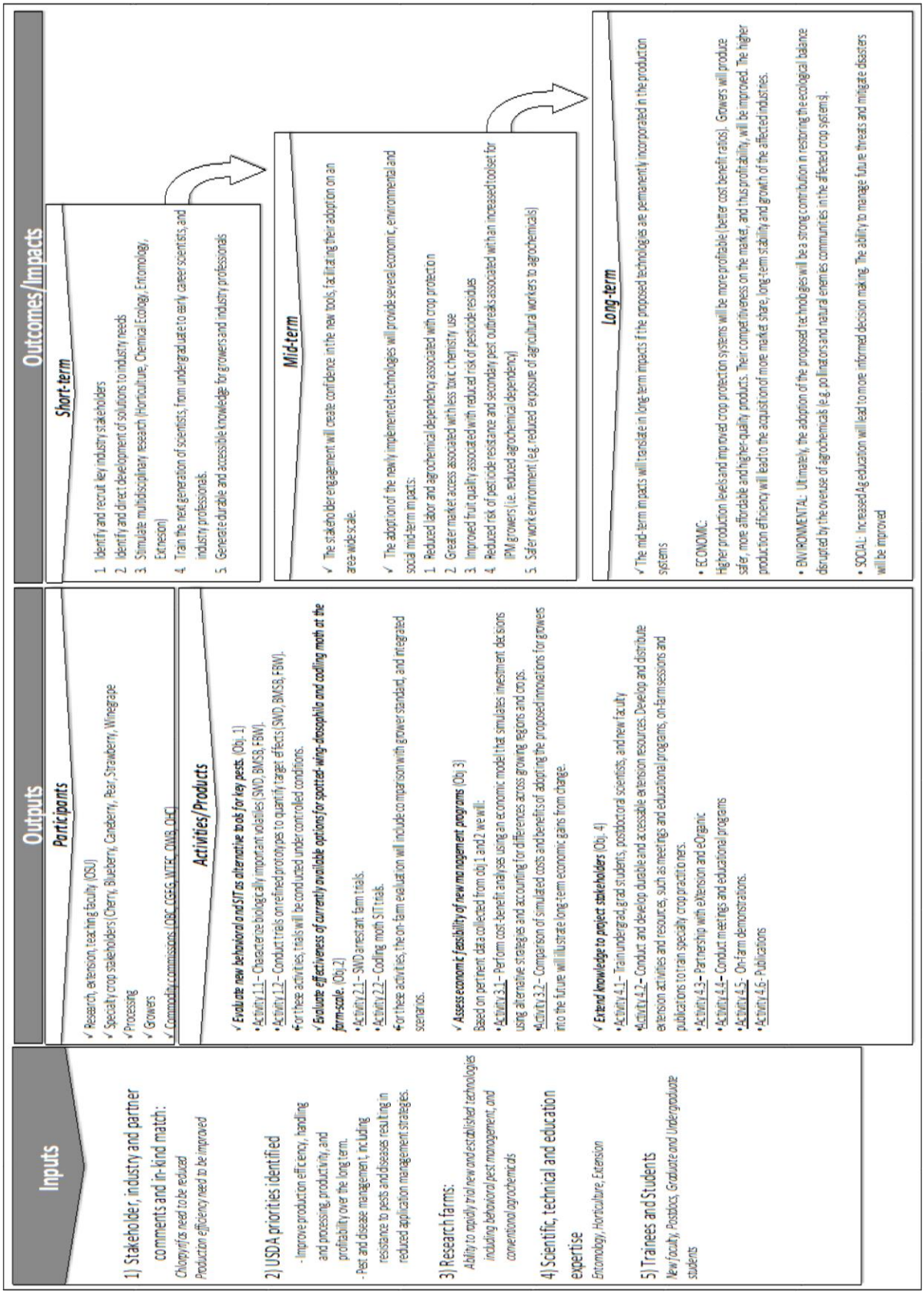
Attachment B – Work Plan: Developing New Alternatives to Replace Chlorpyrifos in Tree and Small Crops

Logic model showing workflow of inputs, outputs and outcomes (Short, medium and long-term)



Objective 1: Evaluate new behavioral formulations and SIT as alternative tools for key pests.

We have identified eight key *arrestant* fatty-acid volatiles that significantly aids in reducing crop damage by SWD. We have implemented mating disruption of FBW and are currently investigation the efficacy of the currently used pheromone, with the goal to refine the formulation (*mating pheromone*). We will explore sterile insect release (SIT) for CM for wild population suppression. For SWD, FBW, and BMSB we want to test a newly formulated *arrestant* and *deterrent* submitted both for patenting at Oregon State University Office of Commercialization and Corporate Development (OCCD). The mating pheromone will be tested only on FBW. All of these formulations are clustered as *behavioral formulations*. We will conduct work on chemical analysis of original and refined SWD *arrestant* and *deterrent* volatiles at OSU. *Arrestant* volatiles will likely only impact SWD, and *deterrent* volatiles will impact SWD and BMSB, and possibly FBW.

Activity 1.1 ***Characterize biologically-important volatiles through chemical and behavioral analysis to develop refined prototypes of the behavioral formulations***. (Miller, Tait). Qualitative and quantitative chemical analysis will better elucidate the chemical field-release of the biologically relevant volatiles for both patented technologies and for the *mating disruptor*. The analysis will allow for formulation improvement and identification of the relative importance of *arrestant*, *mating disruption* and *deterrent* volatiles. The analysis of the volatile extracted from the three products will allow the creation of a volatile library and the establishment of analytical methods for further development of refined prototypes.

1.1.1 ***Electrophysiology response to behavioral formulations*** (Miller, Tait)
Volatile collection. Verification of *behavioral formulations* (attractive, disruption and deterrent) will be conducted by placing a predetermined quantity of product (3 gm) into a glass beaker. Volatiles emanating will be collected from a dynamic headspace collection chamber. This collection chamber is linked to the outlet of an air compressor that forced in turn forced the air sample through a charcoal filter, ensuring entry of pure air (400 $mlmin^{-1}$). Volatiles emitted by the medium are collected on Porapak™ Q (ORBO™ 1103; Porapak™ Q 50/80 mesh; 150/75 mg; Supelco, PA, USA) in a glass tube (5 mm Ø) connected to the collection port on the top of the chamber. A second pump receives air through this conduit. 5 replications will be developed for 24 hours (each) in a climatic chamber at 25 ± 2 °C and 60 ± 5% relative humidity. Trapped volatiles into the sorbent cartridge are then eluted using 1 mL hexane (>99% purity, Sigma-Aldrich) at room temperature. Solvent extracts will be then reduced to a volume of 100 µL via evaporation under a slow air (N_2) stream and preserved at -20°C.

1.1.2 ***GC/EAD analysis***: adult individuals of the three selected species will be anaesthetized by refrigeration at about -20°C for 20s and antennae will be used for recordings. SWD, BMSB and FBW are the designed species that will be tested with the *arrestant* and *deterrent* volatiles, while only FBW will be subjected to the mating disruptor extracts. A glass capillary indifferent electrode filled with Kaissling solution [NaCl (7.5 gL^{-1}); $CaCl_2$ (0.21 gL^{-1}); KCl (0.35 gL^{-1}); and $NaHCO_3$ (0.2 gL^{-1}l)] will be inserted in the severed head of the fly. The different electrode is a similar capillary, brought into contact with the distal end of the fly antenna. The capillary tubes will be drawn to a fine point using a microelectrode puller to get an inner diameter wide enough to enable insertion of the preparation. Samples from the extracts will be tested on at least 10 (5 females and 5 males) individuals. Compounds eluting from the capillary column will be delivered to the antenna of each tested individual through a glass tube (12 cm x 8 mm) via a charcoal-filtered and humidified air stream. For each GC/EAD assay, we either inject 2 µL of the extract in a Hewlett-Packard 5890 GC (Hewlett-Packard, Palo Alto, California) in splitless mode, with

a polar Innowax column (30m x 0.32 mm; J&W Scientific, Folsom, California) programmed from 60 °C (hold 3 min) at 8 °C min^{-1} to 220 °C (hold 7 min) with helium as the carrier gas and interfaced with the EAG apparatus. The GC column effluent will be combined with nitrogen make-up gas and then a 1:1 ratio between the flame ionization detector (FID) and an antenna of each SWD individual. The antennal signal and the FID signal will be amplified and recorded simultaneously using the Syntech software (Syntech, The Netherlands). The EAD responses will be calculated by measuring the maximum amplitude of negative deflection (mV) elicited by the SWD antenna.

1.1.3 ***Volatile characterization by Gas Chromatograph/Mass Spectrometry*** (Miller, Tait).
Chromatographic analyses will be performed by by a solid-phase microextraction (SPME). 3 gm of each product (the same used previously for the CG/EAD analysis) will be confined in a 100-ml glass jar (Tasin et al. 2011; Liu et al. 2018). The opening of the jar will be sealed with a single layer of Parafilm©. After an equilibration time of 30 min, volatiles in the jar will be adsorbed by means of SPME previously conditioned at 250°C for 5 min in a gas-chromatograph injection port (triphasic fiber SPME; 2-cm length; film thickness 50/30 μm; Divinylbenzene/Carboxen/Polydimethylsiloxane coating; Supelco, USA). After a collection time of 60 min, volatiles collected on the fiber will be immediately desorbed and analyzed using a gas chromatograph coupled to a mass spectrometer (GC/MS, Clarus 500, Perkin–Elmer, Waltham, USA) equipped with an Innowax column (30 m × 0.32 mm × 0.5 μm, Agilent, Palo Alto, USA). The SPME fiber will be desorbed in splitless mode for 5 min in the GC injector port at 250°C. The GC oven will be programmed at 40°C for 3 min, raised from 40 to 180 at 4 °C min^{-1}, held at 180°C for 4 min, raised from 180 to 220 at 10 °C min^{-1}, and held at 220 °C for 10 min. Helium will be used as the carrier gas with a constant flow of 1.5 mL min^{-1}. The temperature of the transfer line will be set at 250°C. The mass spectrometer will operate in electron ionization mode (EI, internal ionization source; 70 eV) with a scan range between *m*/*z* 30 and 300. Controls will consist of blank vials containing no added materials and positive controls, which will consist of the authentic reference standards.
The GC/MS database will be analyzed using Agilent MS Software. Compounds will be identified by comparing spectra with those of the Wiley library as well as by comparing their Kovats retention indices with those published in the literature. Kovats indices of compounds are based on retention times of a blend of reference hydrocarbons. Synthetic standards of all identified compounds will be injected to calculate their Kovats index. The standards will also be used to calibrate the GC/MS instrument for quantification of the volatiles in subsequent experiments.

1.1.4 ***EAG tests***. The synthetic compounds (> 95% pure) corresponding to the volatiles identified through GC/EAD coupled with GC/MS will be bought and used to record EAG dose-response curves on the tested adults. areEAG responses to increasing doses of synthetic compounds in hexane solution (4 serial dilutions: 100 $\mu g\mu L^{-1}$; 10 $\mu g\mu L^{-1}$; 1 $\mu g\mu L^{-1}$; 0.1 $\mu g\mu L^{-1}$) will be recorded for antennal activity. Aliquots (25 μL) of each solution will be adsorbed on a piece (1.5 cm^2) of filter paper (Albet 400: SparksLab Supply Limited, Ireland), and inserted in a Pasteur pipette. The solvent will allow to evaporate for 10 min before starting the experiments. The response of *D. suzukii* adult antennae to the individual compounds will be recorded by electroantennography (EAG), through an IDAC-2 acquisition controller (Ockenfels SYNTECH GmbH, Buchenbach, Germany). Two microcapillary tubes containing the ground and the recording silver electrodes and filled with Kaissling solution will be connected to the head of the insect via the occipital aperture and to the distal tip of one antenna. Each compound will be delivered to the antenna through a glass tube (12 cm × 8 mm) via a constant humidified air stream (0.5 L min^{-1}) filtered with charcoal. The air tube will be located 4-5 mm away from the antenna. The test cartridge will be connected to a stimulus controller (CS-55, Ockenfels SYNTECH GmbH) that generated puffs of air. Cartridges will be replaced after fifteen puffs. To avoid bias in

the response amplitude, stimulus presentation will be randomized among individuals. For each odorant, responses from ten females and ten males will be recorded. Odorants will be presented only once to each individual. For each recording, a time interval of 30 sec will allow between one dilution and the following, whereas a time interval of 1 min will be allowed between a synthetic compound and the following. Before and after each recording, EAG responses to solvent (hexane) and air will be recorded. Electroantennogram responses will be analyzed for ten individuals (5 females and 5 males) for each dose with the EAG2000 software (Syntech, The Netherlands), and evaluated by measuring the maximum amplitude of negative deflection (mV) elicited by a given stimulus. Differences in EAG responses will be first evaluated using Student's t-test, to assess differences between male and female individuals. Parametric one-way analysis of variance (ANOVA) followed by Tukey's post-hoc multiple comparison test will be used to assess the effect of each compound dosage on the amplitude of SWD antennal responses. Homogeneity of variance will be determined previously with Levene's test (STATISTICA, version 9; Statsoft Inc., Tulsa, Oklahoma).**1.1.5** ***Attractancy or deterrence***. The synthetic volatiles tested with the EAG procedure will be tested with a choice test to understand if the physiological reaction detected with the EAG test was determined by an attraction or repulsion towards that specific volatile. To test this, singly each characterized volatile will be tested in 2-L Griffin-style graduated, low-form transparent plastic beakers (Rochester, NY) on SWD, BMSB and FBW adults. Containers will be placed upside down on a flat work surface and covered by paper, allowing for easy introduction of test insects and compounds. Constant and uniform airflow will be created within each of the containers using a vacuum at 1.5 L /min from the base and through the upper portion of each of the respective containers. For each beaker, 9 ventilation holes (1 cm diameter) will be cut along the circumference approximately 6 cm from the base. The holes will be covered with fine white mesh in order to prevent individuals from escaping. Two 5 mL plastic cups (Dart Container Corporation, Mason, MI) containing a specific quantity of water and a specific quantity of the synthetic volatile will be placed at the base of each beaker. Both cups will be covered with a wax film (Parafilm® M, Pechiney, Chicago, IL). Three holes (~0.3 cm diameter) will cut the film coverings in order to allow the flies to enter the cups. Twenty mated females and males were released (10 females and 10 males) within each arena, allowing them to orient and eventually enter the cups. After 24 h, the number of adults caught within each cup was counted, as well as flies that did not make any choice. Thanks to this bioassay it will be possible to determine the attraction or repulsion towards a specific compound.

1.1.6. ***Time Course Fingerprinting Experiments*** (Miller, Tait). Qualitative and quantitative chemical analysis of released volatiles will be performed at different time intervals as soon as the product is placed i.e. 1, 3, 9, 15 and 21 days. This process will allow a better understanding of the chemical release rates of the biologically relevant volatiles over time. This experiment will therefore mimic field release of volatiles, indicating changes in attraction over time. We will characterize the volatile blends of chemicals associated with the naturally-occurring additives that are added to the mixture. We will also monitor conversion of the volatile chemicals to non-volatile forms (e.g., hydrolysis or oxidation), since any transformation reactions are likely to impact the length of product efficacy. A series of controlled laboratory experiments will be conducted to determine which environmental variables determine the rate of conversion to non-volatile products, including temperature, pH, and moisture. By understanding the variables that control degradation processes in the field, we can potentially control the chemical release rates of the biologically-relevant volatiles over time.

Expected outcomes. We will determine the presence of biologically active compounds/volatiles for three economically important fruit insects (SWD, FBW and BMSB) for each of the *behavioral formulations*. These respective compounds will be tested for their relative importance and confirmed under controlled conditions. We have already had success and varying levels of commercial adoption of all three technologies (SWD and FBW) and anticipate to build on this success also for BMSB. By studying and characterizing the specific volatiles that elicit the antenna response, we will be able to improve the quality of our technologies by adding that specific volatiles and removing impurities.
Potential pitfalls: Given our success to date, we anticipate making additional progress, however, it is possible that volatile collection and identification might be hampered by equipment failure or misidentification of relevant volatiles. It is possible that the electrophysiological observations might not translate to field implementation because of challenges in delivery method or cost of volatiles, hampering economic implementation and adoption.

Activity 1.2. Conduct trials on refined prototypes to quantify target effects (Walton, Adams)**.** We will conduct laboratory and field bioassays with refined formulations to determine their impacts on target organisms.

1.2.1 Direct impacts on target organisms SWD and BMSB (Adams, Walton, Tait). Thanks to the choice tests, we will be able to identify the specific volatiles that elicit attractivity or repellency. The most promising synthetic attractive and deterrent volatiles will be included respectively in the *arrestant* and *deterrent* to increase the quality of each product. Here we will focus our efforts on two key insects SWD and BMSB in order to maximize future impacts. The formulations will be tested to verify improvements made after laboratory oviposition/damage and longevity tests. Insects will be maintained in the laboratory at 22 °C, 65% RH and a photoperiod of 8:16 h (light:dark). All target insects will be an appropriate age for egg laying and will be previously mated.
The initial formulations improved by the addition of the most promising synthetic volatiles will be tested by using the same 2-L Griffin-style graduated containers described previously. For the choice experiment, we will placed two plastic cups (5 mL, Dart Container Corporation, Mason, MI) at the base of each arena, one with the old formula and the second with the refined formula (untreated control). The treatment and the control cups will contain ~ 3 gm of product respectively. The upper opening of these cups will be is covered by a plastic film with three ~0.3 cm diameter holes (SWD) or mini pyramid–style trap (BMSB). There will be 10 replicates for each formulation. Ten mated females and males each will be placed within each arena for a 24 h period, allowing them to orient and enter the respective traps. The number of SWD/BMSB/FBW captured within the respective traps will be counted, together with individuals not making any choice. At the end of each experiment, arenas will be cleaned and air-dried before reuse. For the full duration of the experiment, the formulations will be exposed to the open air under simulated and real field conditions. The most promising products will be deployed in the field for evaluation. A series of field assays (Objective 3) will be established to evaluate the degree to which resident SWD/BMSB are affected by the respective behavioral formulations and to what extent this leads to reduction in crop damage.

1.2.2 Direct impacts on target organism FBW.
The same process will be performed on the mating disruptor pheromone. A choice test will be run by comparing the attraction towards the old formula or the refined one. In each container will be released 10 males. There will be 10 replicates and the number of flies will checked at 24 h.

1.2.3 Behavior disruption trials (Adams, Walton, Tait). Field trials will be conducted on SWD and BMSB using the most promising refined formulations at the MCAREC and Lewis-Brown experimental farms on blueberry, cherry and pear in the season in Oregon. Fruit or nut clusters containing ~20 berries/nuts (blueberry and cherry, hazelnut) and individual fruit (pear) will be covered 30x30 cm white organza mesh bags (Uline, Pleasant Prairie, WI). Mesh bags will be placed ~1 m apart along plant rows, maintaining comparable sun exposure. All treatment bags on berry crops will contain 10 eight-day-old mated female and male SWD (20 flies total), or 10 BMSB (5 male and female each). All trials will be initiated at 3:00-5:00 pm and collected ~72 hours later to determine the level of egg laying on fruits/nuts and within the gum matrix. All soft or damaged fruits/nuts will be excluded when assessing the egg laying levels in the laboratory. Experiments containing these treatments will be replicated ten or more times on each date and trials will be conducted on at least three separate dates.

Expected outcomes*:* We will determine the relative efficacy of the behavioral controls. Field trials will provide information on translation into field applications, allowing more rapid adoption by growers. *Potential pitfalls:* Previous exposure to volatiles emitted from rearing media may impact SWD/BMSB behavior, thereby reducing the relevancy of the observations. We will however take the necessary steps to minimize these impacts.

Objective 2: (Adams, Tait) The fruit crop research and extension team will evaluate effectiveness of currently available multi-tactic management options for the key insect pests; spotted-wing drosophila, and codling moth at the farm-scale. Here we will focus on on-farm trials using the arrestant and SIT techniques only since these technologies are closest implementation by growers.

Activity 2.1. ***SWD arrestant farm trials***. We will conduct field trials, to determine field-efficacy under standard commercial cherry production conditions at the Mid-Columbia Agricultural Research and Extension Center (MCAREC, 45°68’515’’N, 121°51’67’’W). There will be three treatments and the experiment will likely be conducted over a period of 21-30 days, depending on environmental conditions.
1) Grower standard (GS). Three to six full cover insecticide treatments, depending on SWD pressure, applied every 3-7 days. The first insecticide will be applied on day 0. Toxicants will include a rotation of Mustang Max, Delegate and Malathion at registered field rates, concluding at the appropriate preharvest interval before harvest.
2) Integrated (INT). The first insecticide will be applied on day 0. Two to four full cover insecticide treatments, depending on SWD pressure, applied every 3-7 days, plus A&K. Toxicants will include a rotation of Mustang Max, Delegate and Malathion at registered field rates, concluding at the appropriate preharvest interval before harvest. The A&K treatments will consist of placing the hemp fiber substrate (10x10x0.5 cm, BioComposit, Alberta, Canada) at the base of every 4th tree in a shaded position. The treatments will be applied at the rate of 50 per acre, 7 per 0.14 acre.
3) Arrestant treatments. Arrestant treatments will be applied at day 0. No additional chemical treatments will be applied.

For cherries (MCAREC) and blueberries (OSU Lewis-Brown Farm), there will be 21 plots, each ~0.13 acres in size (~30/150 trees/bushes, Regina cv. sweet cherry, Elliot Blueberry) for a total of 2.8 acres. A similar or larger plot size will be implemented at the two commercial grower locations (one cherry and one blueberry). None of the plots will receive any pesticide applications before the start of the experiment. Seven plots will

be assigned in a gridded pattern for each treatment. Because volatile plumes from the arrestant plots can be influenced by air movement, GS plots will be situated upwind from the INT and arrestant plots to minimize interference caused by drifting volatile plumes originating from the dispensers placed in those plots. At first fruit color, we may conduct supplemental releases of SWD in each plot, dependent on insect pressure. If necessary, we anticipate releasing 200 mated 8-12 day-old SWD in the center of each plot (2,100 total) in order to create a relatively even distribution of populations. No releases will be conducted in any commercial trials. These populations will be released two times, one on day 0 and the second on day 7 of the experimental period. We will collect cherries/blueberries twice per week from first color of fruit starting on day 0 before any pesticide applications or SWD releases. Each collection will contain 10 cherries/blueberries, respectively from the lower (3ft), middle (5ft) and high (7ft) portion of the central two plants in each plot (30 per plant, 60 total per plot and 420 per treatment). The collection will be conducted twice per week and at least during five separate dates. This will depend on the environmental conditions, with warmer weather typically allowing fewer collection opportunities. Assessments of oviposition will be determined considering the number of eggs laid per berry and percent of infected berries. Environmental data will be collected during the field trials using data loggers (HOBO U23 Pro v2 Temperature/%RH; Onset Computer Corp., Bourne, MA) placed in the bottom, middle and top part of the trees. The data loggers will measure ambient air temperature (°C), and relative humidity (%RH). These data will indicate how different SWD pressure levels in each of the microclimates are affected by the treatment.

Activity 2.2. ***Codling moth SIT trials*** (Adams):

The project proposes a unique opportunity for the OR pear industry to expand their CM management tool kit to include sterile insect technique (SIT). The approach entails sterilization of reared insects that are subsequently deployed in large numbers to compete with wild individuals to reduce or even eliminate fertile matings and thus, production of offspring. An area wide program using SIT for CM management in British Columbia has substantially reduced population densities, fruit injury and insecticide sprays. The British Columbia program has initiated an arrangement whereby growers outside of Canada have access to sterile moths for managing CM. An agriculture innovation company, M3CG, has modified small unmanned aerial systems (UAS or Drones) to release these moths over large areas in a short amount of time. We plan to explore how best to use this management strategy. Moths treatments will be: 1) weekly release of sterile moths over the entire 16-week season or 2) by deploying them during only a portion of the season, such as for a single generation. 3) Grower standard management program with sprays in response to action thresholds in monitoring traps. Additionally, we plan to investigate if releasing fewer than the standard 800 moths/acre is sufficient for controlling low to moderate wild CM populations in pear. Widespread use of SIT for managing CM will reduce or dependence on pesticides, promote the growth of the beneficial insect complex, and reduce the density of this key pest long-term. To be effective resources will need to be used efficiently. Our objectives are to 1) determine the effectiveness of different release strategies for applying sterile moths to manage codling moth in Oregon pear orchards. 2) To determine the effectiveness of deploying sterile moths at densities ranging from 200-800/ac for managing codling moth in Oregon pear orchards.

Experimental protocols. The effectiveness of various strategies and deployment densities for mass releasing sterile moths to manage CM will be conducted in commercial pear orchards in regions where CM is most problematic. Field plots will consist of 10 acres commercial pear orchards. All

Figure 1. SIT codling moth in trap marked with internal red dye.

experiments will be set up as a randomized complete block design with one replicate of each treatment within a given orchard plot. There will be a minimum of 40-meter buffers between the treatment blocks. Insecticide sprays will be applied for pests other than CM as needed to protect the crop from commercially unacceptable damage. Captures of wild males in pheromone-baited traps and fruit injury counts at mid-season and prior to harvest will be used to assess treatment effects, i.e., the extent to which adult densities and larval infestation are reduced by treatments. Wild and sterile males can be readily distinguished because sterile individuals are internally marked with a red dye that is incorporated into the larval diet and passed on to adults (Fig. 1). Six Delta-style sticky traps baited with standard pheromone lures will be hung in the upper canopy in the central of each plot and checked weekly throughout both CM flights. Fruit injury will be assessed by inspecting 1000 fruit per plot (20 from each of 50 trees) for the presence of CM infestation (stings or frass).

2.2.1. Effectiveness of various mass release strategies. Oregon pear growers currently rely on insecticides or pheromone-based mating disruption and companion insecticides for CM control. We propose to evaluate the efficacy of sterile release programs as alternatives for managing CM. The overall approach will be to compare the efficacy of releasing moth season-long versus targeted deployment during only a portion of the season. Specifically, we will evaluate three programs: 1) weekly release of sterile moths in place of insecticides for season long control of CM 2) the release of sterile moths for control of CM only during the 3 weeks of peak flight for each of the two generations that occur in MI and 3) the release of sterile moths for control of CM only during second generation. Our research has revealed that SIT moths are more active and effective during the second compared to the first-generation CM flight. Control treatments will be included in which insecticides only or mating disruption plus insecticides will be used for CM control, i.e. no sterile male releases. For all SIT programs, 800 moths/ac will be released weekly from a UAV during the prescribed management period.

2.2.3. Effectiveness of different release rates. Early research suggested that a ratio of 40:1 sterile to wild moths was needed to drive CM to extinction or at least to non-damaging levels. This formed the basis of the prescribed 800 moths/ac release density in the Canadian program. However, the 40:1 ratio was based on modeling, small-cage studies and releasing males only. Our research has indicated that a lower release density can be effective, especially when both males and females are released. Indeed, releasing 400 females/ac provides over 90% suppression of mate-finding by males. Thus, we will directly compare the efficacy of release 200, 400 or 800 SIT mixed-sex moths per acre. The experimental design and methods for assessing treatment effects are as previously described.

Expected outcomes*:* The CM SIT system is both males and females. Females work like flying mating disruption, and could replace the purchase of synthetic MD dispensers. Sterile males will mate with wild females and produce no offspring. The trials will provide field data under commercial systems as one of the final tests of the developed products. Moreover, the trials will be conducted in multiple regions and crop systems as an additional verification of material effectiveness.

Potential pitfalls*:* As with any field trials, these are dependent on the applied insects being active in the system and the grower cooperators not applying pesticides. In some cases, growers may implement management practices without the knowledge of the scientists, impacting research outcomes. The current price structure for this technique may make this tool unaffordable for many growers. Efficiencies in the system will need to be found.

Objective 3: Assess economic feasibility of new management programs (Adams, Miller, Walton)
We will perform empirical analyses of the costs and benefits from adoption of reduced-pesticide whole-system strategies as identified in the project. Initially, we will conduct a comparison of the projected costs of two identified strategies - one for which the treatment relies on reduced pesticide use and the other based on conventional pesticide use; each with different initial costs based on their respective treatments. Subsequent analysis will evaluate the costs (reduced yields) and benefits (reduced pesticide use and increased market access) from adopting the identified strategies so that we can inform growers about the potential gains from these strategies, reduce uncertainty about them and, when cost effective, increase adoption, contributing to long-term profitability and sustainability. The perennial nature of some of these crops and the incidence and life cycle of the pest suggest decisions regarding planting and orchard or field care have effects that will continue into the future. A dynamic economic model captures such temporal interactions. We will adapt the dynamic model, which evaluated Pierce's Disease and Grapevine Trunk Disease management in grape production systems, to production systems associated with the identified crops to derive costs and benefits from adoption of the identified strategies. The model will simulate investment decisions under the alternative strategies, accounting for differences between insects and crops. A comparison of simulated costs and benefits for growers into the future under the alternative strategies will then illustrate long-term economics gains from adoption. To guide model development, we will gather information on cultural practices, grower perceptions on effectiveness and adoption of reduced-pesticide use, and stakeholder insights on market access from surveys (electronic and hard copy as described above) and interviews with stakeholder advisory members, other growers, industry representatives, farm advisors, and research collaborators. The interviews and survey will rely on methods used in past studies. Additional data will be collected from the scientific literature, USDA NASS, and similar sources, and through our proposed research on a model-driven, systems approach.
Expected outcomes*:* We will identify cost-effective strategies for managing SWD, and Codling moth and create educational and extension resources to better inform growers about the potential gains from these strategies that they can use when they face challenging decisions about the long-term profitability and sustainability of their production system.
Potential pitfalls*:* The identified strategies may not be adopted by growers, diminishing the potential to achieve a more sustainable agricultural system.

Objective 4: Extend knowledge from project to stakeholders. As alternatives are identified, pest management recommendations will be revised.
Activity 4.1 ***Train undergraduate and graduate students, postdoctoral scientists*****.** The studies within this project proposal will provide training opportunities for students and postdoctoral scientists who will assist with chemical analyses, laboratory bioassays, insect rearing and field work. We anticipate training graduate and undergraduate students and postdoctoral scientists in the fields of horticulture, chemistry, chemical ecology, and integrated pest management. Undergraduate and graduate students will be trained through incorporation of research outcomes into existing credit courses including a face-to-face course on integrated pest management (IPM).
Expected outcomes*:* We will train undergraduate and graduate students and postdoctoral scientists in horticultural, chemical, chemical ecology and IPM. This training will occur at various levels, adding to valuable experience in each of the scientific fields.
Potential pitfalls*:* None

Activity 4.2 ***Conduct and develop durable and accessible extension activities and resources*** (Adams, Walton, Miller, Tait). In collaboration with a wide range of stakeholders, we will continue to develop a comprehensive outreach program to ensure effective and timely dissemination and implementation of information generated by this project. Our target audiences are conventional cherry, blueberry, hazelnut and pear growers and processors focusing on small, midsize, and large-scale growers, Cooperative Extension personnel, and other stakeholders. Our outreach plan will be achieved in four primary ways: 1) eXtension and eOrganic webinars, 2) meetings, grower field days and educational programs 3) on-farm demonstration trials, and 4) published materials applicable to the respective cropping systems.

Activity 4.3 ***Partnership with eXtension and eOrganic*** This program will deliver information to conventional- and organic-growers. We have a current regional website that complements existing online SWD resources with regionally-specific information relevant to conventional and organic stakeholders. The website will be updated with research results and include project participant bios, links to videos, articles, archived webinars, newsletters, and press releases. The website will be linked to other online resources, including spottedwing.org and berry web sites, hosted by OSU. A 60-minute webinar will be delivered annually to disseminate our findings to all stakeholders. Videos and webinars will be made available via eXtension and eOrganic to reach an audience of up to 12,000.

Activity 4.4 ***Conduct meetings and educational programs***. The project team will meet by conference call every 6 months. We will conduct annual in-person meetings (5 total) with the stakeholders and scientific programs including the Pacific Northwest Tree Fruit Conference, Northwest Center for Small Fruits Research Conference, International Society for Horticultural Science Symposia, Oregon Blueberry Conference, Entomological Society of America, Pacific Branch Annual Conference, Entomological Society of America Annual Conference, and International Entomological Society Congress.

Activity 4.5 ***On-farm demonstrations.*** Participatory research disseminated via demonstrations on conventional and certified organic farms will be opportunities for growers to learn about implementation of new horticultural and behavioral strategies. At least one field day per year per region will be held with grower participants, including: NWREC (OR) for separate blueberry (raspberry/blackberry) Cherry, hazelnut and pear field days. Field day programs and materials will be coordinated among the respective horticultural leads and with input from stakeholder advisors (See supporting industry documents).

Activity 4.6 ***Publications***. We will reach a national audience of stakeholders through industry newsletters and University fact sheets describing whole-system management practices and recommendations. These materials will be updated every two years and will emphasize new behavioral and SIT techniques and their economic benefits, and will be disseminated through state extension networks, eXtension, and eOrganic. Scientific publications will be submitted to refereed journals including Agricultural Systems, Agriculture, Ecosystems and Environment, Agroecology and Sustainable Food Systems, the Journal of Pest Science, Crop Protection, Journal of Economic Entomology, Environmental Entomology, Pest Management Science, and HortTechnology. Further, publications of industry interest such as Oregon's Agricultural Progress, Journal of Sustainable Agriculture, Sustainability, Terra, and California Agriculture, among others, will target extension professionals, practitioners and agricultural consultants.

Expected outcomes*:* Initial field trials will demonstrate effectiveness and shortcomings of behavioral and SIT under varying environmental conditions. Whole-system trials will aid in assessing impacts of new technologies in whole systems. Economic studies will determine economic impacts of new technologies in farming communities. Dissemination of information will allow growers to assess the impacts of new techniques in their respective production systems.

Potential pitfalls: Collaborators will spray affected fields with pesticides, resulting in lack of results.

Timeline: Gantt chart

Objective	Tasks	Task lead(s)
1	Evaluate new behavioral formulations and SIT as alternative tools for key pests	
1.1	Characterize biologically important volatiles	Miller/Tait
1.2	Conduct trials on refined prototypes to quantify target effects	Walton, Adams
2	Evaluate effectiveness of currently available multi-tactic options at the farm scale.	
2.1	SWD Arrestant farm trials	Adams, Tait, Walton
2.2	Codling moth SIT trials	Adams
3	Assess economic feasibility of new management programs.	
3.1	Perform empirical analysis of the costs and benefits	Adams, Miller, Walton
3.2	Adapt dynamic model	Adams Miller Walton
4	Extend knowledge to stakeholders	
4.1	Train undergraduate and graduate students, postdoctoral scientists.	Adams, Walton, Tait, Miller
4.2	Conduct and develop durable and acessible extension activities and resource	Adams, Walton, Tait, Miller
4.3	Partnership with eXtension and eOrganic	Adams, Walton
4.4	Conduct meetings and educational programs	Adams, Walton
4.5	On-Farm demonstratons	Adams, Walton, Miller
4.6	Publications	Adams, Walton, Tait, Miller