Enhancing Biological Control in Western Orchards

enhancedbiocontrol.org

A USDA-NIFA Specialty Crop Research Initiative Project

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

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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 (CM).*
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.*

Tying up the loose ends

Our project has just finished the fourth year of five. We have finished all the field work and nearly all the laboratory work and are in the process of analyzing, synthesizing, writing, and making outreach presentations.

One of our major accomplishments this past year was the two-day biological control (BC) short course that was held in three locations by videoconference on 7-8 February. We had 75 attendees, and 11 speakers from California, Washington, and Oregon covering 15 topics on basic and applied aspects of BC in orchards. The course consisted of presentations, case studies, and discussions with the instructors. It was followed up with a natural enemy identification and sampling course presented at field days at Hood River and the WSU-Sunrise orchard in Wenatchee in August. Information from the courses is on the web site, including narrated presentations from the short course. Attendees were enthusiastic about the course (*page 10*).

Our web site (enhancedbiocontrol.org) is also undergoing continuous upgrades as the field and laboratory research is being completed. We are also adding video stories describing the methods and results of our research. The web site was re-done this year to allow content to be viewed on desktops, laptops, and tablet/smartphones (*page 12*).

A major goal for our project this coming year will be the publication of 14 scientific articles in the journal *Biological Control* as a special issue. These publications will cover all aspects of the project from beginning to end, and will include laboratory and field results as well as our successes and failures in outreach. Working with a high quality journal like *Biological Control* ensures that the information will reach a broad audience and that it is available both on-line and in larger libraries for the foreseeable future (*page 13*).

Finally, we are still aggressively pursuing funding that will allow us to proceed with logical extensions to our project. We have leveraged the funding provided by USDA-NIFA with another $1.2 M (approved or under review) from various sources since the start of the project (*page 15*).

Pesticides Influence Biocontrol Success

I. Pesticide Effects

Mills, Beers, Shearer, Unruh

Milestones: *Completed lab bioassays for all pesticides and natural enemies and completed all field studies.*

Progress summary: *All bioassays have been completed except three sub-lethal assays for the ladybird beetle, Hippodamia convergens. Those assays were delayed until the reason for high immature mortality was tracked down and eliminated. We expect those to be completed in the next three months. All field trials were completed last year, and synthesis and presentation of the data are currently in progress.*

Studies performed this year: We had significant problems with the survival of immature *H. convergens* that were unrelated to pesticide treatment. That problem has been solved and four of the seven sublethal assays have been completed. The current summary of lab studies is found on page 3 (*top*). Significant progress has been made in the analysis of the sublethal effects and all of the work that has been completed has been analyzed. We are also working with the web group (Objective 6) on how to present pesticide effects in a way that is intuitive and allows the interested person to "drill down" to specific causes of reduced population growth. These data will also be combined with a large pesticide effects database compiled (Objective 6) from literature sources and we will strive to provide the most up-to-date information on our web site.

Implications for the Industries

The lab bioassays appear to show differences between predators and parasitoids (*next page*). The combination of the phenology of natural enemies (Objective 2) and the natural enemy susceptibility will provide us with powerful tools to decrease adverse effects on biological control in western orchards. It is clear in some situations we will have to choose which natural enemy to preserve. Further synthesis this coming year will attempt to make a decision tree that can be used to guide management tactics.

Effects of pesticides on natural enemies tested to date. n/a indicates high acute mortality prevents measurement of sublethal effects; white cells are not yet analyzed, cross-hashed cells indicate 10% field rate used because of high acute mortality, color of cell shows reduction from control that is the same as the figure legend. Split cells show adult/immature acute effects.

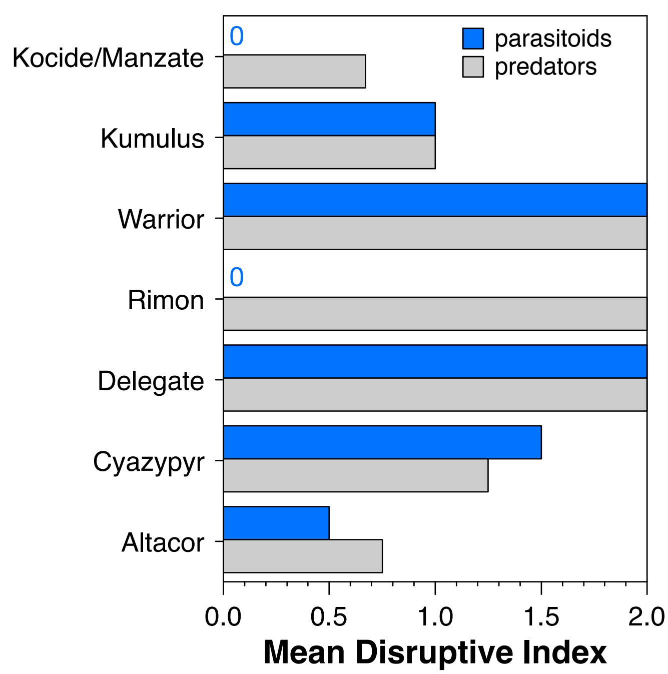
Natural Enemy	Toxicity Measure	Altacor	Cyazypyr	Delegate	Rimon	Warrior	Kumulus	Kocide/ Manzate
Aphelinus mali (Woolly apple aphid parasitoid)	Acute mortality							
	Loss of fertility							
	Pop. Growth Rate							
Trioxys pallidus (Walnut aphid parasitoid)	Acute mortality							
	Loss of fertility		n/a	n/a				
	Pop. Growth Rate							
Deraeocoris brevis (pear psylla and aphid predator)	Acute mortality							
	Loss of fertility					n/a		
	Pop. Growth Rate							
Chrysoperla carnae (lacewing, general predator)	Acute mortality							
	Loss of fertility		n/a					
	Pop. Growth Rate							
Hippodamia convergens (ladybird beetle, aphid predator)	Acute mortality							
	Loss of fertility					n/a		
	Pop. Growth Rate							
Galendromus occidentalis (spider mite predator)	Acute mortality							
	Loss of fertility							
	Pop. Growth Rate							
Misumenops lepidus / Pelegrina aeneola (spiders)	Acute mortality							

% Reduction from Control
- <25%
- 25-75%
- >75%
- adult / immature

Working towards a pesticide disruption index

Do predators and parasitoids respond differently to pesticides?

The chart above shows the current status of the lab bioassays. The population growth rates are probably the best indicator of pesticide effects until we finish some of the modeling efforts discussed in last year's progress report. By assigning a value of 0 for green cells, 1 for yellow, and 2 for red, a very simple index allows us to broadly categorize the effect of each pesticide on each natural enemy. The most interesting comparison in the chart is to evaluate whether predators respond differently than parasitoids to different pesticides.



Delegate and Warrior both show the greatest potential for disruption of biological control (*right*). Cyazypyr and Kumulus both had moderate effects on predators and parasitoids, while Altacor had the lowest effect on both groups. Rimon had a large impact on predators while Kocide/Manzate had moderate effects on predators, but both insecticides had very low effects (< 25% reductions) on the two parasitoids.

The differences between the predators and parasitoids are probably caused by the differences in their life history. Predators are free-living and are exposed to the pesticide residues for their entire life, whereas the two parasitoids we tested are endoparasitoids and thus the immature stage is nearly completely protected within the aphid host.

Knowing Phenology Improves Management Options

2. NE Phenology Models

Jones, Mills, Shearer, Horton, Unruh

Milestones: *Completed analysis and development of models for four different natural enemies that occur in apple, walnut, pear, and sweet cherry.*

Progress summary: *This section exceeded the milestones and goals of the grant. We are still collecting research data using our leveraged funds that will provide additional models and validation information.*

Analysis performed this year: The data in hand from apple, pear, walnut, and sweet cherry allowed us to develop models for two species of lacewings (*Chrysopa nigricornis*, *Chrysoperla carnea*), a syrphid fly (*Eupeodes fumipennis*), and the mirid bug, *Deraeocoris brevis.* All of these natural enemies are important generalist predators contributing to suppression of multiple species of aphids, pear psylla, spider mites, small lepidopterous larvae, mealybugs, and other soft-bodied insects and mites.

Our data set included not only information on temperature and abundance of the different natural enemies, but also when pesticides were applied throughout the season. Our analysis showed that some of the pesticides strongly disrupted natural enemies and that normal early spray programs (especially lime sulfur + oil) in apple, pear, and sweet cherry are applied multiple times as three of the four natural enemies we studied emerged in the spring. These applications thus expose the adults throughout their emergence period, and the eggs and immature stages of the first generation. The standard supposition has been that these sprays occur when natural enemies are not present, but our research showed otherwise.

Implications for the Industries:

We will be working with pathologists and horticulturalists to see which sprays can be changed to non-toxic alternatives or moved to either late fall or earlier in the season before natural enemies emerge. These changes should boost natural enemy population levels and reduce secondary pest problems that have been an issue as our management programs have moved to newer insecticides.


Syrphid fly larva eating an aphid


Deraeocoris brevis **eating pear psylla**


Lacewing larva eating woolly apple aphid

Making a natural enemy model

Start with the data collection

We are using traps developed in Objective 3 to monitor the natural enemies in a consistent manner throughout the entire season. Traps are checked 1-2 times a week and the number of each natural enemy species recorded. These raw data are then combined with temperature records taken either in that specific orchard or within only a short distance. We also collect the spray records for each orchard so that any deviation in the phenology can be traced back to pesticides applied or application timing. With data from multiple locations in each state over a period of three or more years, we are able to generate a model in a short amount of time.

Development of a model

Development of a model requires data on how fast a natural enemy completes development. Insect developmental rates are directly related to the environmental temperatures they experience and can be modeled using heat units called degree-days (DD). Most of the time this information can be obtained from the literature or from work specifically done in the laboratory of one of our investigators. If the developmental data are comprehensive enough, we can determine the lower threshold for development and start to evaluate phenology in the field data. If the literature or laboratory data are very cursory, we will have to estimate the developmental thresholds using our field data.

To generate the model, we start by separating the data into two groups, one used for model generation and one used for model validation. We normally developed the models using data from the studies in apple, and then used the rest of the data to evaluate model accuracy. In situations where the data set was not large enough across multiple sites/ crops, we either break it up by year or acquire supplemental data collected from some of our leveraged funding.

The models we developed are all based on fitting a Weibull distribution to the field data. This was done using a programmable statistical package that allows us to assess fit, and then graph the results with overlays of the predicted emergence period. Further graphics allow us to overlay spray program information to assess spray impacts on phenology.

Validation

All the models need to be tested with data independent of the information used to generate the models initially. Comparing the model fit with independent data allows us to evaluate the strengths and weaknesses of the models and the scope of their applicability.

Multitasking data: Eco-informatics

In developing the models, one of the things that jumped out at us is how sprays at certain times affected model performance. Each year we evaluated phenology in a minimum of three orchards per crop, and often considerably more. For each of these locations, spray records allow us to evaluate how natural enemies are affected by different spray timings and pesticide used. These data will be supplemental to the field tests done in Objective 1, and will encompass a much broader range of pesticides and timings than the controlled experiments in that objective. This will require a larger analytical effort, and will likely give less precise conclusions, but the results will be based on work in commercial orchards and better reflect spray programs normally used. This is an area we will be pursuing in the coming year.

Natural enemy phenology by crop

What are the obvious differences by crop?

Our data were collected across a wide geographical area so that climate, regional, host availability, and spray program differences are reflected.

Climatic effects: Across four insect models, it is apparent that not every generation possible occurs at all locations. For example, we found that *C. carnea* only went through two generations per year in California, despite having enough heat to complete four generations. Washington had the greatest number of generations of *C. carnea*, with three generations completed. The syrphid fly, *E. fumipennis* was even more variable, with some locations recording only a single generation and others up to four (*page 6 top*); differences between sites may also be related to the spray programs or host availability.

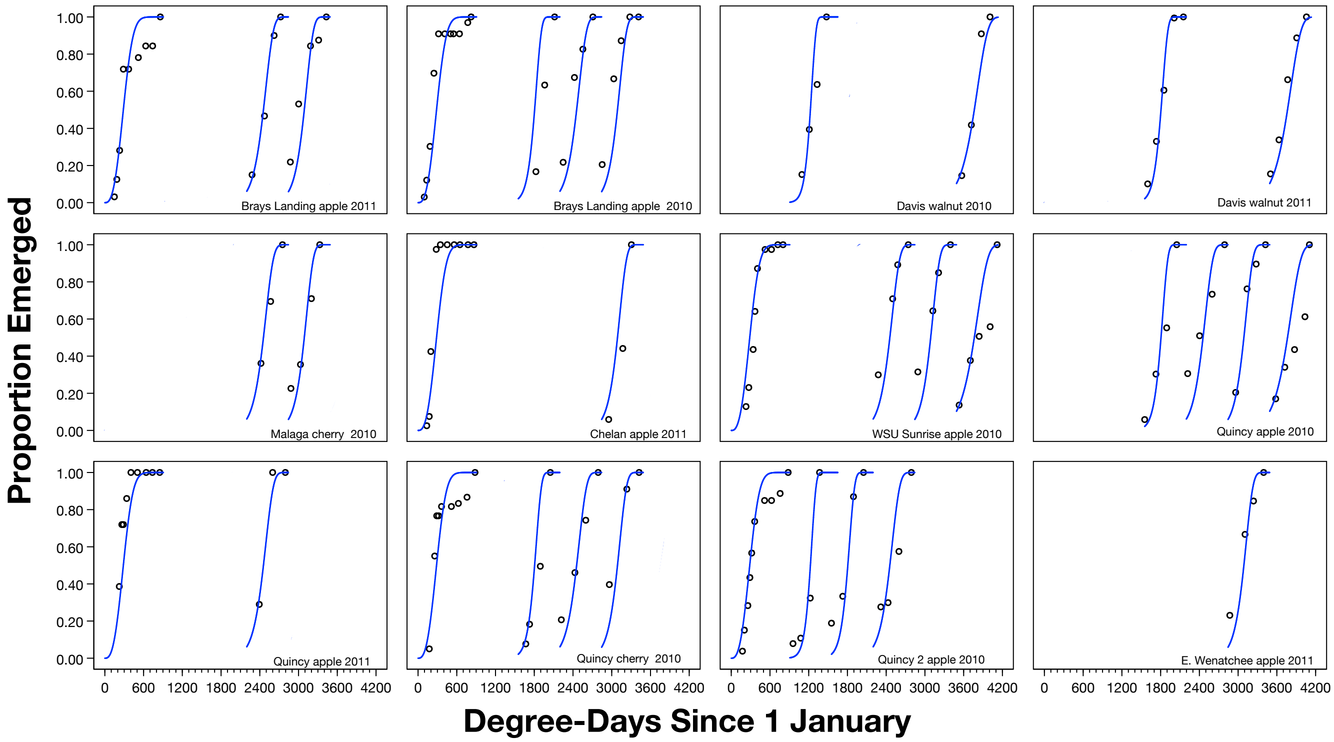
The Hood River locations recorded the fewest number of generations of all species, because seasonal temperature profiles there were considerably cooler than our sites in California or Washington.

Spray programs: Spray programs vary dramatically between crops, with few sprays being applied in walnuts, and a large number in pears. Apple and sweet cherry programs were highly variable, with greater differences between orchards than between crops. All three fruit crops have very intense programs early in the season and tend to be very moderate later in the season. Different spray programs can result in the apparent loss of a particular generation for some natural enemies.

Regional differences: Natural enemy species abundance varied dramatically between the three regions. Some of the differences were likely caused by simple temperature effects, but also by surrounding vegetation and crop systems. Washington orchards had dramatically higher lacewing populations than the California or Oregon orchards surveyed. The apple, sweet cherry, and walnut orchards all had relatively abundant and diverse syrphid fly faunas, while the fauna in pear was considerably less abundant because aphids tend to be rare in pears.

Conclusions: Variations in phenology between crops were no greater than variability seen between locations within a crop. Although climatic differences in California may be causing diapause or reduced population levels during the heat of the summer with *C. carnea*, we do not have evidence of crop effects on phenology (versus climatic, pesticide effects, or host abundances).

Phenology of *Eupeodes fumipennis* in apple, walnut, or sweet cherry from 2010-2011. Blue lines are model predictions, black open circles are the observed data. Note not all generations are present in all locations because of either climatic or pesticide effects.



Improved Monitoring Tools Make Biocontrol Visible

3. NE Monitoring Tools

Jones, Mills, Shearer, Horton, Unruh

Milestones: *We have completed studies on lure longevity, optimal release rates, trap types, and mixtures versus separate lures, with >65 attractant blends.*

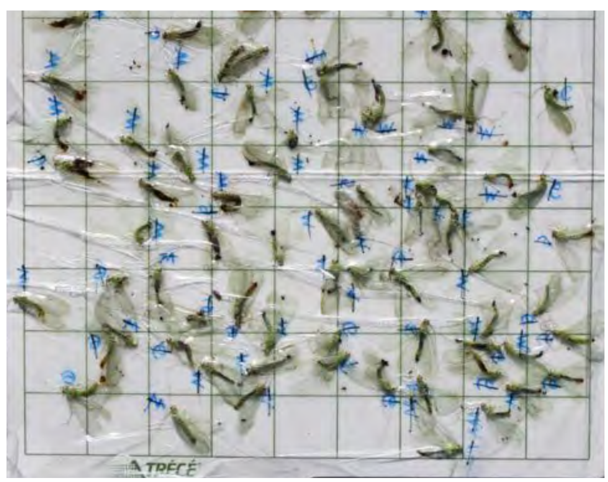
Progress summary: *This section exceeded the milestones and goals of the grant. Summary and synthesis of this information will continue for the next 1-2 years.*

Analyses performed this year: All field studies have been completed and we are in the process of a complete analysis of the different regional studies. One of the issues we face is that often we get no trap catch in our unbaited control traps, which confounds the statistical analysis. This also occurs with acetic acid traps for some of our natural enemy groups, although when acetic acid is added to another attractant, we get synergistic effects. Thus, a great deal of time is being spent trying to choose the best statistical analysis, even though the results are generally straightforward. As discussed in the progress report last year, we can tailor our attractive blends to target certain natural enemies that are important in each of the systems.

We also worked with the Objective 6 group to put out six grower/consultant trials in Washington and Oregon of the squalene lure, which attracts the lacewing *Chrysopa nigricornis*. These trials were to familiarize participants with the lures and compare different management tactics on the lacewing.

Implications for the Industries

Our work is providing effective and simple sampling tools for natural enemies. We need to have more industry involvement with the development of commercially available lures. We hope to make more progress on that goal this year, but it is possible that this will require more time than is left in the grant.



Three predator groups are dominant

4. Predation On Codling Moth

Unruh

Milestones: *A rapid and robust method to evaluate gut content of arthropod predators was developed. Over 2400 samples were evaluated to estimate predation rates of likely codling moth predators.*

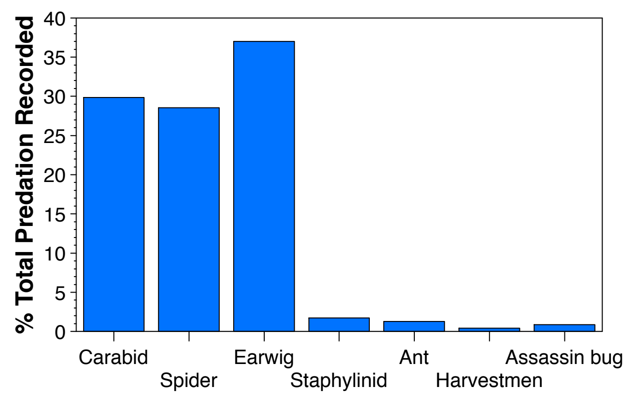
Progress Summary: *Samples analyzed this past year have clarified the ecological role of three different predator groups. The work on DNA preservatives used in pitfall traps has resulted in better specimens being collected and new PCR primers developed in 2010 allow the amplification of codling moth DNA without requiring purification. These results are a major advance in our ability to evaluate food chain relationships between different predators and prey species.*

Studies performed this year: Our samples collected from seven apple orchards over a three year period showed predation rate on codling moth was 9.2%. We also found that a remarkable 95.5% of the total predation could be accounted for by just three predator groups: ground beetles (Carabidae), the European earwig (*Forficula auricularia)* and the spider complex (Araneae) (*right*). Predation rates across orchards generally correspond to management intensity; in orchards with lower management intensity, abundance of ground dwelling predators, particularly carabids, is high.

Implications for the Industries

Predation of codling moth on the ground appears to be dominated by predacious ground beetles, while spiders and earwigs are both on the ground and in the canopy. With the newer high density apple orchards, more codling moth are likely to overwinter in the ground cover (versus on the tree) because there are fewer overwintering sites on the smooth bark in the younger orchards, thus our knowledge of ground fauna and their impact on codling moth will help shape future management programs.

Percentage of the total number of predator gut content samples that tested positive for codling moth from seven orchards over a three year period.



Why "apparent" predation rates?

How DNA gut content analysis works

The whole idea behind DNA gut content analysis is that we can collect various predators and evaluate if they have fed on codling moth by using PCR to look for specific sequences of DNA found only in codling moth. While this is straightforward, the problem is that the DNA is only detectable for a relatively narrow window in time after the predation event. The length of time is a function of the length of the DNA sequence the primers are designed to detect. The longer the DNA sequence, the quicker it might be destroyed by the digestive enzyme in the predator. In addition, because insects' metabolic rates are related to the temperature that they experience, the rate of degradation is quicker in the warmer times of the year, which reduces the time over which the target DNA sequence can be detected. There are also differences in the digestive rates between different groups of natural enemies (e.g., spiders versus ground beetles), which also confuses the interpretation of the data. Thus, while we might only detect 10% predation from a particular group, that number only provides a snapshot of what happened within a fairly narrow window (<3 days) in time. To provide an estimate of the predator assemblage impact on codling moth, we need to take long time series of samples and integrate the effect over each generation of codling moth. This analysis is ongoing.

What is the Cost of Enhanced Biocontrol?

5. Economic Analysis

Gallardo, Brunner, Castagnoli, Grant

Milestones: *Synthesize information on growers' willingness to pay for indirect benefits of IPM, develop an expected profit model using enhanced BC and synthesis for use in Objective 6.*

Progress summary: *This objective is on track to meet the goals and milestones of the grant.*

Studies this past year: Pesticide cost analysis showed that IPM costs Oregon pear growers an average of $811/acre, compared to $288/acre for Washington apple growers. Most of this difference in cost is for control of pear psylla (*see below*). Unlike the apple analysis, we found no relationship between codling moth control programs and disruption of pear psylla biological control. Instead, pear psylla programs appear to be the biggest disruptor of biological control of psylla and spider mites.

Analysis of walnut data likewise showed no relationship between use of highly disruptive insecticides and costs of control for secondary pests.

One analysis does not fit all….

Analysis of the apple data last year suggested that there was a straightforward relationship between the the use of pesticides disruptive to biological control and the cost of management for secondary pests such as aphids and mites. However, when running the same analyses on pear and walnut, there were no differences detected between orchards that used highly disruptive or non-disruptive insecticide treatments. What makes the pear and walnut systems different and can we capture the value of biological control in those systems?

Pear

The pear system is distinctly different from apple and walnut because pear psylla is the driving force behind much of the management program and psylla sprays are often applied prophylactically. Psylla is considered to be an induced pest that would normally be controlled by predators, if the predators were not suppressed by insecticides applied for psylla or codling moth.

Pear psylla and honeydew droplet

A second major difference is that biological control of mites is much more tenuous in pear because even low level mite feeding can result in leaf necrosis. This sensitivity to mite feeding leads many growers to apply miticides in a tank mix with insecticides targeted at pear psylla. The third major difference from apples is that aphids are relatively rare in pears, probably because the insecticides used in control of pear psylla tend to be very effective against aphids as well.

Walnuts

Walnut Husk Fly

The walnut system is also considerably different than the apple system. In walnuts, many of the insecticide treatments occur later in the season and are targeted against later generations of codling moth and against the walnut husk fly. Walnut aphid is both an early and a late season pest, with reduced growth during the summer. Thus sprays in the early season might be disruptive, but those in the summer are much less likely to cause aphid outbreaks. Early season control of codling moth is also not as much of an issue in walnuts, so again, early season treatments are not as common, which gives the parasitoid *Trioxys pallidus* and generalist predators a better chance to suppress walnut aphid numbers. Spider mites can be an issue in walnuts, but again tend to be a later season pest, so disruption early in the season would play a large part in outbreak scenarios. Finally, the large size of walnut trees makes it much harder to get uniform coverage of pesticides, particularly in the upper canopy. This results in the upper canopy acting as a partial refuge for natural enemies and likely gives a more stable predator/prey interaction than would be found in systems where spray coverage is more uniform.

Getting the Results To the Users

6. Outreach

Brunner, Goldberger, All participants

Milestones: *Use survey results to guide development of educational and outreach programs, synthesize data from completed objectives and implement into management programs, present results to industry.*

Progress summary: *This section has met and exceeded the goals of the grant in many aspects.*

Progress this year: Our group has begun the various outreach programs as information has become available. We have offered short courses, workshops, and given presentations at numerous grower meetings and field days. Our team has updated and developed new handouts on our progress, identification of key natural enemy groups and synthesized literature information of pesticide impacts on natural enemies (*page 12*). Team members have collaborated with industry publications (*Good Fruit Grower, Capital Press,* and *Western Farm Grower*) to provide information on various parts of the project. We have also conducted real-time surveys at grower meetings to evaluate where growers and consultants obtain information for pest management and their attitudes towards biological control and perceived barriers to its' implementation (*below*).

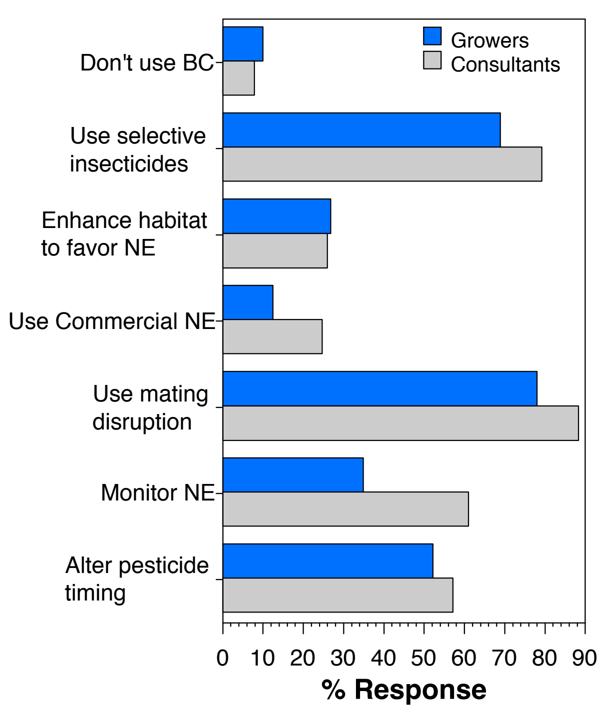
Tracing information flow and practices

Using an audience response system ("clickers"), we conducted surveys of grower/managers and crop consultants working with apples at four winter meetings in north-central Washington. The surveys captured how industry stakeholders obtained information about pest management and biological control, and their use of conservation biological control. We surveyed 207 grower/managers and 77 crop consultants. Summaries of these will be on our web site shortly.

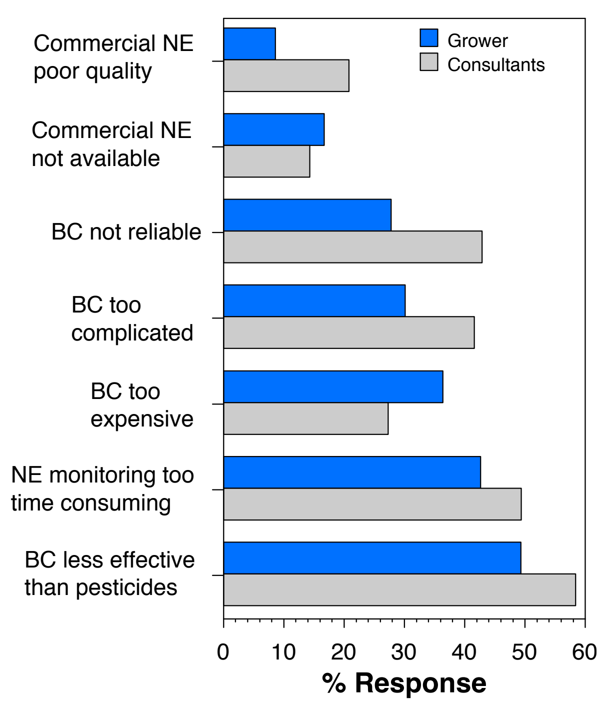
Information Sources:

The top three ways Grower/Managers wanted information were in person meetings/courses (57%), field days (48%), and printed materials (42%). Consultants wanted information by in person meetings/courses (60%), website resources (51%) or email (47%). To optimize information flow, we must address both groups' preferences.

Use of BC:



Perceived Barriers to Adoption:



Organize, synthesize, provide: a two-day short course

Biocontrol: information intensive

Successful integration of biological and chemical control requires a better understanding of the crop systems and how different tactics affect natural enemies.

A two day short course

In February 2012, our project members, advisory group, and colleagues presented a comprehensive course highlighting the information needed to use and implement biological control in orchard systems. The course was offered simultaneously to 75 participants in Washington at Wenatchee and Pasco, and in Oregon at Hood River via videoconferencing. The majority of the presentations from the course as well as participant feedback are available on our website at enhancedbiocontrol.org

Course Content:

Day 1

General Overview and Introduction to Biological Control: Nick Mills, Vince Jones

Principles of Pest/Natural Enemy Interactions: Vince Jones, Nick Mills, Andrea Bixby-Brosi

Key Natural Enemy Groups: Life histories and pests controlled: Nick Mills, Dave Horton

Exercise: ***Natural Enemy Identification: Predaceous insects, parasitoids and spiders:*** Gene Miliczky

Natural Enemy Monitoring: Vince Jones, Nick Mills, Dave Horton, Tom Unruh, Peter Shearer

Natural Enemy Phenology, modeling, and IPM: Vince Jones

Biocontrol Resources on the Web: Ute Chambers, Angela Gadino, Steve Castagnoli

Exercise: ***Windows of Opportunity***: Ute Chambers

Effects of Pesticides on Natural Enemies: Nick Mills, Betsy Beers, Tom Unruh, Peter Shearer

Case Study: ***Secondary Pest Problems – Why did they get out of control?*** : Jay Brunner

Day 2

Effects of Pesticides in the Field: Peter Shearer, Betsy Beers

Use of Bait Sprays in IPM Programs: Marshall Johnson

Microbial Control in Orchard Systems: Ute Chambers, Andrea Bixby-Brosi, Jay Brunner

Synthesis of Pesticide Effects: Jay Brunner, Nick Mills

Using Commercially Available Natural Enemies for Biological Control: Lynn LeBeck

Conservation Biological Control through Habitat Modifications: Tom Unruh

Case Study: ***Designing BC Friendly IPM Programs for Apple or Pear:*** Jay Brunner

Case Study: ***Restoring BC after a Major Disruptive Event and Dealing with New Invasive Pests***: Jay Brunner

Followup to achieve results…

A single short course isn't enough to effect change in the industries. In addition to the two-day short course, we supplemented our course with lab and field presentations featured at the OSU Hood River Experiment Station field day on 3 Aug and the WSU Sunrise Field Day on 23 Aug. Participants received high quality color handouts of the major natural enemy groups and identification tips using microscopes (handouts are on our web site). Once they finished the lab work, we moved to the field, demonstrated various collection techniques and then had the students collect and identify the different natural enemy groups. More of these short identification workshops will be held this coming season to broaden our audience and help develop a core group of people with understanding of the various natural enemies and the pests they control.

Web-based information transfer

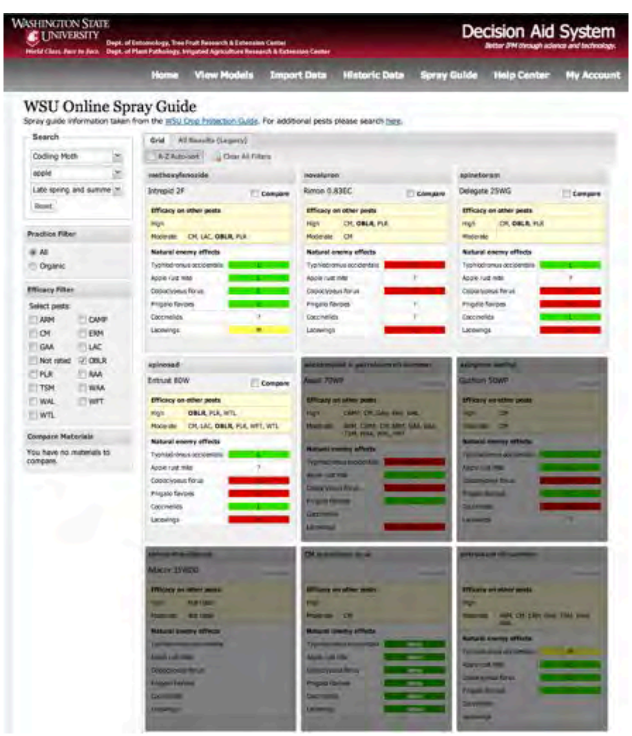
Leaving a legacy for the future .....

Project web resources

As our project enters the final year, we are concentrating resources to leave a legacy of web resources describing the findings of our project. Normally, researchers have an incredibly annoying habit of moving on to new projects as they finish old ones, but in our case, we know that we need to preserve, organize, and provide the information generated in the project. We have already provided narrated slide shows from our short course and are working to get other presentations given by project members up on the web. Three YouTube videos of methods used in the project are already on-line and at least four more are in production. We are also making a complete archive of stories written by various media sources about the project, publications associated with the project, and both photo and video galleries of natural enemies in action. The new web site is also useable with tablet and smartphones as well as the normal desktop/laptop computers.
enhancedbiocontrol.org

Pesticide Effects on Natural Enemies Database

We have performed a survey of pesticide effects on natural enemies in orchard systems. This has been compiled into a database, and will be available on-line sometime in the spring. This database synthesizes research on a broad range of pesticides (not just those evaluated in this project) done in Europe, California, Oregon, Michigan, New York, Ohio, Pennsylvania, and Washington giving users a broader perspective about natural enemy effects across a wide range of conditions and locations.



WSU-Decision Aid System (WSU-DAS)

WSU-DAS allows us to share in real time information on IPM tactics, models of pests and natural enemies, pesticide choices that minimize natural enemy mortality, and provide timely stories important for IPM decision makers. DAS will feature prominently in the outreach within Washington state as we finish and validate the models for the lacewings *Chrysopa nigricornis* and *Chrysoperla carnea*, the syrphid fly, *Eupeodes fumipennis*, and the predaceous bug, *Deraeocoris brevis* (Objective 2). These models and the spray recommendations (*left*) will be crucial in enhancing biological control in our apple, pear, and sweet cherry orchards. We will also provide the information to our colleagues in California and Oregon, as well as provide the information on our project web site. The new version of DAS is fully HTML 5 compliant and will allow iOS and android smart phones to access to all features of the web site. das.wsu.edu

A summary for the future

Publication is critical

While web and popular articles are important, our project members are committed to publishing of our findings in high quality peer-reviewed journals. Towards this end, we have contacted the journal *Biological Control* and arranged for the publication of a special issue with 14 different articles (*below*) all by our team members. These articles will go through the normal peer review process and be published together in a single issue devoted to our project. This method of publication brings our work together in a single location available in the best libraries in the world as well as available on the internet. We are proud to work with *Biological Control* in this project and especially thank their editors, and particularly Dr. Ed Lewis (UC Davis), who has agreed to serve as the coordinating editor.

Articles:

From Planning to Execution to the Future: An Overview of a Concerted Effort to Enhance Biological Control in Western Apple, Pear, and Walnut Orchards

Jones VP, NJ Mills, JF Brunner, DR Horton, EH Beers, TR Unruh, PW Shearer, J Goldberger, K Gallardo, S Castagnoli, N Lehrer, SA Steffan, KG Amarasekare, U Chambers, AN Gadino

Testing the Selectivity of Pesticide Effects on Natural Enemies in Laboratory Bioassays

Amarasekare KG, PW Shearer, NJ Mills

Comparative Analysis of Pesticide Effects on Natural Enemies in Western Orchards: a Synthesis of Laboratory Bioassay Data

Mills NJ, EH Beers, PW Shearer, TR Unruh, KG Amarasekare

Large-Plot Field Studies to Assess Impacts of Newer Insecticides on Non-Target Arthropods in Oregon Pear Orchards

Shearer PW, KG Amarasekare, EH Beers, NJ Mills, VP Jones

Nontarget Effects of Orchard Pesticides on Natural Enemies: Lessons From the Field and Laboratory

Beers EH, NJ Mills, PW Shearer, DR Horton, E Milickzy, KG Amarasekare

Evaluating Release Rates and Longevity of Natural Enemy Attractant Lures

Jones VP, CC Baker, AJ Bixby-Brosi

Optimizing Herbivore-Induced Plant Volatiles and Floral Volatiles for Monitoring of Key Natural Enemies in Apple, Sweet Cherry, Pear and Walnut

Jones VP, CC Baker, TD Melton, SA Steffan, NJ Mills, PW Shearer, KG Amarasekare, TR Unruh, DR Horton, E Milickzy

Using Herbivore-Induced Plant Volatiles and Floral Volatiles to Attract Natural Enemies for Studies of Ecosystem Structure and Function

Jones VP, CC Baker, SA Steffan, TD Melton, NJ Mills, TR Unruh, DR Horton, PW Shearer, KG Amarasekare, A Bixby-Brosi, E Milickzy

Using Natural Enemy Lures to Develop Phenology Models for IPM Purposes: Examples from Lacewings and Syrphids.

Jones VP, NJ Mills, PW Shearer, TR Unruh, DR Horton, E Milickzy, TD Melton, CC Baker

The Spider Fauna Using Codling Moth, Cydia pomonella, in Apple Orchards as Determined by Molecular Gut Content Analysis.

Unruh TR, E Milickzy, DR Horton

Capturing the Economic Value of Biological Control

Gallardo K, JF Brunner, S Castagnoli, NJ Mills, J Grant

Biological Control Adoption in Western Orchard Systems: Results from Grower Surveys

Golberger J, N Lehrer, JF Brunner, NJ Mills

Web-based Outreach for Orchard Management Decision-Makers

Jones WE, U Chambers, AN Gadino, JF Brunner, VP Jones

A Perspective on the Extension of Research-Based Information to Orchard Management Decision-Makers: Successes and Failures and Potential Future Directions.

Gadino AN, JF Brunner, U Chambers, S Castagnoli, WE Jones

Project Output 2012

Presentations:

Beers EH, L Gontijo, B Greenfield, P Smytheman. Nontarget effects of pesticides on natural enemies: Woolly apple aphid as a case study. Western Orchard Pest and Disease Management Conference, Portland, OR. 11-13 Jan.

Beers EH. Biocontrol and IPM: the key component or the missing link? Pacific Branch Entomological Society of America, Portland, OR. 26-28 March (invited symposium speaker).

Beers EH. Update on invasive pests and their management. Washington State Horticultural Association Annual Meeting, Yakima, WA. 3-5 Dec. (invited speaker).

Brunner JF. Key pests and their management. Washington State Horticultural Association Annual Meeting, Yakima, WA. 3-5 Dec. (invited speaker).

Chambers U, VP Jones, GG Grove. Evaluation of environmental data used for IPM models. Washington Tree Fruit Research Commission Technology meeting. Ellensburg, WA. 10 May.

Chambers U, VP Jones, GG Grove. Evaluation of environmental data used for IPM models. Pacific Branch Entomological Society of America, Portland, OR. 26-28 Mar.

Gadino AN, VP Jones, JF Brunner, EH Beers, K Gallardo, J Goldberger, NJ Mills, PW Shearer, S Castagnoli, DR Horton, TR Unruh. Enhancing biological control to stabilize western orchard IPM programs. Western Orchard Pest and Disease Management Conference, Portland, OR. 11-13 Jan.

Gadino AN. Using clicker technology as an innovative tool for capturing information in research and extension. Pacific Branch Entomological Society of America, Portland, OR. 26-28 Mar. (invited symposium speaker).

Gadino AN, JF Brunner. Stinkbugs: A formidable enemy and a clicker survey of BC practices in orchards. Chelan Fruit meeting. Okanagan, WA. 1 Mar.

Gadino AN, VP Jones, JF Brunner, EH Beers, K Gallardo, J Goldberger, N Mills, PW Shearer, S. Castagnoli, DR Horton, TR Unruh. Enhancing BC to stabilize western orchard IPM and a clicker survey of BC practices in orchards. Lake Chelan fruit education meeting. Lake Chelan, WA. 16 Jan.

Gadino AN, VP Jones, JF Brunner, EH Beers, K Gallardo, J Goldberger, N Mills, PW Shearer, S. Castagnoli, DR Horton, TR Unruh. Enhancing BC to stabilize western orchard IPM and a clicker survey of BC practices in orchards. WSU Winter Apple meetings. Wenatchee, WA. 18 Jan.

Gadino AN, VP Jones, JF Brunner, EH Beers, K Gallardo, J Goldberger, N Mills, PW Shearer, S. Castagnoli, DR Horton, TR Unruh. Enhancing BC to stabilize western orchard IPM. North Central Washington Fieldman's Association. 1 April. Wenatchee, WA.

Gallardo K. Cost of production of apple, cherry, and pear. Washington State Horticultural Association Annual Meeting, Yakima, WA. 3-5 Dec. (invited speaker).

Jones VP, NJ Mills, AJ Bixby-Brosi, DR Horton, TR Unruh, PW Shearer. Using HIPVs to sample natural enemies in Western apple, pear, and walnut orchards. Western Orchard Pest and Disease Management Conference, Portland, OR. 11-13 Jan.

Jones VP, AN Gadino, JF Brunner. Models to assess pesticide impacts on CM, OBLR and the lacewing *C. nigricornis*. Washington Tree Fruit Research Commission Pest Management Meeting, Pasco, WA. 25-26 Jan.

Jones VP, U Chambers, AJ Bixby-Brosi. Enhancing BC in apples: how do conventional and organic systems differ? Washington Tree Fruit Research Commission Pest Management Meeting, Pasco, WA. 25-26 Jan.

Jones VP. Peering into the future: The directions for apple IPM and the role of Biocontrol. Washington Tree Fruit Research Commission Pest Management Meeting, Pasco, WA. 25-26 Jan. (invited speaker)

Jones VP, U Chambers, B Petit. Decision support systems to aid in the adoption of IPM programs in tree fruits. Symposium presentation, Pacific Branch Entomological Society of America, Portland, OR. 26-28 Mar. (invited symposium speaker).

Jones VP. How a perfect storm of technology, legislation, and applied ecology can potentially lead to IPM in Western Orchards. Purdue University, Dept. Entomology seminar, West Lafayette, IN. 11-13 Apr. (invited speaker).

Jones VP. How a perfect storm of technology, legislation, and applied ecology can potentially lead to IPM in Western Orchards. UC Davis, Dept. Entomology seminar, Davis, CA. 24-25 Apr. (invited speaker)

Jones VP, NJ Mills, DR Horton, TR Unruh, PW Shearer. Monitoring and modeling natural enemies to enhance biological control in Western USA tree crops. 2nd International Organic Fruit Research Symposium. International Association of Horticultural Science, Leavenworth, WA. 18-20 Jun. (invited speaker).

Jones VP. Information transfer using low and high technology. Afghan Executive Management training course. Wenatchee, WA. 13 Sept. (45 min presentation).

Jones VP. Using the WSU-Decision Aid System to manage tree fruit pests in nursery situations. Northwest Nursery Improvement Institute. Wenatchee, WA. 11 Oct. (invited speaker).

Jones VP, U Chambers, GG Grove. Evaluation of environmental data used for IPM models. Washington Tree Fruit Research Commission Technology meeting. Ellensburg, WA. 25 Oct.

Jones VP, U Chambers. Long-range forecasts, virtual weather stations, and new models for WSU-DAS. Washington Tree Fruit Research Commission Technology meeting. Ellensburg, WA. 25 Oct.

Jones VP. Update on WSU-Decision Aid System and Biocontrol research. Washington State Horticultural Association Annual Meeting, Yakima, WA. 3-5 Dec. (invited speaker).

Lehrer N, J Goldberger. Following the money: impacts and implications of new federal funding for fruit and vegetable research. Agriculture, Food, and Human Values Society Ann. Meeting, NY, NY. 20-24 Jun.

Mills NJ. Selective pesticides and biological control in walnut pest management. Annual Research Conference, Bodega Bay, CA, Jan. 27.

Mills NJ. The role of biological control in walnut production. Quad-county Walnut Institute, Stockton, CA, Feb. 16, 230 growers and PCAs.

Mills NJ. Selective pesticides and biological control in walnut pest management. Tri-county Walnut Day, Yuba City, CA, Feb. 29 – 220 growers, 70 PCAs.

Mills NJ. Biological pest control in organic tree crops in the western U.S.: An overview. 2nd International Organic Fruit Symposium, Leavenworth, WA, Jun. 19.

Mills NJ. Patterns in the biodiversity of natural enemies in California walnut orchards. 24th International Congress of Entomology, Daegu, Korea, Aug. 24.

Shearer PW, KG Amarasekare and PH Brown. Developing new information and tools to enhance biological control in pear and sweet cherry orchards. Winter Horticulture Meeting, Oregon State University Extension Service, Hood River, OR.

Smith TJ, VP Jones. Effects of sublethal pesticide residues on the dispersal capabilities of codling moth (*Cydia pomonella*) and obliquebanded leafroller (*Choristoneura rosaceana*). Pacific Branch Entomological Society of America, Portland, OR. 26-28 Mar. (invited symposium speaker).

Unruh TR. Evolution toward softer IPM for tree fruits may enhance biological control of codling moth. Western Orchard Pest and Disease Management Conference, Portland, OR. 11-13 Jan.

Posters:

Amarasekare KG, PW Shearer, N Allum, AA Borel. Effects of newer insecticides on the green lacewing *Chrysoperla carnea*. Annual Meeting of Orchard Pest and Disease Management Conference, Portland, OR. 11-13 Jan.

Amarasekare KG, PW Shearer, N Allum, AA Borel. Lethal and sublethal effects of insecticides on *Chrysoperla carnea* (Neuroptera: Chrysopidae). 7th International IPM Symposium, Memphis, TN. 27-29 Mar.

Amarasekare KG, PW Shearer, N Allum, AA Borel. Effects of newer insecticides on the green lacewing *Chrysoperla carnea*. Annual Meeting of the Pacific Branch Entomological Society of America (ESA), Portland, OR. 11-13 Jan.

Bixby-Brosi AJ, VP Jones, Evaluating the attractive radius of HIPV lures in western orchards (Poster). Washington State Horticulture Association. Yakima, WA. 3-4 Dec.

Bixby-Brosi AJ, U Chambers, V Jones, Enhancing biological control in apples: How do conventional and organic systems differ? (Poster). Washington Tree Fruit Research Commission. 25-26 Jan. Pasco, WA.

Jones, WE, AN Gadino, U Chambers, JF Brunner, VP Jones. Digital Outreach: Educating Stakeholders about Enhanced Orchard Biological Control. Washington State Horticultural Association Annual Meeting, Yakima, WA. 3-5 Dec.

Smith TJ, VP Jones. The effects of sublethal pesticide residues and flight on codling moth, *Cydia pomonella* (Linnaeus), obliquebanded leafroller, *Choristoneura rosaceana* (Harris) and convergent ladybird beetle, *Hippodamia convergens* (Guérin−Méneville). Pacific Branch Entomological Society of America, Portland, OR. 26-28 Mar.

Gadino AN, WE Jones, U Chambers. Natural enemies and enhancing BC in your orchard. Washington State Horticultural Association Annual Meeting, Yakima, WA. 3-4 Dec.

Popular Articles:

Warner, G. Watch out, codling moth! Spiders will eat anything they can physically tackle, including codling moth larvae and pupae. Good Fruit Grower. May 1.

Hansen, M. Easier access to MRLs. Visit the DAS web site. Good Fruit Grower. March 15.

Warner, G. Let natural enemies play a role. IPM means managing pests, not eliminating them. Good Fruit Grower. February 1.

Publications 2012 only:

Jones VP, NG Wiman. Age-based mating success in codling moth and obliquebanded leafroller. *J. Insect Sci. (in press)*

NG Wiman, VP Jones. Influence of oviposition strategy of *Nemorilla pyste* and *Nilea erecta* (Diptera: Tachinidae) on parasitoid fertility and host mortality. *Biol. Control (in press)*

Horton DR, E Miliczky, VP Jones, CC Baker, TR Unruh. 2012. Diversity and phenology of the generalist predator community in apple orchards of Central Washington State (Insecta, Araneae) *Can. Entomol. 144: 691-710.*

Jones VP, NG Wiman 2012. Modeling the interaction of physiological time, seasonal weather patterns, and delayed mating on population dynamics of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae). *Popul. Ecology* 54: 421-429.

Jones VP, R Hilton, JF Brunner, WJ Bentley, DG Alston, B Barrett, RA Van Steenwyk, LA Hull, JF Walgenbach, WW Coates, TJ Smith. Predicting emergence of codling moth, *Cydia pomonella* (Lepidoptera: Tortricidae) in North America. *J. Pest Management Sci*. *(submitted)*

Smith TJ. 2012. Effects of flight and sublethal pesticide residues on codling moth (*Cydia pomonella* (L.), obliquebanded leafroller, *Choristoneura rosaceana* (Harris), and convergent ladybird beetle, *Hippodamia convergens* (Guérin−Méneville). MS Thesis, Washington State University, Department of Entomology, Pullman, WA.

Wiman NG, VP Jones. Sublethal effects of pyriproxyfen and methoxyfenozide on *Nemorilla pyste* and *Nilea erecta* (Diptera: Tachinidae), parasitoids of leafrollers (Lepidoptera: Tortricidae) in tree fruits. *J. Pest Management Sci. (in press)*

Misc. Outreach

Amarasekare KG. KIHR- (Local Radio Station, Hood River, OR) - Radio Talk on enhancing biological control in tree fruit orchards. 5 Jan.

Shearer, PW. KIHR - (Local Radio Station, Hood River, OR). Radio Talk Biological control; using good bugs to take care of bad bugs.

Meetings Attended/Hosted

Enhanced Biocontrol in Western Orchards Research and Advisory Committee meeting, Portland, OR. 9-10 Jan.

Western Orchard Pest and Disease Management Conference, Portland, OR. 11-13 Jan.

Washington Tree Fruit Research Commission Pest Management Meeting, Pasco, WA. 25-26 Jan.

Enhanced Biocontrol in Western Orchards Short course, 8-9 Feb. Wenatchee and Tricities, WA; Hood River, OR (teleconference to all locations and speakers at all locations).

Pacific Branch Entomological Society of America, Portland, OR. 26-28 March

Washington Tree Fruit Research Commission Technology meeting. Ellensburg, WA. 10 May.

2nd International Organic Fruit Research Symposium. International Association of Horticultural Science, Leavenworth, WA. 18-20 June

Enhanced Biocontrol in Western Orchards Research Committee meeting, Wenatchee, WA. 21-22 June.

Enhanced Biocontrol in Western Orchards natural enemy identification and sampling workshop. Hood River, OR. Aug 3.

Enhanced Biocontrol in Western Orchards natural enemy identification and sampling workshop. Wenatchee, WA. Aug 23.

Northwest Nursery Improvement Institute. Wenatchee, WA. 11 Oct

Washington Tree Fruit Research Commission Technology meeting. Ellensburg, WA. 25 Oct.

Washington State Horticultural Association Annual Meeting, Yakima, WA. 3-5 Dec.

Agriculture, Food, and Human Values Society Ann. Meeting, NY, NY. 20-24 June.

New Leveraged Funding

Jones VP, U Chambers. Enhancing BC in apples: how do conventional and organic systems differ? Washington Tree Fruit Research Commission. $303,858 (2011-2014)

Jones VP, U Chambers, JF Brunner. Enhancing tree fruit IPM decision-making through advances on WSU-DAS and training of growers and pest management advisors. Wash. State Dept. Agric. SCRI block grant. $214,215 (2011-2014)

Jones VP, A Gadino, JF Brunner. Models to assess pesticide impacts on CM, OBLR, and *C. nigricornis*. Washington Tree Fruit Research Commission $226,690 (2012-2015).

Jones VP, U Chambers. Long-range forecasts, virtual weather stations, and new models for WSU-DAS. Washington Tree Fruit Research Commission $397,129 (2013-2015, *submitted*).

Acknowledgements

Matching Funds Sources:

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

Grower Cooperators:

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

Participating Research Personnel

Beers Lab
Technical support - Objective 1
Bruce Greenfield

Brunner Lab
Technical Support - Objective 6
Wendy Jones

Gallardo Program
Technical support - Objective 5
Qianqian Wang (Graduate Student)

Goldberger Program
Post-Doctoral Research Scientist - Objective 6
Nadine Lehrer

Technical support - Objective 6
Emily Green-Tracewicz (Graduate Student)

Horton and Unruh Labs
Post-Doctoral Research Scientist - Objectives 2-3
Dr. Eugene Miliczky

Technical support - Objectives 2-3
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Deb Broers
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Jones Lab
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Dr. Andrea Bixby-Brosi
Dr. Angela Gadino

Technical support - Objectives 2-3
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Tawnee D. Melton
Teah Smith (Graduate Student)
Brad Petit (Obj. 6)
Stacey McDonald
Nik Wiman (Graduate Student)

Mills Lab
Technical Support - Objectives 1-3
Kevi Mace-Hill
Laura Jones
Lisa Fernandez (Graduate Student)

Shearer Lab
Post-Doctoral Research Scientist - Objectives 1-3
Dr. Kaushalya Amarasekare

Technical support - Objectives 1-3
Preston Brown