Enhancing BC in Western Orchards

A collaborative project between Washington State University, University of California at Berkeley, Oregon State University, USDA-ARS, and USDA-NIFA, and the apple, pear and walnut industries in California, Oregon, and Washington

Year 2 Summary Report **November 2010**

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Project Goals

- *Improve the long-term sustainability of the apple, pear and walnut industries in the western US by enhancing biological control (BC) of pest insects and mites.*
- *Synthesize the information developed in this project along with existing information to provide the outreach tools needed to bring about change in grower practices.*

Objectives

1. *Evaluate the sublethal effects of newer pesticides on key natural enemies in laboratory and field assays in apple, pear, and walnut orchards.*
2. *Characterize natural enemy phenology, including timing of emergence from overwintering areas, entry into orchard, and development within the orchard.*
3. *Evaluate attractants as natural enemy monitoring tools and compare them to traditional methods.*
4. *Develop molecular and video methods to monitor predation of codling moth.*
5. *Conduct economic analyses to determine long-term costs associated with IPM programs with and without various levels of biological control.*
6. *Survey clientele to identify optimal ways to present information that will lead to quicker adoption of new technologies; synthesize existing and new information to provide real-time support for pest control decisions by stakeholders.*

Pesticides Influence BC Success

1. Pesticide Effects

Mills, Beers, Shearer, Unruh

Cumulative Milestones to Date: *Complete laboratory bioassays for half of the pesticides being evaluated; complete first year of field studies.*

Progress Summary: *We are meeting the goals and milestones as laid out in the grant.*

Year 1.

- In lab bioassays, the tested pesticides showed variable acute toxicity to different developmental stages of four predator and one parasitoid species.
- Initial lab bioassays with selected natural enemies revealed that the tested chemicals may alter sex ratio, fecundity, prey consumption, or decrease the long-term (chronic) mortality depending on the natural enemy and pesticide evaluated.
- The Beers lab performed a pilot study to evaluate potential problems with our field tests scheduled for year 2. This study showed that chemicals classified by laboratory studies as being harsh on natural enemies resulted in higher densities of woolly apple aphid and lower earwigs densities and parasitism of aphids in treated blocks.
- Each laboratory had to develop assays for each of their chosen natural enemies. Methods vary between natural enemies, but all labs use the same principle of having multiple methods of exposing the natural enemy (contact, residue, and treated prey or hosts).

Year 2. – *Laboratory Studies*

- All assays for *Trioxys pallidus*, the walnut aphid parasitoid (Mills lab) and *Galendromus occidentalis*, the Western Orchard Predatory Mite (Beers lab) are completed, but some analysis remains on the *G. occidentalis* data.
- The assays for *Deraeocoris brevis* (a predatory bug) (Shearer lab) are completed; ≈ 50% of the *Pelegrina aeneola* spider assays (Unruh lab) are completed.
- Work has begun on the other natural enemies: ladybird beetles (Mills), lacewings (Shearer), and a parasitoid of woolly apple aphid (Beers).
- Most spiders in orchards live for a year and will not mate in the lab as needed for sublethal studies. Sublethal effects will be completed only for the spider *Peligrina aeneola.* Acute mortality assays will be done with up to four species using mid-sized spiders; assays for *Misumenops lepidus* are 80% done.
- We are summarizing this information using tables (*e.g., see below*) that will be distributed to growers via our web site (enhancedbc.tfrec.wsu.edu), the WSU–Decision Aid System (das.wsu.edu), and the UC IPM web sites this spring.

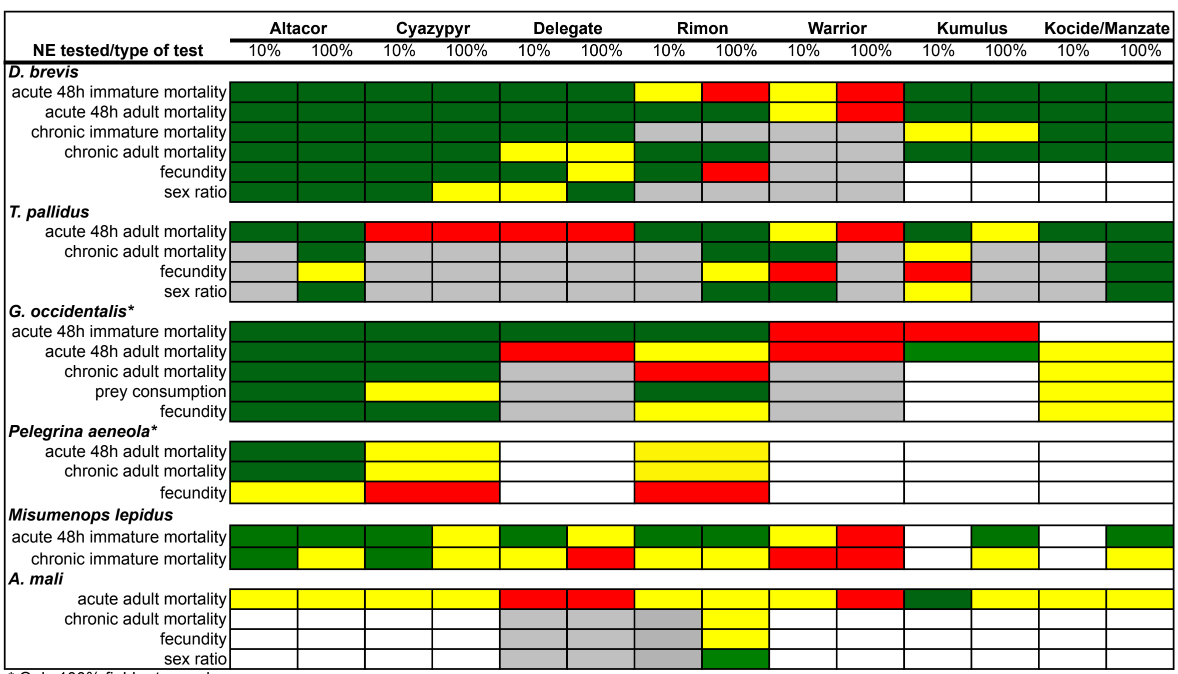
Year 2. – *Field Studies*

- This is the first year that all labs performed large plot replicated field tests of different pesticide treatments to determine their effects on natural enemies and pest population levels (*see results on page 3*).

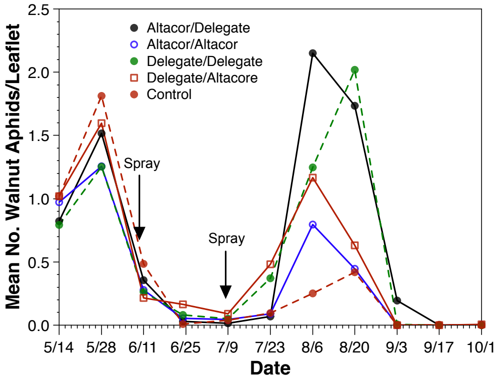
Plans for Next Year: To complete the laboratory-based acute and sublethal bioassays for those natural enemy species and pesticide combinations that remain. During the next field season we will also carry out additional replicated field trials in each of the three states to verify the effects seen in 2010.

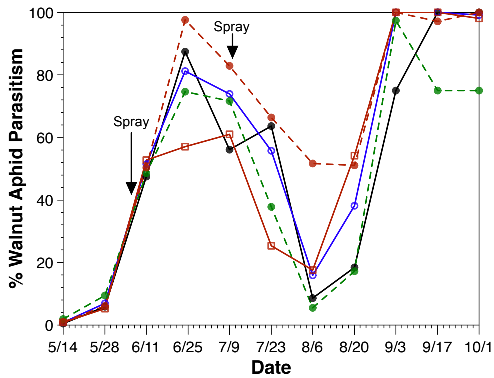
Implications for the Industries: The laboratory and field assays will allow us to recommend IPM programs that enhance biological control by minimizing disruption of the natural enemy community in orchards. The results of this research will be added to the WSU-DAS and UC-IPM web sites this coming season. We expect these recommendations to lead to increased biological control in our orchards, which should reduce pesticide inputs leading to higher grower profits and lower worker safety problems and environment issues.

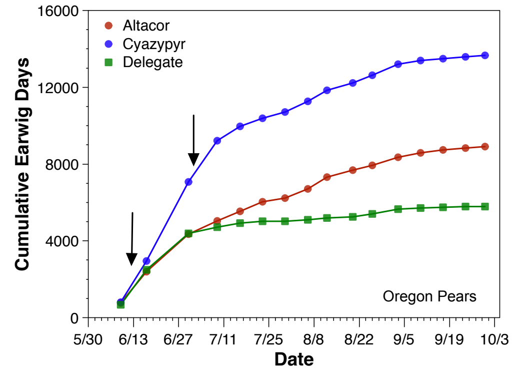
Effects of pesticides on natural enemies tested to date. Cell color reflects changes in natural enemy attribute: green (< 25% reduction), yellow (25–75% reduction), or red (≥ 75% reduction); white – test not yet analyzed, grey – test not applicable.



* Only 100% field rate used







Field Studies of Pesticide Effects

Field trials were conducted in each state. Pesticides chosen for evaluation were Delegate and Altacor with each state adding one additional treatment. The treatments were timed for codling moth management and applied either twice during the first generation (OR pears, WA apples) or once during each of the first two generations (CA walnuts). WA treatments also had a petal fall treatment of either Intrepid or Rimon applied, the other treatments were cover sprays. Treatments are summarized in the table (*below left*). All studies were conducted in commercial orchards using plots between 0.55 - 1.5 acres in size, and with each treatment randomized in three to four replicate blocks. Aphids and spider mites (CA and WA) or pear psylla (OR) and their natural enemies were sampled at 1-2 week intervals throughout the season.

State	Treatments
CA Walnuts	Altacor/Altacor; Delegate/Delegate; Altacor/Delegate; Delegate/Altacor; Control
OR Pears	Cyazypyr/Cyazypyr; Altacor/Altacor; Delegate/Delegate
WA Apples	Intrepid (petal fall), Altacor/Altacor Intrepid (petal fall), Delegate/Delegate Rimon (petal fall), Altacor/Altacor Rimon (petal fall), Delegate/Delegate

Results – Walnuts: Walnut aphid populations remained low throughout the cool summer. However, they grew to significantly higher levels in August in plots treated with Delegate in the second generation of codling moth (*above left*, arrows indicate pesticide applications). This was matched by a significant reduction in the parasitism of *Trioxys pallidus* during the same period for all plots treated with insecticides. This effect lasted longest in those plots treated with Delegate for the second spray (*above middle*).

Pears: Pear psylla abundance did not differ between treatments, but the earwig data clearly showed differences between the three treatments (*above right*). The two Delegate treatments resulted in the earwig population declining and the cumulative earwig-days (a measure of the potential predation) was relatively flat after the second spray, indicating elimination of most earwigs. The earwig-days in the Altacor treatment and the Cyazypyr treatments both showed increases, but Cyazypyr had a lower impact on earwig population growth.

Apples: Woolly apple aphid population levels were highest in the plots treated with Rimon followed by Delegate and lowest in the Intrepid followed by Altacor treatment. These results are the same as observed in the same block in 2009. There were no significant differences in spider mite populations between treatments.

Heroes and Villains Gallery

Field studies of the effect of insecticides on natural enemies focused on key groups of secondary pests and their natural enemies. The European earwig (*top left*) can fall under both hero and villain - in some cases when prey are not available, they can cause minor damage to leaves or fruit. However, they can be key predators of aphids, pear psylla, mites, and insect eggs (including codling moth). Woolly apple aphid (*top middle photo* - the dark ones are parasitized by *Aphelinus mali*) can be found both above ground infesting shoots, or below ground attacking the roots. Pear psylla (*top right*) is a key pest of pears and treatments for it are highly disruptive to natural enemies. Unlike apple and walnut, where codling moth drives most of the management decisions, in pears, pear psylla and codling moth each require multiple pesticide applications at different timings, which makes it difficult to tease out pesticide effects compared to the other two crops.

The walnut aphid is a key secondary pest of walnuts and is controlled by the parasitoid, *Trioxys pallidus* (*bottom left*). However, sprays for codling moth can disrupt *T. pallidus* and result in walnut aphid outbreaks. Spider mites (*bottom middle photo*) are typically controlled by the western predatory mite, *Galendromus occidentalis* (*bottom right*) unless disruptive materials are applied.

Knowing Phenology Improves Management Options

2. NE Phenology

JONES, MILLS, SHEARER, HORTON

Cumulative Milestones to Date: *Evaluate natural enemy (NE) phenology in eight apple, five pear, and three walnut orchards.*

Progress Summary: *We are exceeding the milestones as laid out in our plan of work.*

Year 1

- Squalene-baited traps were highly effective and showed that the lacewing *Chrysopa nigricornis* is one of the most abundant generalist predators in apple, walnut and pear orchards.
- Beat tray samples were completed in apple orchards, and first year work completed in pears
- *C. nigricorni*s phenology data were collected using data from apple, walnut, and pear orchards using squalene traps.

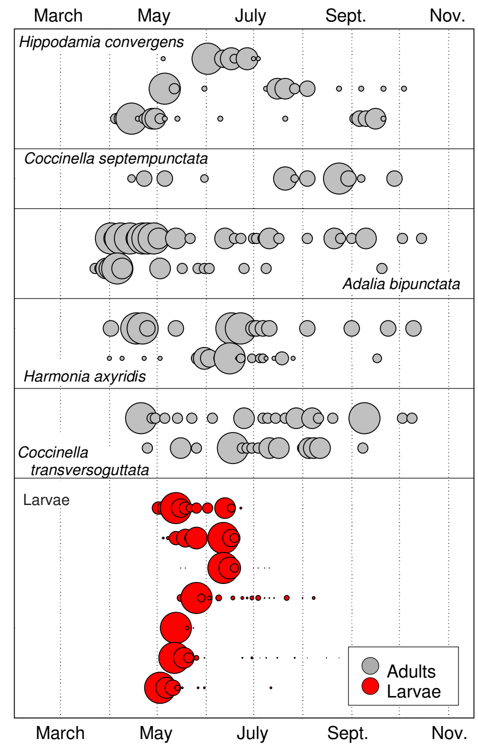
Year 2

- We sampled an additional eight apple orchards, three walnut orchards, and five pear orchards using four HIPV (herbivore-induced plant volatile) attractant blends that year 1 experiments (objective 3) showed were effective at attracting a broad range of natural enemies.
- Our data this year showed that our GMP blend (see objective 3) was markedly better than acetaphenone or phenylacetaldehyde attractants, which will simplify next year's studies.
- Shearer and Jones obtained commodity funding to expand our efforts into sweet cherries, where both labs used the same four HIPVs to monitor season-long natural enemy phenology and diversity.
- Analysis of the apple beating tray data from 2008-2009 collected by Horton and Jones in central Washington showed that our aphid eating ladybird beetles (Coccinellids) have only a single generation per year within the orchard (*figure right*). All spiders collected also had only a single generation per year.
- Our lacewings and some of the predaceous bugs (*Orius* and *Deraeocoris*) had two or more generations per year.
- Our *C. nigricornis* model is nearing completion and may provide us with a new method of evaluating pesticide effects on natural enemies (*see below*).

Plans for Next Year: This coming year we should finish up the field studies needed for development and validation of the natural enemy models. We will also begin the preliminary analysis of phenology models for other natural enemies.

Implications for the Industries: Quantifying when, where, and how many natural enemies are present at various times of the season will allow us to design management programs to minimize their exposure to pesticides and enhance their pest suppression. The potential to use changes in phenology as a tool (as discussed below) to assess pesticide effects is a key finding.

Beat tray data of the capture of several species of adult ladybird beetles in WA apples. Each row of circles is a separate orchard. Size of circle is proportional to the number collected.



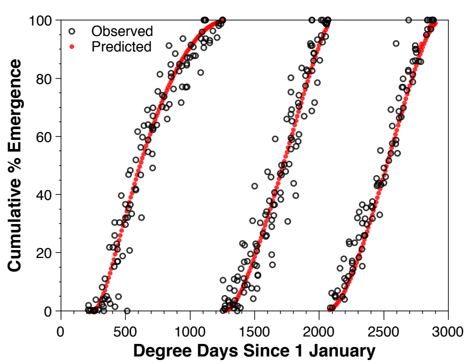
Phenology of the Lacewing *Chrysopa nigricornis*

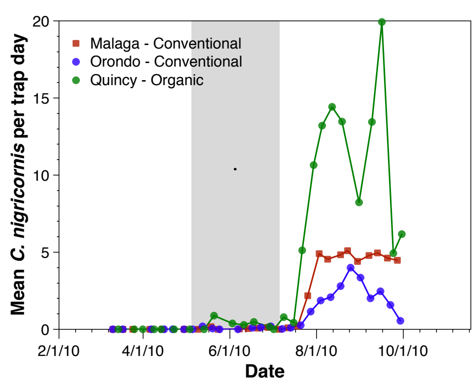
Analysis of all the data sets shows that a common phenology model is likely to work for apple, walnut, and cherry (*graph below left*). We found the number of flights varies from two (WA cherries) to three and most of a fourth flight (CA walnuts).

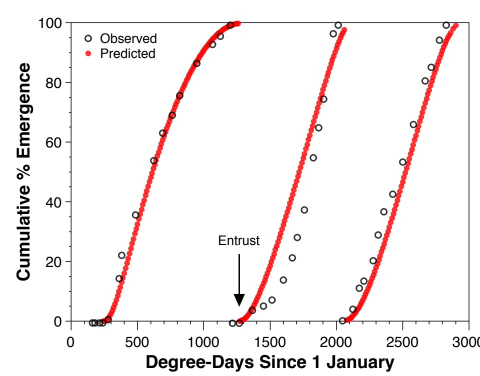
Washington cherry orchards were missing the majority of the first flight because of spray programs during that time; after sprays stopped the second flight occurred at the normal time (*graph below center* - gray box is time the first generation should occur).

C. nigicornis phenology in pear is highly distorted by the frequent pesticide applications for pear psylla. We will be obtaining the spray records, but it appears that most of the population fluctuations in pear are masked or caused by pesticide applications.

Pesticide effects are a concern in model development using data from commercial orchards, but even when phenology was distorted in a particular generation, the other generations typically occurred at the predicted times (*graph below right*). This distortion of phenology may be useful in assessing pesticide impacts on natural enemies and will be investigated this coming year.







Improved Monitoring Tools Make BC Visible

3. NE Sampling Tools

Jones, Mills, Shearer, Horton, Unruh

Cumulative Milestones to Date: *Complete studies on longevity and optimal release rates for eight different lures and four different trap types to sample natural enemies (NEs) in apple, pear, and walnut orchards over two different years.*

Progress Summary: *This section is exceeding the milestones and goals of the grant.*

Year 1.

- We developed and field tested a lure system that allows us to control release rates of the different herbivore-induced plant volatile (HIPV) attractants.
- We evaluated three trap types, 4 release rates, and 14 different HIPV combinations in apple, pear, and walnut orchards. The yellow sticky card was consistently one of the most sensitive for all natural enemies, while reducing capture of honeybees.
- The diversity and abundance of natural enemies is much higher in all three crops than previously suspected, and our research provided us with a sub-set of five lures that were moved to Objective 2 this year.
- We developed an attractant blend that contains geraniol + methyl salicylate + 2-phenylethanol (GMP blend) that is highly attractive to a broad range of natural enemies, especially syrphid flies, parasitic Hymenoptera, and the lacewing *Chrysoperla plorabunda*.
- Tests also showed us several other attractive compounds that are more restricted in activity and that need to be tested alone or in combinations in a factorial design in year 2 to determine their usefulness.

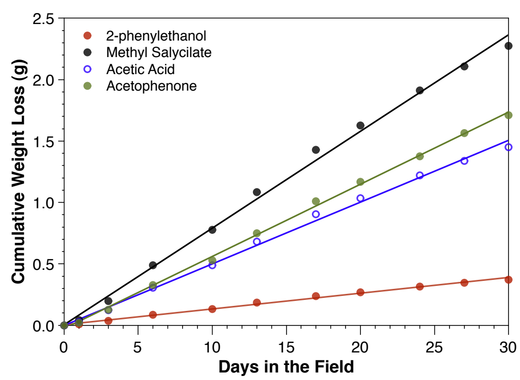
Year 2.

- All labs focused this year on large 4-way factorial experiments with promising compounds from last year's tests. These experiments were designed to optimize attractant blends for incorporation into objective 2 in year 3 of our phenology studies.
- The Jones lab ran a factorial experiment using yellow panels (versus white delta traps used in our other studies) and four lures. We found that the combination of visual and chemical lures allows us to monitor several predatory and parasitoid groups that don't respond to our normal delta traps.
- The Jones lab tested the release rate of lures in direct sunlight to make sure that we could use them with traps that don't shade the lure (*see below*). The release rates were similar to lures placed inside a trap, which will allow us to use different trap types in the future without affecting the lure.

Plans for Next Year: Our studies on lures will be directed entirely towards optimizing lures to capture given taxa and exclude others. We hope to be able to minimize the effort to count certain groups by blending attractants appropriately. We will also run one more factorial experiment to evaluate the importance of methyl salicylate and acetic acid as synergists for certain natural enemy groups.

Implications for the Industries: Having new sampling tools will change pest management radically and is showing that orchards are not the ecologically simple systems previously suspected, opening the door for broader use of biological control tactics.

Improving the Trapping System



Last year we tested our HIPV traps using the white delta trap (*second from right in above picture*). This trap is the standard trap commonly used in all three industries and it provides protection from sunlight to the lure which is placed inside the trap. However, we found this trap caught large numbers of honeybees, and appeared to be sub-optimal for some natural enemy taxa because appropriate visual stimuli were not present. To address this issue, last year we tested yellow panel traps as a replacement for the white delta traps, and found they brought in more natural enemy taxa and eliminated problem of honeybee attraction. This year we tested the yellow panels but rolled into tubes so that the lures would be protected from direct sunlight (*above*). At the same time, we ran all our lure longevity studies again in mid-summer to see how the lure release rate would be affected by being placed directly in the sun. If this worked, the panels could be used as panels, rather than tubes, which is much more convenient to use in the field and to store and count in the lab.

Results: The yellow tubes were efficient at attracting syrphid flies, lacewings, and parasitic wasps in several families. Honeybee capture was minimal. Our lure longevity in the direct sunlight was very consistent, and only a few lures required modification (*above right* figure showing a subset of the data). In all cases where early depletion occurred, we were able to simply increase the amount of attractant loaded into the lure and still maintain a one-month life in the field. Next year all of our studies will use the yellow panels and lures placed directly in the sun. These will be cheaper than the delta traps, easier to handle, and easier to count because of fewer honeybees and non-target insects. In addition, our studies show that some parasitoids (e.g., *Aphelinus mali*, the parasitoid of woolly apple aphid) are easily monitored, even without HIPV lures.

Refining the Attractants

Last year, all labs evaluated a series of attractants in apple, pear, and walnut orchards. As expected, we found that there are multiple natural enemy species in common between the different systems, but the relative abundances were different between orchard types and locations. Studies in the Jones lab last year allowed us to refine a general attractant blend (geraniol + methyl salicylate + 2-phenylethanol or "GMP") that brings in large numbers of syrphid flies (feed on aphids), lacewings (feed on aphids, spider mites, small soft-bodied insects), and specific parasitoids. That lure was particularly useful this year in our phenology studies and its use in the future should decrease the labor needed to monitor natural enemies.

The attractant studies this year in all labs concentrated on four different compounds (2-phenylethanol (PE), acetic acid (AA), phenylacetaldehyde (PAA), and acetophenone (AP)) that proved promising last year. In an attempt to evaluate the importance of these in mixtures, we ran an all possible combinations experiment (factorial) - this required us to test 16 different treatment combinations (each replicated 4 times per orchard). This trial was run three times in apple, and a single time in pear and walnut orchards. To date, only the apple data are complete enough to evaluate effects on specific natural enemies.

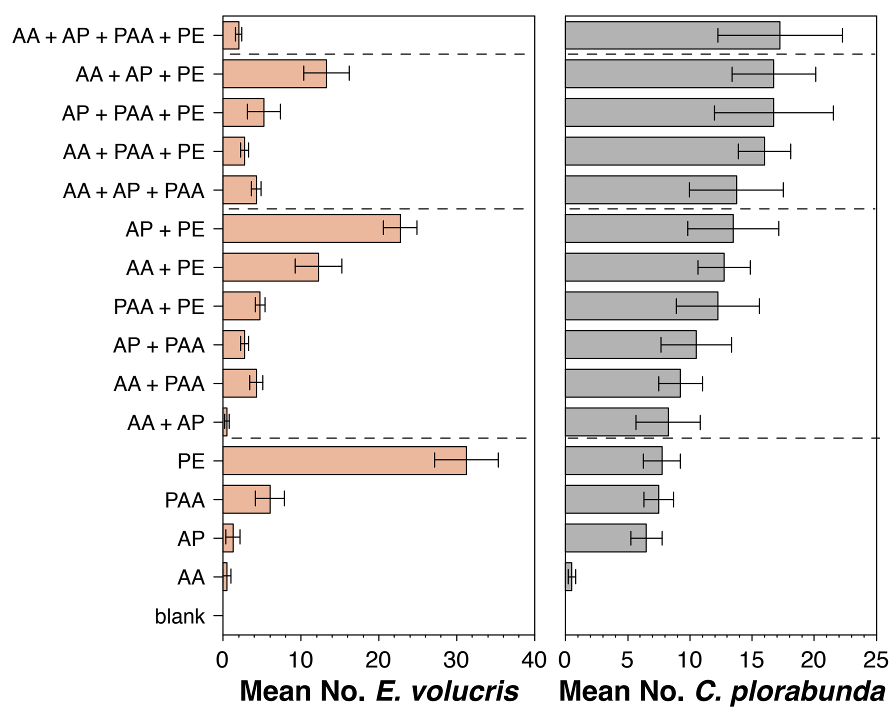
Results: The complete factorial design is very cumbersome and expensive to perform, but it provides a very clear picture of how the different attractant combinations work in the field. For the syrphid fly, *Eupeodes volucris*, it is clear that its response is similar in all three apple orchards, with the best attractant being PE by itself (*graph right tan bars*). Addition of any of the other compounds did not improve capture, and many combinations actually decreased the capture over PE alone. This is in contrast to the lacewing *Chrysoperla plorabunda*, which responds to a wide range of blends and nearly always responds better with two or more of the attractants (*gray bars*). For *C. plorabunda*, the top binary blends were not significantly different from either the three or four component blends.

Other Experiments: Over multiple experiments, it appears that both acetic acid (AA) and methyl salicylate (MS) are relatively inactive on their own, but act to synergize the activity of other attractants, at least for *C. plorabunda*. In contrast, *E. volucris* attraction in four different experiments was always best with single attractants, and multiple attractants either made no improvement or significantly reduced trap catch.

In another factorial experiment, attraction of *C. plorabunda* was tested where both MS and AA were run in combination with PAA. We found the three way combination was highly synergized by the combination of both MS and AA with PAA, compared to the single blends or the different two way combinations. This effect of AA and MS is one that will be tested this coming year in combination with other attractants.

Next Year: Running the full factorial experiment allows us to custom tune a blend to attract a range of natural enemies and reduce capture of those of less interest. Once the full data set from all labs is available, we will design some blends that attract the desired range of natural enemies and test them in the field next year. For example, our apple data suggest that we could use several of the three component blends (e.g., AA + PAA + PE) to limit catch of *E. volucris*, while still capturing *C. plorabunda*. We will also run one more factorial experiment this coming year, combining the best attractants of 2009 and 2010 to finalize our blends down to 3-4 lures targeting key natural enemy taxa.

Comparison of trap capture of the syrphid fly, *Eupeodes volucris* and the lacewing, *Chrysoperla plorabunda* in the large factorial experiment evaluating all possible combinations of AA, AP, PAA, and PE. Dotted ines within a graph separate one, two, three and four component blends.



Which Predators are Eating Codling Moth?

4. CM Predators

Unruh

Cumulative Milestones to Date: *Field video monitoring of and complementary laboratory feeding trials with potential codling moth (CM) predators. Development of a robust and reliable method for molecular gut contest analysis of arthropod CM predators.*

Progress Summary: *This section fell slightly behind the milestones and goals of the grant due to unanticipated difficulties. We expect to meet the milestones and goals again after year 3.*

Year 1.

- Field video monitoring was problematic and did not give data that was useful in supplementing the molecular gut content analysis.
- Motion triggered video recordings in one apple and one pear orchard captured 1,114 video hours showing only 11 predation events: by mice (7), ants (3), and earwig (1). These results suggest that ground dwelling predatory arthropods have less impact on cocooned CM than do vertebrates. But it is uncertain that this reflects normal orchard situations or if the few observed predation events are due to the artificial observation arenas or the times of the season recordings were made (June, July).
- We developed and evaluated loop-mediated DNA amplification (LAMP) to detect DNA remains of codling moth in whole-body homogenates of arthropod predators (for gut content analysis to evaluate which predators fed on CM). The test was extremely sensitive, but was plagued by contamination issues.

Year 2.

- The LAMP contamination issues persisted and it was dropped as a gut content analysis method. Instead, a PCR protocol that detects a portion of a CM odorant receptor gene and which uses a specialized buffer system to allow processing of whole-body homogenates was completed in the fall.
- To explain the inconsistency in dominant CM predators between our field observations (vertebrates) and the literature (arthropods) the Unruh lab conducted feeding trials in the laboratory (*see box below*).
- We captured ground-dwelling predators in pitfall traps with propylene glycol which preserves predator DNA, but it turned out to be marginal in preserving DNA inside the stomachs of the predators.
- Limited numbers of gut content analysis using the new protocol were conducted: *Opiliones* (n = 18), earwigs (n = 167), spiders (n = 129), and the carabid, *Pterostichus melanaria* (n = 48). We found that 6, 2, 4 and 10% of the *Opiliones*, earwigs, carabids, and spiders (respectively) tested positive for consumption of codling moth within the previous 24 hours (after 24 hours, the codling moth DNA breaks down and is not detectable).

Plans for Next Year. Lab studies to test an improved DNA preservation fluid for pitfall trapping will be performed this winter. We will repeat season-long trapping of ground-dwelling predators employing the improved storage medium and new PCR protocols throughout the season. In addition, >2,000 existing frozen dry-trapped predator samples will be processed.

We will also complete lab studies on the digestion rates of *P. melanaria*, earwigs, and *Opiliones* to clarify interpretation of positive gut content assays (*i.e.*, if digestion is complete by 24 hrs then a positive result would suggest at least one feeding event in the past 24 hr).

Additional field studies will provide new estimates of predation rates by ground dwelling arthropods using two methods: 1) measuring predator abundance in closed arenas with pitfall traps and 2) estimating mortality of sentinel cocooned and tethered codling moth larvae.

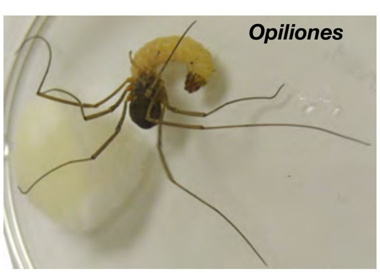
Implications for the Industries: The gut content analysis weighted by predator abundance will help clarify which natural enemies are important for our conservation efforts as well as providing targets for our monitoring efforts.

Laboratory Feeding Studies of Four Potential Codling Moth Predators

Four arthropod groups that were large enough to be potential predators of free living or cocooned codling moth (CM) larvae were collected by pitfall trapping and tested in the lab. Pictured below (from left to right), these arthropod predators were harvestmen (*Opiliones*), several species of large wolf spiders, the predatory ground beetle *Pterostichus melanaria*, and the European earwig (*Forficula auricularia*).

Each predatory species was offered either late instar CM larvae or cocooned CM larvae and their behavior and prey consumption were monitored in 70-100 replicates/species/host type.

The studies showed that earwigs (93%) and daddy long legs (95%) ate free-living CM larvae but not cocooned larvae (0% for both species). In contrast, the carabid beetle, *P. melanaria* and wolf spiders ate both free-living 5th instar larvae and cocooned larvae equally (>95% for both host types for both species). The carabid and the wolf spiders were voracious predators; they attacked and consumed the CM larvae within one hour of presentation; cocooned CM consumption took several hours. The daddy long legs and earwigs were slower at prey consumption and took many hours (4–24) to attack and consume the free-living larvae.



What is the Cost of Enhanced Biological Control?

5. Economic Analysis

GALLARDO, BRUNNER

Cumulative Milestones to Date: *Gather data from objective 1 to evaluate estimates of IPM cost structures. Develop an expected profit model with data on indirect IPM benefits obtained from survey.*

Progress Summary: *This section is meeting the milestones and goals of the grant.*

Year 1.

- Basic economic models were developed to determine the costs associated with conventional and enhanced biological control (BC) programs.
- We developed different IPM scenarios that represent a spectrum of programs that are expected to have varying degrees of impact on BC in apple orchards based on data generated in objective 1.
- These nine scenarios assume different codling moth (CM) densities (risk of crop injury) that would be treated using different pesticide combinations to prevent CM damage. The scenarios also include additional treatments of secondary pest outbreaks associated with certain CM control strategies (*see below*).
- A literature review was conducted to formulate a model to include growers' willingness to pay for IPM indirect benefits.

Year 2.

- The basic economic models were paired with pest control risk/cost scenarios developed in year 1 for apple.
- We formulated a partial budgeting for the nine different IPM scenarios developed in year 1 and modeled cost variations over time (*see below*).
- The results indicate IPM program costs are correlated to pesticide costs, but are mainly driven by initial pest pressure.
- Apple growers are being interviewed about how they value insecticides' attributes associated with the environment and worker safety.

Cost Analysis of Biological Control in Apples

The budget developed for nine IPM scenarios assumed different densities (pressure) of the key pest, codling moth (CM) and typical pesticide programs. The value of biological control (BC) is built into the assumed negative impacts of certain pesticides on BC agents resulting in additional pesticide inputs (increased costs). Program costs per acre include the costs of the active ingredient plus application.

In general, results show that lower initial pest pressures lead to lower total pesticide costs. Traditionally, pesticide programs based on organophosphate (OP) alternatives + mating disruption (MD) are thought to be more costly than programs based on OPs only. However, we found that OP-alternative programs are not always more costly (*table*).

The budget was applied to our economic model, which used six likely scenarios that reflect expected change in practices over a five year period. These scenarios assumed different CM pressures (risk of crop injury) and grower pesticide use that would provide acceptable control of all pests.

Results: Scenario 1 is an OP-based program, initially without MD, starting with high pest pressure that transitioned to a low pest pressure OP + MD program. This sequence would not represent current practice but might have occurred historically. Due to the initially high CM pressure, it is not the cheapest scenario even though OP costs are lower than OP-alternative costs.

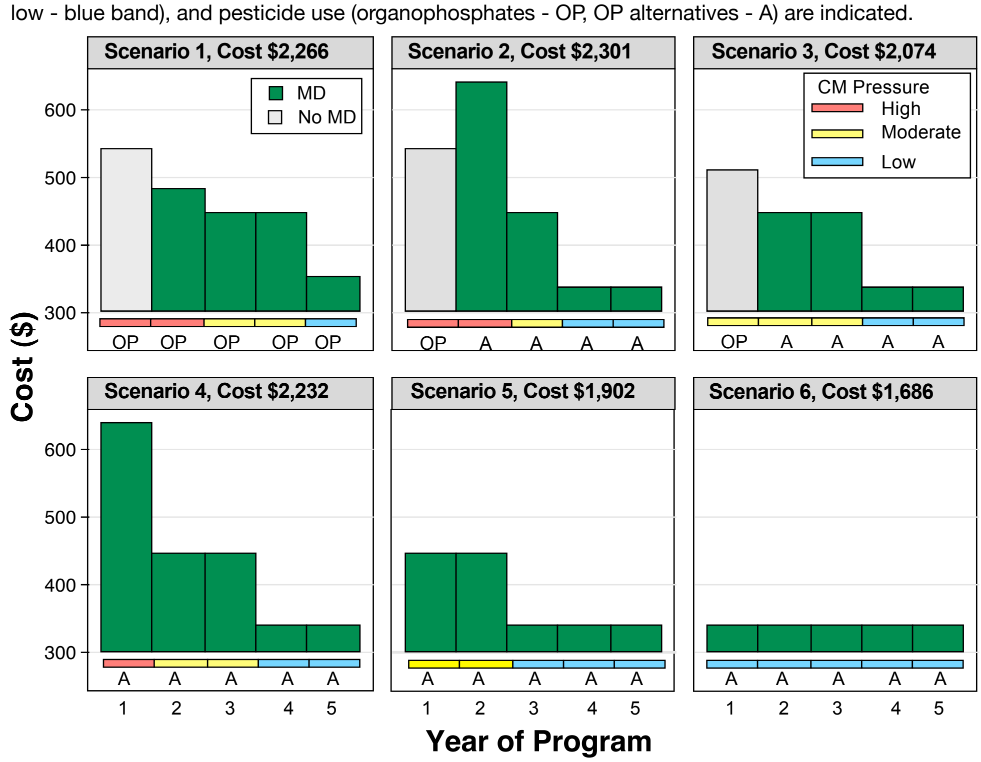
Pesticide programs in scenarios 2 and 3 are OP-based transitioning to OP alternative + MD programs. The cost of scenario 2 is the highest of all scenarios because of the switch from OPs to OP alternatives with high CM pressure. In contrast, scenario 3 with an initial moderate CM pressure resulted in lower total program costs.

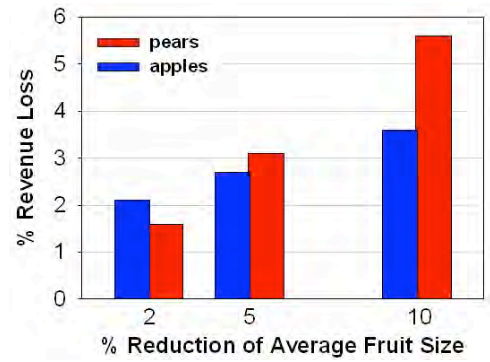
Scenarios 4-6 represent OP alternative + MD programs that start with different pest pressures. These scenarios represent likely patterns that might be encountered as OP insecticides are phased out. All these scenarios have a lower five-year cost than the OP based programs in scenarios 1 and 2.

Scenario 6 represents a desired stable and sustainable IPM program using enhanced BC. It is the least expensive of all the scenarios over five years and points out the potential value of BC through conserving natural enemies in apple orchards.

	CM Pressure		
Pesticide Program	**High**	**Moderate**	**Low**
OP only (No MD)	$542	$509	$407
OP + MD	$482	$396	$352
OP alternative + MD	$639	$445	$337

Costs per year and total cost for the six different scenarios. For each year, the use of mating disruption (MD - green bar, no MD - gray bar), CM pressure (high - red band, moderate - yellow band, low - blue band), and pesticide use (organophosphates - OP, OP alternatives - A) are indicated.





- We have also evaluated the effect of delayed re-entry times on timing of fruit thinning and the resultant final fruit size distribution.

We found a delay in time of fruit thinning results in fruit size decreasing, which affects the final profit. In apples, we found that decreasing the mean of the size distribution by 2, 5 or 10% resulted in 2.1, 2.7, or 3.6% decrease in total revenues. In pears, the same changes in the distribution of mean fruit sizes caused a 1.6, 3.1 and 5.6% reduction in total revenue.

Plans for Next Year. The next step in applying our economic model to pest control scenarios will be to incorporate synthesized information from Objectives 1 and 2 into a more realistic representation of the impact of OP alternatives on BC. Input from pear and walnut growers is being collected in order to develop an economic model similar to apple. The survey interviews to evaluate the growers' willingness to pay for BC will continue for apple and will be conducted for pear and walnut.

Implications for the Industries: Information generated by economic models and surveys will help to inform growers and consultants of the value of conserving BC agents in orchards. The outcomes will be used in designing education programs that link the relative impacts of new insecticides on natural enemies based on results from objectives 1-2.

Optimizing Technology Transfer

6. Outreach

Goldberger, Brunner, All PD's

Cumulative Milestones to Date: *Survey of walnut growers is completed and analysis has begun; the project website is set up providing details on progress and general information to stakeholders.*

Progress Summary: *This objective is ahead of the goals and milestones assigned by the grant.*

Year 1.

- Our website showcases our accomplishments and is online at: enhancedbc.tfrec.wsu.edu.
- Field days were held in each state to discuss the project.
- We developed a survey tool for walnuts (Goldberger) that was approved for distribution last fall.
- We were invited to write a paper entitled "*Tree fruit IPM programs in the Western United States: The challenge of enhancing biological control through intensive management*" for a special issue of the Journal *Pest Management Science* on the 50th anniversary of IPM.

Year 2.

- Analysis of the California walnut survey has begun (Goldberger); the complete results are on our website and a summary is on the next page.
- Preliminary analysis has shown that the top two information sources used by growers were PCA's associated with a chemical sales company and insecticide label information.
- 75% of growers felt that the most important factors in choosing control strategies were economic costs and impacts on worker health (both equally important).
- Environmental impacts were considered very important by 60% respondents.
- The survey for the pear growers was developed and approved this fall and we should have the results in late summer 2011.
- Our project has been highlighted at field days, grower meetings, academic showcases (at WSU), and scientific society meetings.
- We are putting a large effort into decision support systems to help leave a legacy that will continue to help growers after the project is finished. The WSU - Decision Aid System is the prototype for this sort of effort, and we expect to provide modules as requested by the outreach personnel in California and Oregon to help those states provide the best outreach possible.

Plans for Next Year. We will send out our survey to Oregon pear growers. The apple survey will be prepared next year and sent out in 2011. We will develop new IPM programs by integrating data from objectives 1 and 5. In addition, we will usher in the implementation of the project's educational program. The goal is to deliver a synthesis and transfer new knowledge and technology to stakeholders in a manner that will provide a lasting impact.

Implications for the Industries: Our surveys of growers and consultants are providing the information needed to improve outreach and leave a legacy of information once the project is completed.

The Experiences and Perspectives of California Walnut Growers

Survey Methods

A survey of California walnut growers (N=2,688) in the top-ten walnut-producing counties was conducted from March through June 2010. Half of growers received a paper questionnaire, the other half was asked to participate in the survey online. The response rates for the two groups were 31% and 11%, respectively (21% combined).

Orchard Characteristics

The majority of survey respondents (87%) were orchard owners, partners, or lessees, while 9% were hired managers. Approximately 70% of respondents described their farm operations as family or individual operations. Respondents operated, on average, 385 acres of farm/ranch land in 2009. Over one half (54%) of respondents produced walnuts in addition to other agricultural products (*e.g.*, almonds, cherries, grapes, peaches, prunes).

Pest Management Decision-Making

When making pest management decisions, 75% of respondents rated economic cost and health impacts as "very important", while 60% believed environmental impacts are "very important."

The most important sources of information for making pest management decisions were Pest Control Advisors (PCAs) affiliated with chemical companies, followed by insecticide label information, formal education and continuing education classes, University of California Cooperative Extension (UCCE) publications, and UCCE advisors.

Most survey respondents (90%) used the services of a PCA. Of those respondents, 17% consulted with their PCA more than once a week, 33% once a week, 25% every 2-3 weeks, and 26% once a month or less. Most respondents (90%) followed either most or all of their PCA's advice.

Survey respondents reported varying levels of contact with UCCE with regard to their walnut orchards. The most frequent forms of contact were reading UCCE bulletins (76%), attending meetings, workshops or field days (63%), and visiting UCCE websites (45%). Office visits, on-farm visits, and research collaborations with UCCE advisors were less common (39%, 25%, and 18%, respectively).

General Pest Management

Respondents were asked about changes in their use of selected pest management practices during 2007–2009. Nearly 30% of respondents decreased their use of insecticides more harmful to non-target species. Over 25% of respondents increased their use of insecticides less harmful to non-target species; 20% increased their use of monitoring for insect pests; 14% increased their use of pheromone or sticky trips; 11% increased their use of monitoring for natural enemies; and 8% increased their use of biological control practices.

Biological Control Practices

Over half (54%) of the survey respondents relied on one or more biological control practices to control for insect pests in their walnut orchards in 2009. Of those respondents, 87% minimized factors that harm natural enemies, 39% enhanced natural enemy habitats, and 6% released commercially produced natural enemies. Respondents, on average, had been using "conservation biological control" (i.e., minimizing factors that harm natural enemies and enhancing natural enemy habitats) for 10 years and "augmentative biological control" (i.e., releasing commercially produced natural enemies) for 7 years.

Primary Walnut Pests

Respondents were asked if they select insecticides and time insecticide applications (for control of primary walnut pests) so they are least disruptive to the natural enemies of secondary pests. They were also asked if they use spot sprays to minimize harm to the natural enemies. Responses indicate that selective insecticide choice and application timing are more common than spot sprays (*see table*).

Secondary Walnut Pests

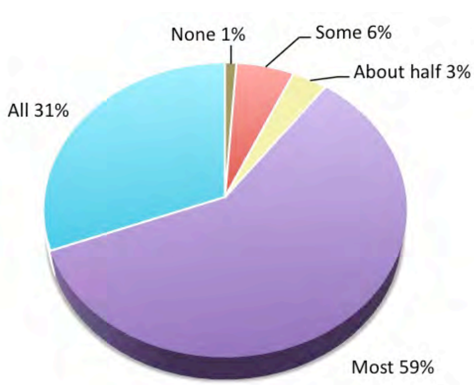
Survey respondents were asked if certain secondary walnut pests required treatment in their walnut orchards in 2009. The following pests required treatment by the reported percentages of respondents: twospotted or Pacific mite (43%), European red mite (16%), walnut aphid (9%), scales (7%), redhumped caterpillar (4%), leafroller (3%), green fruitworm (1%), and dusky-veined aphid (1%). Forty-four percent of respondents reported that no secondary pests required treatment; 11% did not know if secondary pests required treatment. Most respondents report that they did not face increased secondary pest problems during 2007-2009.

First Conclusions

The survey responses demonstrate that the educational process needs to be strengthened, including IPM critical content and ways to improve information transfer.

Full Survey online at enhancedbc.tfrec.wsu.edu

Amount of PCA's Advice Followed by Walnut Growers



Use of selected pest management practices to minimize harm to natural enemies (NEs) when controlling primary walnut pests.

	Never	Some-times	Always	Don't know
Codling Moth				
Select insecticides so they are least disruptive to NEs	7.7%	37.0%	30.8%	24.5%
Time insecticide application so they are least disruptive to NEs	16.2%	34.9%	19.7%	29.2%
Use spot sprays to minimize harm to NEs	61.1%	21.4%	3.3%	14.1%
Walnut Husk Fly				
Select insecticides so they are least disruptive to NEs	16.0%	34.0%	22.3%	27.7%
Time insecticide application so they are least disruptive to NEs	23.0%	28.9%	17.1%	31.0%
Use spot sprays to minimize harm to NEs	43.5%	28.2%	10.5%	17.9%
Navel Orangeworm				
Select insecticides so they are least disruptive to NEs	25.3%	26.0%	15.9%	32.7%
Time insecticide application so they are least disruptive to NEs	28.8%	22.6%	13.5%	35.1%
Use spot sprays to minimize harm to NEs	58.8%	14.6%	4.3%	22.3%

Project Output

National Symposium

We will have a 3 hour symposium on our project at the Entomological Society of America Annual Meeting in San Diego, CA (15 Dec 2010) entitled "Building the Framework to Enhance Biological Control in Orchard System: Progress and Problems in the Western U.S." - 10 presentations:

- Jones VP. Overview and information needed to integrate conservation BC into orchard systems.
- Horton DR, E Miliczky, VP Jones. Diversity and phenology of the predator complex in orchards.
- Steffan SA, VP Jones, CC Baker, TD Melton. Use of HIPV lures to evaluate natural enemy abundance, diversity and phenology.
- Mills, NJ. How do we estimate direct and indirect effects of pesticides on BC? An overview of problems and solutions.
- Amarasekare KG, PW Shearer. Use of laboratory assays to estimate pesticide effects on BC agents.
- Beers EH, L Gontijo. Connecting the dots: do laboratory bioassays predict disruption of BC in the field?
- Gallardo K, JF Brunner, Z Wang. The importance of economics in the adoption of BC programs: use of budgets and case studies.
- Goldberger J, N Lehrer. Use of grower surveys to evaluate BC adoption and knowledge transfer.
- Chambers U, VP Jones, JF Brunner, B Petit. Decision support systems as a method to enhance adoption of BC.
- Brunner JF, C Pickel, S Castagnoli, K Lewis, P van Buskirk, WE Jones, TJ Smith. Synthesis and outreach programs: leaving a legacy useful to growers and consultants.

Other Presentations

- Jones VP. 2010. Enhancing Biocontrol in Western orchards: an Overview. Wash. State Horticultural Assoc. 7 Dec. Yakima, WA.
- Steffan SA and VP Jones. 2010. New monitoring systems for natural enemies. Wash. State Horticultural Assoc. 7 Dec. Yakima, WA.
- Jones VP. 2010. Conservation BC in Western Orchard Crops: A comprehensive approach. WRCC 2185 Annual Meeting, Coeur d' Alene, ID. Oct. 25.
- Jones VP and SA Steffan. 2010. Update on the USDA Specialty Crops Research Initiative project on "Enhancing Biological Control in Western Orchards". WSU-Sunrise Research Orchard Field Day. 29 July.
- Amarasekare KG, PW Shearer and AA Borel. 2010. Effects of newer insecticides on the natural enemy *Deraeocoris brevis* (Uhler) (Hemiptera: Miridae). Poster. Pacific Branch Entomological Society of America's 94th annual meeting. Boise, ID. 11-14 April. (PDF 580KB)
- Amarasekare K, PW Shearer and AA Borel. 2010. Effects of newer insecticides on the natural enemy *Deraeocoris brevis* (Uhler) (Hemiptera: Miridae). Poster. International Organization for Biological Control. Workshop on "Sustainable protection of fruit crops in the Mediterranean area". Vico del Gargano, Italy. Sept. 12-17.
- Mills, NJ. 2010. Selective pesticides and the biological control of walnut pests. Walnut Research Conference, Bodega Bay, Jan 28, 2010.
- Brunner JF, MD Doerr. 2010. Control of Direct Pests of Organic Apples: Successes and Challenges. Symposium presentation, Pacific Branch of the Entomological Society of America's 94th annual meeting, Boise, ID. 11-14 April.
- Jones VP, SA Steffan, DR Horton, NJ Mills, PW Shearer. 2010. Enhancing BC in Organic Orchards Using HIPV Lures to Characterize, Monitor and Manipulate Natural Enemies. Symposium presentation, Pacific Branch of the Entomological Society of America's 94th annual meeting, Boise, ID. 11-14 April.
- Mills NJ. 2010. Predation of Aphids in Organic Prunes: How Many Predators are Enough? Symposium presentation, Pacific Branch of the Entomological Society of America's 94th annual meeting, Boise, ID. 11-14 April.
- Shearer PW. 2010. Peach Orchard Ground Cover Management Mitigates Bug Damage. Symposium presentation, Pacific Branch of the Entomological Society of America's 94th annual meeting, Boise, ID. 11-14 April.
- Steffan SA, VP Jones, CC Baker, and TD Melton. 2010. Chumming for predators: HIPV lures as monitoring tools for natural enemies. Pacific Branch of the Entomological Society of America's 94th annual meeting, Boise, ID. 11-14 April.
- Unruh TR. 2010. Who's Eating Whom? Evaluating Predators and Parasitoids and the Influence of the Farmscape Using Protein-Marking and Gut Content Analysis. Pacific Branch of the Entomological Society of America's 94th annual meeting, Boise, ID. 11-14 April.
- Jones VP, S Steffan, JF Brunner, EH Beers, J Goldberger, K Gallardo, U Chambers, NJ Mills, DR Horton, T Unruh, PW Shearer and S Castagnolli. 2010. Enhancing Biological Control to Stabilize Western Orchard IPM Systems. Poster. WSU Academic Showcase. (PDF 8.4MB)
- Jones VP, U Chambers, B Petit. 2010. WSU-DAS and virtual weather stations. SAGES Climate Change Meetings, Vancouver, BC. 24 March 24.
- Amarasekare KG, PW Shearer and AA Borel. 2010. Lethal and sublethal effects of newer insecticides on the natural enemy *Deraeocoris brevis* (Hemiptera: Miridae). Presentation (Oral). 84th Annual Western Orchard Pest and Disease Management Conference. Portland, OR. 13-15 January.
- Jones VP, SA Steffan, CC Baker, TD Melton. 2010. Enhancing biological control in orchard systems: using HIPV's as monitoring tools. 84th Annual Western Orchard Pest and Disease Management Conference. Portland, OR. 13-15 January.
- Steffan SA. 2009. Biocontrol Innovation at the WSU Tree Fruit Research and Extension Center. WSU Tree Fruit Field Day. 22 July.
- Unruh TR. 2009. Enhancing western orchard biological control. WSU Tree Fruit Field Day. 15 July.
- Steffan SA. 2009. Biocontrol in Pacific NW Orchards. Pest Management Transition Project outreach meetings in north central WA. 28 May, 3 June, 10 June.
- Jones VP, JF Brunner, GG Grove, B Petit, GV Tangren, WE Jones. 2009. Evolution and implementation of decision support systems in perennial crops. Pacific Branch Ent. Soc. of Am., San Diego, CA. 31 April.
- Beers EH. 2009. Cover Crops: Inviting Natural Enemies into Your Orchard. Int. IPM Symposium. Portland, OR. 24-26 March.
- Beers EH. 2009. Disruption of Secondary Pests of Apple in the Northwest by Reduced-Risk Pesticides. Int. IPM Symposioum. Portland, OR. 24-26 March.
- Jones VP. 2009. Using pest and natural enemy phenology to enhance biological control in orchards. Int. IPM Symposium. Portland, OR 24-26 March Publications.

Publications

- Jones VP, SA Steffan, NG Wiman, DR Horton, E Miliczky, QH Zhang, CC Baker. 2011. Evaluation of herbivore-induced plant volatiles for monitoring green lacewings in Washington apple orchards. Biol. Control. 56: 98-105 doi:10.1016/j.biocontrol.2010.10.001
- Jones VP, SA Steffan, LA Hull, JF Brunner, DJ Biddinger. 2010. Effects of the loss of organophosphate pesticides in the US: Opportunities and needs to improve IPM programs. Outlooks in Pest Management (invited paper) 21: 161-166.
- Steffan SA, and WE Snyder. 2010. Cascading diversity effects transmitted exclusively by behavioral interactions. Ecology 91: 2242-2252. (PDF 308KB)
- Jones VP, JF Brunner, GG Grove, B Petit, GV Tangren, WE Jones. 2010. A web-based decision support system to enhance IPM programs in Washington tree fruit. Pest Management Sci. 66:587-595. (311KB)
- Horton DR, VP Jones, TR Unruh. 2009. Use of a new immunomarking method to assess movement by generalist predators between a cover crop and tree canopy in a pear orchard. Am. Entomol. 55:49-56. (3.4MB)

- Jones VP, TR Unruh, DR Horton, NJ Mills, JF Brunner, EH Beers and PW Shearer. 2009. Tree Fruit IPM Programs in the Western United States: The challenge of enhancing biological control through intensive management. Pest Management Sci. 65: 1305-1310. (PDF 168KB)

Web Pages:

- We have continuously updated the Enhanced BC web site (*below left*) to have publications, research reports, the walnut survey, and information on pesticide impacts. The web site can be found at: enhancedbc.tfrec.wsu.edu

- The WSU DAS website also has new information posted on a regular basis that is generated through this grant (*below right*). The web site can be found at: das.wsu.edu.

Popular Articles on Project:

Steury T. 2010. Cultivated landscapes: The kinder, gentler orchard. Washington State Magazine 9(4): 38-43. (PDF 1.24MB)

New Leveraging Funds Grants: (submitted or funded)

- Jones VP, U Chambers. 2011. Enhancing BC in apples: how do conventional and organic systems differ? Washington Tree Fruit Research Commission (submitted: 3 years, $303,858).

- Jones VP, U Chambers, JF Brunner. 2011. Web-based IPM and biological control educational programs. Washington Tree Fruit Research Commission (submitted: 3 years, $114,990)

- Shearer PW, K Amarasekare, VP Jones, SA Steffan. Improving biological control of insect pests of cherry. Washington Tree Fruit Research Commission (funded 2 years, $79,485).

- Jones VP, SA Steffan. Enhancing biological control in cherries. Washington State Commission on Pesticide Registration (funded 1 year, $23,189).

- Unruh TR, DR Horton, EH Beers. Efficacy and best practices for predator releases: lacewing, beetles, and mites. Washington Tree Fruit Research Commission (funded 3 years, $237,997).

Acknowledgments

Matching Funds Sources:

- Washington Tree Fruit Research Commission
- Washington State Commission on Pesticide Registration
- California Walnut Board
- Washington State University
- Oregon State University
- University of California, Berkeley
- USDA-ARS Yakima Ag. Research Lab

Grower Cooperators:

- California walnut growers in Suisun Valley and Davis
- Oregon Pear Growers in Hood River
- Washington apple growers in Quincy, Bridgeport, Frenchman Hills, Yakima, and Wapato

Participating Research Personnel

Although the project directors are ultimately responsible for the work done in this project, there is also a key group of post-doctoral research scientists and technical support personnel that have been essential to our project through their dedication and hard work. We gratefully acknowledge their efforts to make the project a success:

Beers Lab

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Lessando Gontijo (Graduate Student)

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Technical Support - Objectives 2-3
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