Impacts of the Regional Integrated Pest Management Competitive Grants Program in the Western United States

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Executive Summary

The Regional IPM competitive grant program promoted scientific advances in integrated pest management to reduce risks of pest and pest management practices. From 2003 to 2014, the Western IPM Center organized the grant-review panel, which selected projects based in part on regional priorities. The RIPM program, as it was known, was discontinued in 2014 and its funding combined into a new program administered nationally.

The impacts highlighted here were generated by 66 research and extension projects funded from 2003 to 2012. They involved 83 project directors and 107 collaborators in 15 universities across all 13 Western states. Six projects from 2012 and 2013 are ongoing and not included.

New Pest Management Tools

The 66 Western RIPM projects developed six weather-based pest development models, five information-technology tools, 42 pest-management tools, six pest-monitoring and scouting procedures, four diagnostic tools, two pest-management economic models and one mosquito adulticide dispersal model.

Two of those projects contributed to the development and continual upgrading of the weather decision-support tools online at uspest.org. In 2013 alone, growers and pest managers used uspest.org to view 45,000 degree-day models tracking pest development, 57,000 hourly plant-disease forecasts, and 43,000 map views of pest development – nearly 400 uses every day just for those three resources. In addition, users have conducted 1,893 runs of the hop downy mildew forecasting model and 5,234 runs of the orange tortrix degree-day development model tracking the development of this caneberry pest. Three Western RIPM projects also contributed to developing the High Plains IPM site, which growers searched 34,000 times for wheat pests and homeowners searched 9,000 times for woody ornamental pests.

Pesticide Reductions and Economic Benefits

Based on outreach supported by Western RIPM projects, growers adopted new IPM practices to manage pests in caneberries, chiles, cotton, eggs, grapes, hops, lettuce, pear, poplar, potato, spinach seed, timothy grass hay and wheat.

In Arizona, two RIPM projects promoted adoption of IPM practices that have saved cotton growers a cumulative $451 million in pesticide costs and reduced the amount of insecticide used by 21 million pounds. Currently, 20% of cotton acreage in Arizona is not sprayed for insects. In California, IPM adoption supported by the RIPM program eliminated the use of about 1,000 pounds of malathion each year by timothy grass hay growers.

In Washington and Oregon, RIPM-supported IPM practices allow spinach-seed growers to continue to produce on ground that would otherwise be unsuitable because it was contaminated with the Fusarium wilt of spinach pathogen. Also in the Pacific Northwest, changing sulfur application programs in hops reduced mite pressure and allowed a reduction in miticide use.

Advanced Scientific Knowledge

Western RIPM projects created new scientific

List of Illustrations

knowledge that researchers continue to build on. The 66 projects generated 175 scientific presentations and 149 peer-reviewed scientific articles, which to date have been cited in other peer-reviewed scientific articles a whopping 2,292 times.

New Pest Management Products

Western RIPM projects supported the development of four pest management products now available or in commercial development. These are Prionus beetle pheromone traps to control a major pest of hops and fruit orchards; a diagnostic assay used by two states to test for fireblight in pears; and a bacterium and fungus in development as bio-pesticides.

Expanded IPM Knowledge

The 66 projects expanded IPM information available to growers and pest managers by creating 497 extension publications, 26 trade publications and 316 oral presentations to growers and others that reached an audience of at least 8,000. The trade publications, oral presentations and audience numbers were not consistently reported and are likely significantly under-stated. At least 38 undergraduate and graduate students were also trained in IPM science during these projects.

Leveraged Additional Funding

The 66 projects received a total of $6.1 million in RIPM funding, and then leveraged at least an additional $8.2 million in funding through 37 other grants. These figures are low, as not all project directors reported their leveraged grants or amounts.

Conclusion

The Regional IPM program contributed significantly to the expansion of available IPM tools and practices for Western agriculture, and growers used those tools to manage pests in ways that reduced risks to people and the environment while protecting their economic bottom line. The $6.1 million invested into the project leveraged at least an addition $8.2 million in funding, and resulted in an undoubtedly much larger overall economic benefit to Western growers and consumers.

Continued investment in integrated pest management research and extension, particularly projects that address regional priority needs, is clearly a sound investment that benefits the people, environment and economy of the Unites States.

Western RIPM Impacts

At a Glance

TOOLS

Created
- 42 pest-management tools
- 5 IT tools
- 6 monitoring and scouting tools
- 4 diagnostic tools
- 2 economic models
- 6 weather-based pest-development models

PRACTICES

- IPM practices adopted in cotton, eggs, caneberries, chiles, grapes, hops, lettuce and more
- In cotton alone, reduced pesticide costs by $451 million and insecticide use by 21 million pounds

KNOWLEDGE

- Generated 149 scientific papers, which have been cited 2,292 times so far
- Created 497 grower-training publications, and trained more than 8,000 end-users
- Trained at least 38 students

PRODUCTS

- Created a pheromone trap for Prionus beetle in hops
- Created a fireblight test for pears
- Led to two bio-pesticides in development
- Leveraged $8.2 million more in funds

Figure 1: Western RIPM impacts at a glance.

Introduction

This report follows the logic model format and organizes the impacts of the projects into short-, medium- and long-term impacts. Short-term impacts are the most easily identified since they result directly from the project. Medium- and long-term impacts are more difficult to assess. They may occur years after completion of the project and submission of the final project report, and the project may be one of many factors contributing to a change in action or condition. Therefore, the report documents fewer medium-term and long-term impacts.

Short-term impacts of Western RIPM projects included increase in scientific knowledge, increase in extension and end-user knowledge, development of new IPM tools and development of new information technology tools to support IPM implementation. Changes in knowledge include increased scientific knowledge as documented by scientific articles in peer-reviewed journals, citation of these articles in subsequent peer-reviewed articles and presentations at scientific meetings. Changes in grower, pest-management professional or other stakeholder knowledge are documented through presentations to appropriate stakeholder groups, and may include surveys or pre- and post-tests of knowledge gained. Changes in technology include new pest management tools (such as monitoring methods, traps, pheromones and pesticides), decision-support programs, weather-based pest models and information-technology tools and apps.

Medium-term impacts are changes in behavior in target stakeholder communities. Medium-term impacts include adoption of IPM practices, use of extension publications and use of information resources to support pest management decision-making. These impacts include actively seeking pest management information, using weather-based pest forecasting models and adoption of new pest-management tools.

Long-term impacts are changes in social, economic and environmental condition. Long-term impacts include improved pest control, higher yields or higher quality, reduced pest management costs, increased farm profit, reduced pesticide applications, reduced environmental impact, and training the next generation of pest-management professionals. These long-term changes can take many years to manifest, are due to many contributing factors and can be only partially ascribed to individual two-to-three-year grant projects. Although not specifically described in this review, continued profitable agricultural production, despite increasing pest- and pest-management challenges, should also be viewed as long-term impacts.

This report details the short-, medium- and long-term impacts of the Western RIPM projects funded from 2003 to 2012. Many of the projects will continue to generate impacts into the future as research is translated into extension education programs and stakeholders adopt these new IPM tools. As with any research and development program, not all project results were positive and not all of the IPM tools developed by the projects have been adopted. Nevertheless, the breadth and depth of impacts of the Western RIPM projects is quite impressive.

IPM Decision-Support Projects

In 2003, Len Coop at Oregon State University received funding for a project titled "Regional internet and GIS-based multiple pest forecasting and risk management system." The project contributed to the development of the www.uspest.org decision-support-tools website. The site allows users to run weather-based pest and crop development models with data gathered from networks of weather stations. The 2003 project improved system capabilities and the number of weather stations, added a new algorithm to estimate missing weather data, expanded the use of hourly weather forecasts for plant diseases, validated the pear scab model and incorporated a new method for estimating leaf wetness. The outputs of the project contributed to an increase in scientific knowledge through publication of three scientific articles and six scientific presentations. In addition, the project contributed to an increase in crop consultant and grower knowledge through 10 extension publications and one presentation to a grower group. The medium-term impacts of the project are based on a survey of pest control advisors trained to use the uspest.org site. According to the survey, 100% said they were able to make "more informed pest management recommendations," and use of the forecasting tools resulted in "improved timing of applications" and "more effective pest control." Use of the codling moth degree-day development model has become standard practice in apple production in the Pacific Northwest. Long-term impacts

were documented based on a survey of pest control advisors, in which 85% said use of the pest forecasting models "reduced pesticide use" and 76% said yields increased.

In 2005, Len Coop received funding for a project, titled "Determining the potential for release of lepidopteran parasitoids from pesticide limitations enable biologically-based IPM caneberries." Orange tortrix (*Argyrotaenia francisana*) is a leafroller pest of caneberries. The project developed and validated the orange tortrix degree-day development model, which is available on the uspest.org site. After one year of RIPM funding, the project switched to funding by the USDA-NIFA Crops At Risk program. The medium-term impact of the project is the continued use of the orange tortrix degree-day development model. The number of model runs from the uspest.org site has increased 3,500% from 2006 to 2014 (Figure 2).

Year	Model Runs
2006	104
2007	77
2008	70
2009	225
2010	304
2011	289
2012	544
2013	375
2014	3,736

Figure 2. Number of individual model runs per year for the orange tortrix degree-day development model at uspest.org

In 2009, Len Coop received funding for a project titled "IPM disease risk forecasts and virtual weather for Western states." The project developed "virtual weather stations" by integrating data from nearby weather stations with geographic data. Disease predictions based on virtual weather stations were validated in hops and grapes in Oregon and hops, cherries and grapes in Washington in two years. The outputs of the project contributed to an increase in scientific knowledge through publication of three scientific articles and 10 scientific presentations. In addition, the project contributed to an increase in crop consultant and grower knowledge through 30 presentations to industry groups reaching a total audience of 1,900. The attendees' post-event self-evaluations of their ability to create and use virtual weather stations increased an average of 2.6 points on a 7-point scale. The medium-term impacts are that 300 users have registered for continuous automated text, voicemail or email weather and disease alerts through the Ag Alertz system and 96 users have registered 222 different virtual weather stations locations since 2011.

All three projects conducted by Coop have contributed to the development of the www.uspest.org site for supporting weather-based decision-support tools. The uspest.org site now provides 82 degree-day and 23 hourly weather-driven models and draws data from more than 24,000 weather stations throughout the United States. The number of model runs has gradually increased over time, from 32,000 model runs during 2009 to more than 162,000 model runs during 2013. The 2013 use data includes more than 45,000 degree-day phenology model runs, over 57,000 hourly plant disease and related model runs, and more than 43,000 Google map views of late blight, fire blight, Tomcast disease severity values, soybean rust, and boxwood blight model-based disease risk maps. This work became the foundation of the Regional Infrastructure for Climate and Weather-based Decision Support Tools Signature Program of the Western IPM Center in 2012.

Three RIPM projects contributed decision-support tools to the High Plains IPM website. In 2006, Ned Tisserat at Colorado State University received funding for a project titled "Development and deployment of an electronic, multi-access key for diagnosing disease, arthropod and abiotic problems of small grains." The project developed a Lucid multi-access key for plant health problems in small grains. Lucid keys are designed to be easier for laypeople to use than traditional dichotomous keys since they allow starting with any character and only entering the characters the user can observe. The small grains key is available at the High Plains IPM website. In 2008, Fabian Menalled at Montana State University received funding for a grant titled "An electronic, multi-entry key for identifying weedy plant species in small grain fields." The project developed a Lucid key to identify weeds in small grains and assembled 100 weed factsheets by 21 authors. The weed key and fact sheets are available at the High Plains IPM website. The

medium-term impact is a change in users' information-seeking behavior. Both the Tisserat and Menalled Lucid keys and fact sheets are accessed from the High Plains IPM Small Grains page, which has received over 34,000 hits.

In 2009, Mary Burrows at Montana State University received funding for a project titled "Creation of online urban IPM resources for the High Plains region." The project developed a Lucid key for urban woody ornamental pests and 250 facts sheets on woody ornamental pests for landscape professionals and homeowners. The medium-term impact is a change in users' information-seeking behavior. The Lucid key and fact sheets are accessed from the High Plains IPM for Woody Ornamentals page, which has received more than 9,000 hits.

Vegetable IPM Projects

In 2003, Howard Schwartz at Colorado State University received funding for a project titled "Seed transmission and ecology of *Xanthomonas campestris* on onion." Schwartz developed new management tools for Xanthomonas leaf blight on onion by identifying resistant cultivars and determining that applications of acibenzolar-S-methyl and bacteriophages reduced disease at a level equivalent to copper-mancozeb applications. He also determined that very high nitrogen fertilization increased severity and therefore over fertilization with nitrogen should be avoided. The outputs of the project contributed to an increase in scientific knowledge through publication of four scientific articles and two scientific presentations. The project also contributed to an increase in crop consultant and grower knowledge through one extension publication.

In 2007, Howard Schwartz received funding for a project entitled "Cultivar resistance to IYSV and thrips in bulb onion in the Western United States." Iris Yellow Spot Virus (IYSV) is a devastating disease of onions that is transmitted by thrips. Schwartz identified onion cultivars with greater resistance to IYSV. He also determined that crop rotation, sanitation, weed management, cultural management to reduce crop stress are all components of an IPM program for IYSV on onions. The outputs of the project contributed to an increase in scientific knowledge through publication of two scientific articles. In addition, the project contributed to an increase in crop consultant and grower knowledge through six industry presentations to an audience of 350. The medium-term impact is grower adoption of the IPM tools. Personal contact between Schwartz and onion growers indicates that some Western state onion growers are selecting less susceptible onion cultivars and integrating crop rotation, sanitation, weed management and other management practices to reduce crop stress in a program to manage thrips and IYSV in onion.

In 2007, Hanu Pappu at Washington State University received funding for a project titled "Developing a monitoring program for thrips-Iris Yellow Spot Virus complex: Adding a novel management component to the IPM program in bulb and seed onion crop." Pappu developed a rapid and practical Enzyme-Linked ImmunoSorbent Assay (ELISA) test for IYSV. The ELISA test was then used to identify IYSV in volunteer Alliums, weeds, and thrips and to establish that growers should control volunteer Alliums and weed hosts of IYSV in order to reduce sources of infection. The outputs of the project contributed to an increase in scientific knowledge through publication of nine scientific articles and eight scientific presentations. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 174 times. This project contributed to Pappu's on-going program in IYSV and onion, which led to 19 additional scientific articles. The agricultural diagnostic company BioReba is developing IYSV test kits based on the antibodies identified by this project. The medium-term impact is grower adoption of the IPM tools. Personal contact between Pappu and onion growers indicates that some have improved weed and volunteer Allium control in order to reduce the sources of virus inoculum in the field.

In 2003, Rebecca Creamer at New Mexico State University received funding for a project titled "The influence of climate on London rocket and beet leafhoppers and their role in curly top infection of chile in New Mexico." Creamer determined that precipitation in October supports London rocket seed germination and establishment. These weeds survive into April and can support large populations of beet leafhopper, the vector for the beet curly top virus, which causes disease in chiles. The outputs of the project contributed to an increase in scientific knowledge through publication of two scientific articles. In 2007, Rebecca Creamer received funding for a project entitled "Seasonal phe-

nology of the beet leafhopper in relation to its weed hosts and beet curly top virus infection." Creamer documented that there is one distinct generation of beet leafhopper on weed hosts in southern New Mexico. Control of weed hosts in fall reduces beet leafhopper populations and subsequent transmission of beet curly top virus to chiles. The outputs of the project contributed to an increase in scientific knowledge through seven scientific presentations. The medium-term impacts are adoption of the IPM tools. Personal contact between Creamer and New Mexico chile growers indicates that some growers now manage these weed hosts in the fall in order to prevent transmission of the virus in the spring.

In 2004, Barry Pryor at University of Arizona received funding for a project titled "Biological control of lettuce drop: An essential element in developing an IPM program for desert-grown winter lettuce." Arizona and California grow 95% of lettuce and leafy salad greens in the United States. Pryor documented that the biological control agent *Coniothyrium minitans* – trade name Contans – reduces populations of the lettuce drop pathogen, *Sclerotinia sclerotiorum*, and reduces losses to the disease. However, Contans did not control lettuce drop caused by the related species *Sclerotinia minor*. The outputs of the project contributed to an increase in scientific knowledge through two scientific articles and one scientific presentation. Figure 3 includes all Contans applications to lettuce and fallow fields in Arizona. According to University of Arizona extension, total Arizona acreage of lettuce and leafy greens varied between 77,300 and 87,500 acres during 2004 to 2014.

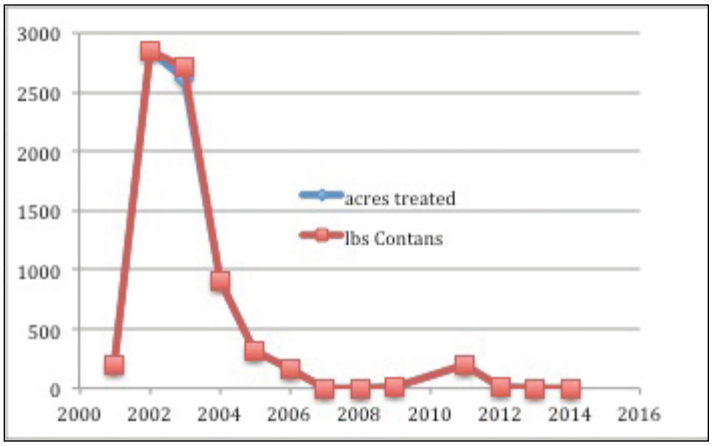

Figure 3. Total pounds of Contans applied and acres of lettuce and fallow ground treated in Arizona from 2001 to 2014. The average rate of application was one pound per acre, resulting in convergent lines.

In 2008, Krishna Subbarao at University of California Davis received funding for a project titled "Optimizing lettuce drop control caused by *Sclerotinia minor* using Contans, a biopesticide." The product had previously shown little or no efficacy against *S. minor* but through this research was developed into an effective treatment by altering the application time to match the most vulnerable stage of the pathogen. Subbarao determined that three Contans applications during the lettuce season gave comparable lettuce-drop control to grower's standard boscalid fungicide treatment. The outputs of the project contributed to an increase in scientific knowledge through one scientific article and to an increase in crop consultant and grower knowledge through four industry presentations. The medium-term impact is a low but recently increasing use of the bio-pesticide Contans. Since 2008, Contans applications in California have increased in pounds of product and acres treated in lettuce. Figure 4 includes all Contans applications to lettuce and fallow fields in California. According to USDA-NASS, total California acreage of head, leaf and Romaine

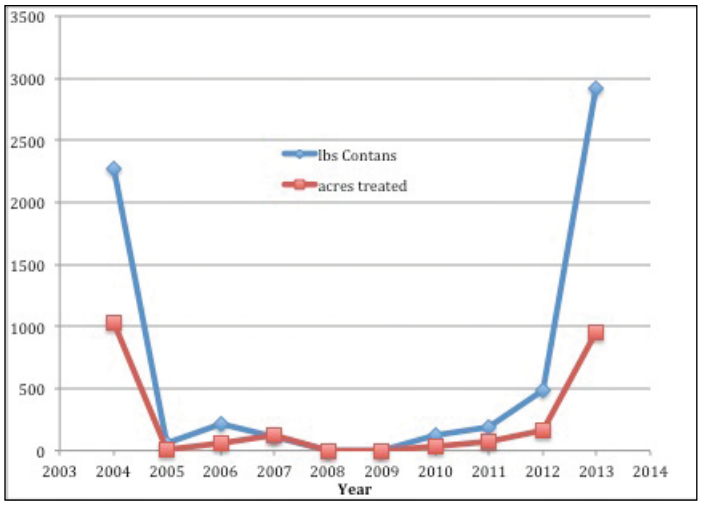

Figure 4. Total pounds of Contans applied and acres of lettuce treated in California from 2004 to 2013.

lettuce was between 167,100 and 246,100 acres during 2004 to 2013. Therefore, the percentage of total California lettuce acres treated with Contans was less than 0.5% in all years.

In 2011, Alexandra Stone at Oregon State University received funding for a project titled "Integrating biological control of white mold into conventional and organic vegetable rotations." Stone documented that Contans applications reduced the survival of the sclerotia of *Sclerotinia sclerot-*

iorum and subsequently disease losses to white mold in snap beans. The level of disease control was enhanced when combined with moderately white-mold-resistant snap bean cultivars. The outputs of the project contributed to an increase in scientific knowledge through two scientific presentations and to an increase in crop consultant and grower knowledge through two industry publications and nine industry presentations to 185 attendees. The medium-term impact is a low but increasing use of the bio-pesticide Contans in California in non-lettuce crops, including arugula, radicchio, spinach, broccoli, cabbage, cauliflower, swiss chard, carrots, corn salad, peppers and tomatoes (Fig. 5).

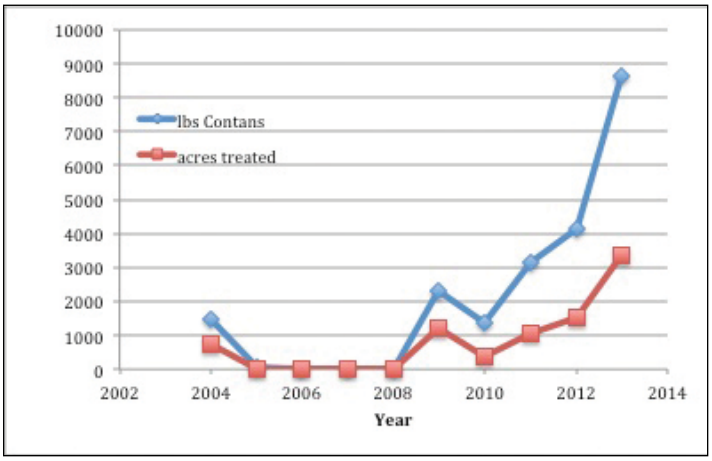

Figure 5. Total pounds of Contans applied and acres of non-lettuce crops treated in California from 2004 to 2013.

In 2009, Lindsey du Toit at Washington State University received funding for a project titled "Assessing the ability to increase the capacity for spinach seed production in the U.S. by developing soils suppressive to Fusarium wilt." Spinach seed is produced on about 4,000 acres in Oregon and Washington and valued at $9 to $10 million. du Toit and a PhD student funded by the grant, Emily Gatch, developed a soil bioassay to test the level of *Fusarium oxysporum* f. sp. *spinaciae* in the soil. They determined that annual applications of one to two tons of agricultural limestone per acre for three years prior to planting a spinach seed crop significantly suppressed Fusarium wilt of spinach. The outputs of the project contributed to an increase in scientific knowledge through three scientific articles and to an increase in crop consultant and grower knowledge through 11 industry presentations. The medium-term impacts are annual grower use of the bioassay as a risk-prediction service and adoption of limestone soil amendments more routinely for spinach seed production. Spinach seed growers have submitted soil from more than 200 fields in northwestern Washington for Fusarium wilt testing at a cost of $200 per field. Based on bioassay results, growers apply two tons of limestone per acre for one to three years prior to growing spinach for seed crops. The IPM tools generated by this project have facilitated a reduction in the length of crop rotation between spinach seed crops from the previous 12 to 16 years to five to 10 years without increasing losses to Fusarium wilt. This has increased the acreage available for spinach seed production by 50%. The increase in available acres is critical since spinach seed production is limited to very specific latitudes due to daylength required for flowering coupled with mild temperatures and dry conditions during summers. Spinach seed production occurs in only about six regions worldwide with these conditions.

In 2003, Doug Walsh at Washington State University received funding for a project titled "Integrating biological control in the management of solanaceous weeds." Walsh determined that Colorado potato beetle feeding and low doses of herbicides controls volunteer potatoes, cutleaf nightshade and hairy nightshade in carrot crops grown in rotation with potatoes.

In 2005, Barry Jacobsen at Montana State University received funding for a project titled "Developing integrated management programs for soilborne potato diseases using mycofumigation, *Trichoderma* sp., pesticides and host resistance." Jacobsen determined that mycofumigation with *Muscodor albus* isolate 620 controlled Rhizoctonia stem and stolon canker, Rhizoctonia black scurf, Verticillium wilt, and black dot of potato at a level equivalent to standard fungicide applications. The outputs of the project contributed to an increase in scientific knowledge through one scientific presentation and to an increase in crop consultant and grower knowledge through five industry presentations to 820 attendees. AgraQuest, now owned by Bayer CropScience, began developing the mycofumigation fungus *Muscodor alba* into a commercial product with the trade name Arabesque. Commercial development was dropped by AgraQuest, but picked up by Marrone BioInnovations. A commercial mycofumigation product is currently in the registration process.

In 2007, Barry Jacobsen received funding for a project entitled "Development and demonstration of integrated systems for control of soilborne, foliar and viral diseases of potato." Jacobsen determined that an integrated program of mycofumigation with *Muscodor albus* isolate 620, infurrow azoystrobin application and foliar applications of *Bacillus mycoides* isolate J alternated with pyraclostrobin was equivalent to synthetic fungicide program for control of potato scab, stem and stolon canker, black scurf, black dot, and Potato Virus Y. The outputs of the project contributed to an increase in crop consultant and grower knowledge through one extension publication, three industry publications and nine industry presentations. Certis has developed a commercial product based on *Bacillus mycoides* isolate J and submitted registration materials to the Environmental Protection Agency for approval.

In 2012, Barry Jacobsen received funding for a project titled "Integrating *Bacillus mycoides* isolate J (BmJ) induced resistance, stylet oils and rogueing with insecticides for management of Potato Virus Y." Jacobsen demonstrated that Potato Virus Y can be managed with an integrated program of *Bacillus mycoides* isolate J applications, stylet oil applications, rogueing PVY-infected potato plants, and a no-gap insecticide program. The outputs of the project contributed to an increase in scientific knowledge through two scientific presentations. The medium-term impact is that Montana potato growers have integrated stylet oil applications into their control programs for Potato Virus Y.

In 2009 Juan Alvarez at University of Idaho received funding for a project entitled "Mitigating the threat of PVY: Understanding and exploiting the biological and epidemiological factors behind the increasing incidence of PVY." After Alvarez left University of Idaho, Pamela Hutchinson completed the project. Hutchinson determined the specific Potato Virus Y strain transmission rates by green peach aphid for mixtures of strains O, N:O, and NTN on potato cultivars Russet Burbank, Ranger Russet, Yukon Gold and Premier Russet. The data from the project was presented to the multi-state project WERA89 - Potato Virus and Virus-like Disease Management.

In 2010, Ronda Hirnyck at University of Idaho received funding for a project titled "Alaska potato scouting IPM manual: A pocket guide in English and Russian." The "Alaska Field Guide to Potato Pests and Beneficial Insects in English and Russian" was published and is available on-line at http://www.cals.uidaho.edu/edcomm/pdf/BUL/BUL0879.pdf. The manual contributed to an increase in grower knowledge through two grower trainings to 25 attendees in Alaska.

In 2004, Carol Mallory-Smith at Oregon State University received funding for a project titled "Integrated management of wild proso millet in vegetable cropping rotations." Mallory-Smith determined that fall tillage was not sufficient to control wild proso millet and that reduction of the weed seed bank by beetle seed predation combined with spring tillage resulted in the best control. The outputs of the project contributed to an increase in scientific knowledge through three scientific presentations. The medium-term impact is that most vegetable growers in Oregon cultivate the soil in spring to manage wild proso millet.

In 2006, Ed Peachey at Oregon State University received funding for a project titled "Effect of primary tillage sequence, insecticides and weed seed placement on seed predator conservation, efficacy and weed emergence." Peachey determined that weed-seed predation by invertebrates, such as carabid beetles, is an important source of weed-seed mortality. Providing invertebrate seed predators with refugees through strip-tillage, not tilling in spring or not applying soil insecticides in spring can increase seed predation. The outputs of the project contributed to an increase in scientific knowledge through three scientific presentations. In addition, the project contributed to an increase in crop consultant and grower knowledge through 10 grower presentations to 910 attendees.

In 2004, Mark Wright, Cerruti Hooks, and Roshan Manandhar at University of Hawaii received funding for a project titled "Cultural management of insect pests: using barrier crops to protect against insect inflicted plant impairments." They determined that growing zucchini with a cover crop of either buckwheat, white clover or sunnhemp can significantly reduce the incidence of aphid transmitted Papaya Ringspot Virus–w. The outputs of the project contributed to an increase in scientific knowledge through two scientific articles and to growers through an extension publication. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 43 times. University of Hawaii extension personnel

regularly recommend using intercropping with cover crops, based in part on this work.

In 2008, Judith Brown at University of Arizona received funding for a project titled "Integrated management and regional GIS mapping of CYSDV-vector complex in the desert southwest." Brown identified Cucurbit Yellow Stunt Disorder Virus (CYSDV) in alkali mallow, morning glory, ground cherry, velvetleaf, silverleaf nightshade, lambsquarters, pigweed, London rocket, and five hook bassia, alfalfa, canteloupe, honeydew, cassaba, cucumber, watermelon, bean, lettuce (romaine), hibiscus and papaya. She also determined that whiteflies could acquire CYSDV from lettuce, buffalo gourd, alkali mallow, and ground cherry and transmit it to melon plants. Brown developed an IT tool named Whitefly Tracker (cals.arizona.edu/whiteflytracker) to provide growers with data on whitefly populations and whiteflies with CYSDV. WhiteflyTracker is currently not supported or used. The outputs of the project contributed to an increase in scientific knowledge through one scientific article.

In 2011, Larry Godfrey at University of California Davis received funding for a project entitled "Life history and refined management of cucumber beetle in central California melons." Godfrey increased our understanding of biology of striped cucumber beetles and spotted cucumber beetles and determined the rates of cucumber beetle parasitism by a tachinid fly. He also determined that kairomone-baited yellow sticky traps are the best monitoring method and that Cide-TrakD feeding stimulant combined with carbaryl provides good control of cucumber beetles. The outputs of the project contributed to an increase in scientific knowledge through one scientific article. Melon crop acreage and cucumber beetle numbers in California have declined due to drought conditions the last four years, so growers have not needed to adopt the practices developed in this project yet. However, cucumber beetles have recently become increasingly important in Arizona.

In 2011, Tom Perring and Jocelyn Millar at University of California Riverside and John Palumbo at University of Arizona received funding for a project titled "Development of an IPM program for the invasive bagrada bug in the southwest desert vegetable production systems." They increased our understanding of the biology of bagrada bug, established a degree-day development model, determined the optimum monitoring method, documented migration of bagrada bug from weedy crucifers to crucifer crops, and determined the efficacy of several insecticides. They also demonstrated strong attraction of bagrada bugs to several of the isothiocyanate chemicals produced by damaged brassicaceous plants, and those preliminary results are being followed up to develop attractant-based traps for this invasive pest. The outputs of the proj-

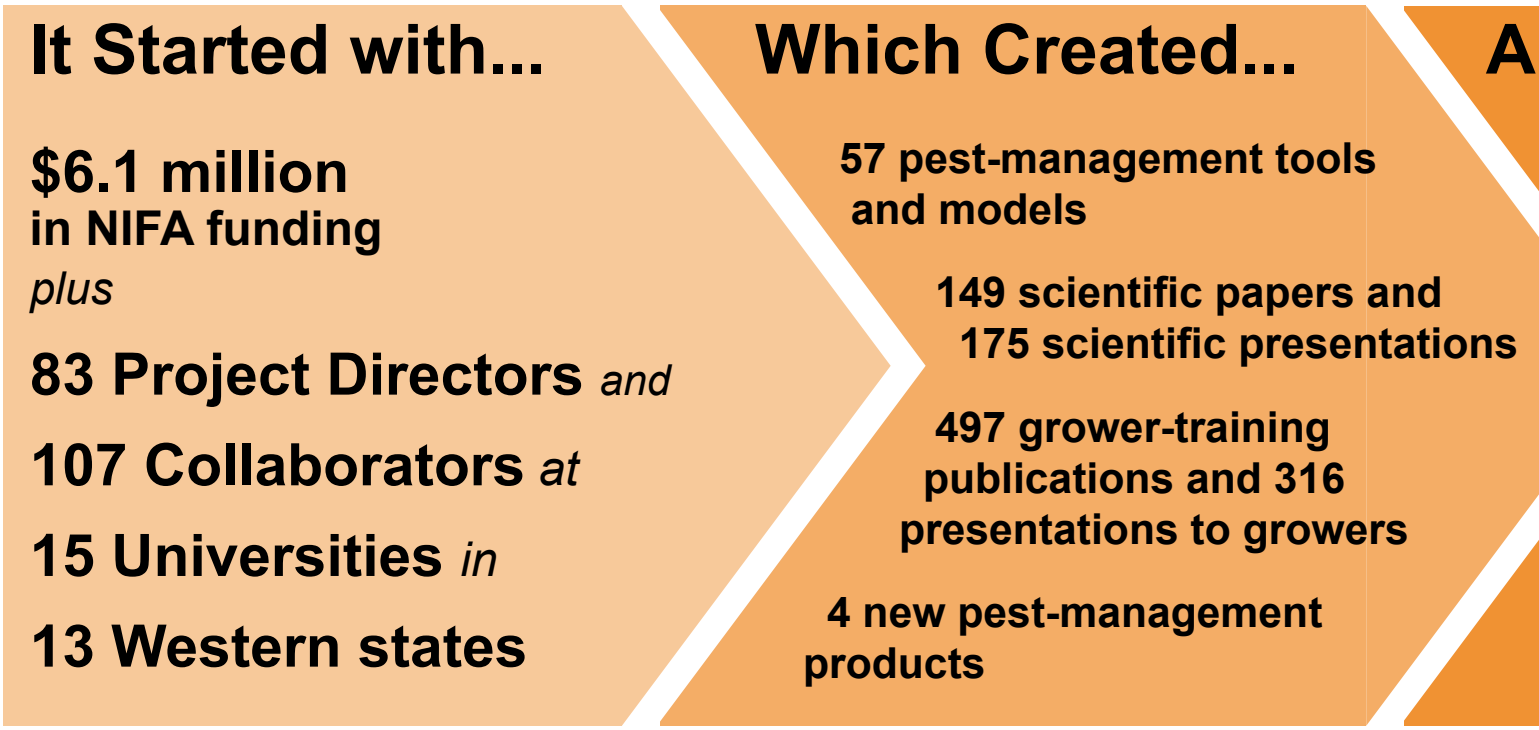

 Figure 6: Accomplishments of Western RIPM Projects

ect contributed to an increase in scientific knowledge through six scientific articles, to an increase in industry knowledge through five extension publications, and were the topic of a symposium at the national Entomological Society of America annual meeting, organized by the PDs of this project.

In 2004, Kent Daane at University of California Berkeley received funding for a project titled "Using intercrops and alternative prey to boost predatory flies in lettuce." Daane determined that intercropping barley, bell beans or vetch in lettuce crops did not increase syrphid fly populations or decrease aphids in lettuce. The outputs of the project contributed to an increase in scientific knowledge through three scientific articles and five scientific presentations. In addition, the project contributed to an increase in crop consultant and grower knowledge through four presentations.

Agronomic Crop IPM Projects

In 2005, Peter Ellsworth at University of Arizona received funding for a project titled "Spatially explicit approaches to measuring and implementing higher level, multi-crop, multi-pest IPM." Ellsworth partnered with the Arizona Department of Agriculture to develop a Pesticides Use Report database for 2001-2005 based on Arizona Department of Agriculture pesticide-use report forms. Usage data were examined to determine the level of adoption of cross-commodity IPM guidelines, which had been published and promoted through outreach in 2003. State-licensed pest control advisors (PCAs) were interviewed to determine factors affecting pest-management decision making and behaviors. The outputs of the project contributed to an increase in scientific knowledge through two scientific articles and nine scientific presentations. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 83 times. The outputs of this project led to an increase in industry knowledge through one extension publication and six pest control advisor presentations. The medium-term impacts were changes in PCA and grower behavior. Qualitative analysis of PCA interviews documented that more than half of PCAs indicated their pest management decisions were influenced by the guidelines. Factors positively affecting guidelines adoption were University of Arizona Cooperative Extension outreach, participation in guidelines generation, low whitefly populations, availability of many product choices and registration of new effective aphicides in lettuce. Factors that negatively affected adoption of the guidelines included influence of the grower on PCA product choice, lower cost of neonicotinoid products versus insect growth regulators, situational factors that influenced product choice, availability of generic neonicotinoids, and prevalence of imidacloprid-treated cotton seed in some areas. Some PCAs indicated

nd Led to...

Hundreds of thousands of uses of the models and tools

2,292 peer-reviewed citations of the RIPM-produce papers

8,000 growers trained

A pear fireblight test now used by labs in two states

Resulting in...

IPM practices being adopted in cotton, eggs, caneberries, chiles, grapes, hops, lettuce, pear, poplar, spinach seed, timothy grass hay and wheat

Reductions in pesticide costs by $451 million and use by 21 million pounds in cotton

$8.2 million in new funding to continue the research

that a desire to comply with the guidelines could not override immediate needs to control whiteflies. Interestingly, some PCAs with little awareness of the guidelines were in compliance with them, but made decisions based on other criteria. Most PCAs felt the guidelines should be updated and some indicated incorporation of non-neonicotinoid products would be helpful. Medium-term impacts were changes in pesticide applications. Quantitative analysis of Arizona pesticide use reporting data revealed reduced use of neonicotinoids in multi-crop communities versus cotton-intensive communities (10% of sprays versus 45% of sprays) by Yuma cotton growers in 2005. This indicates partial adoption of the guidelines. Also, differential trends in uses of pyriproxifen and buprofezin (both insect growth regulators) in Yuma between cotton growers in cotton intensive versus multi-crop communities were generally consistent with guideline recommendations. Pesticide-use report data analysis of grower behaviors in Pinal County showed no significant differences in neonicotinoid use by cotton growers in cotton-intensive versus multi-crop communities following the education program, indicating a general lack of adoption of the guidelines in this central Arizona county. One reason for this, as revealed through PCA interviews, was that central Arizona growers generally failed to recognize the existence of multi-crop communities in their area, which is largely dominated by cotton-intensive communities. Pesticide-use report analysis of grower behaviors in Maricopa County showed a dramatic difference before (2003) and after (2004-05) the education programs, with a 2.3-fold reduction in use of neonicotinoids in multi-crop communities. However, in 2005, 15% of sprays in multi-crop communities included a neonicotinoid, indicating less than full adoption of the guidelines. An examination of 2012 pesticide use reports indicates that growers are continuing to follow the cross-commodity IPM guidelines for neonicotinoids – a long-term change in behavior. Presentations from the original project and 2012 re-evaluation are available at http://cals.arizona.edu/crops/presentations/presentations.html#cross. This work was used as a good example of insect resistance management on pages 97 to 99 in the chapter "Adopting Insect Resistance Management Programs to Local Needs" by Graham Head and Caydee Savinelli in the book Insect Resistance Management: Biology, Economics and Prediction edited by David W. Onstad (Academic Press, 2008).

Two recently funded Ellsworth and colleagues' projects will continue to leverage this work on cross-commodity management of whiteflies in Arizona and Southern California, this time with a focus on developing tools for pro-active resistance-management decision making. They are a 2014 USDA-NIFA Applied Research and Development Program grant and a 2015 Monsanto Insect Knowledge Research Program grant. Significantly, the 2005 RIPM project also served as a starting point for increasing capacity of the Arizona Pest Management Center to measure pesticide-related outcomes and impacts, as it led to the development of the Arizona pesticide use records database (1991 to current). This database is now routinely used to help document project impacts where pesticide use outcomes are targeted. For example, a series of two USDA-AMS Specialty Crop Block Grant (Fournier and colleagues) projects, done in collaboration with Oregon State University Integrated Plant Protection Center, analyzed reductions in pesticide risk over time based on all reported applications in Arizona lettuce from 1991 to 2013.

In 2012, Peter Ellsworth received funding for a project titled "Integrating biological control into management decisions: Advancing the IPM continuum through research and implementation." Ellsworth developed action thresholds for sweetpotato whitefly (*Bemisia tabaci*) based on ratios of six whitefly predators to whiteflies and conducted outreach to promote adoption. Eight state-licensed pest control advisors in Arizona and 10 pest managers in Mexico participated by collecting season-long predator-prey ratios and based whitefly control decisions on the new guidelines. Adoption of the ratio-based guidelines delayed the time of first insecticide application up to seven weeks. The outputs of the project contributed to an increase in scientific knowledge through nine scientific presentations. The graduate student trained on this project later leveraged a Western IPM Center grant on outreach and evaluation of the management guidelines developed by the Western RIPM-funded project.

Both of Ellsworth's Western RIPM projects (2005 and 2012) have supported the long-term success of the Arizona cotton IPM program and long-term impacts in Arizona. Arizona cotton growers have cumulatively saved over $451 million in 2014 constant dollars and prevented over 21 million pounds of insecticide active ingredient from reaching the

environment (1996–2014). On average today, approximately 20% of Arizona cotton acreage is never sprayed for arthropods. A component of the Arizona IPM program is annual in-depth surveys of pest control advisors to ascertain crop pest losses and pest-management decisions. Figure 7 is an example of the data generated by this survey. This portion of the Arizona IPM program became the Crop Pest Losses and Impact Assessment Signature Program of the Western IPM Center in 2012 after several years as a Western IPM Center-funded work group.

In 2003, James Knight at Montana State University received funding for a project titled "Economic and technical guidelines for control of ground squirrels in alfalfa." Knight developed monitoring and control guidelines for ground squirrels in alfalfa that include squirrel-control toxicants that do not persist in carcass tissue and therefore eliminate the potential for secondary poisoning of vertebrate predators. The outputs of the project contributed to an increase in scientific knowledge through one scientific article and an increase in grower knowledge through two extension publications and six presentations at grower meetings.

In 2005, Larry Godfrey at University of California Davis received funding for a project titled "Development of an IPM program for arthropod pests of cool-season grass hay crops." Godfrey developed scouting methods and thresholds for thrips and mites in timothy grass hay. He also determined the efficacy of oils, cyfluthrin and bifenazate as replacements for organophosphate insecticides. In addition, wheat curl mite infestation in timothy grass was documented for the first time. The outputs of the project contributed to an increase in scientific knowledge through six scientific presentations and an increase in grower knowledge through eight presentations to grower meetings. The medium-term impacts are a change in pesticide applications. Timothy hay growers have adopted alternatives to organophosphates for thrips and mites. In 2006, 989 pounds of malathion was applied to 774 acres of timothy hay in California. Since 2007 there have been no applications of malathion in timothy hay in California. Therefore, the long-term impact of this project is the elimination of approximately 1,000 pounds of malathion annually in timothy grass production in California. Pesticide use data for Oregon and Washington are not available but are expected to reflect a similar trend.

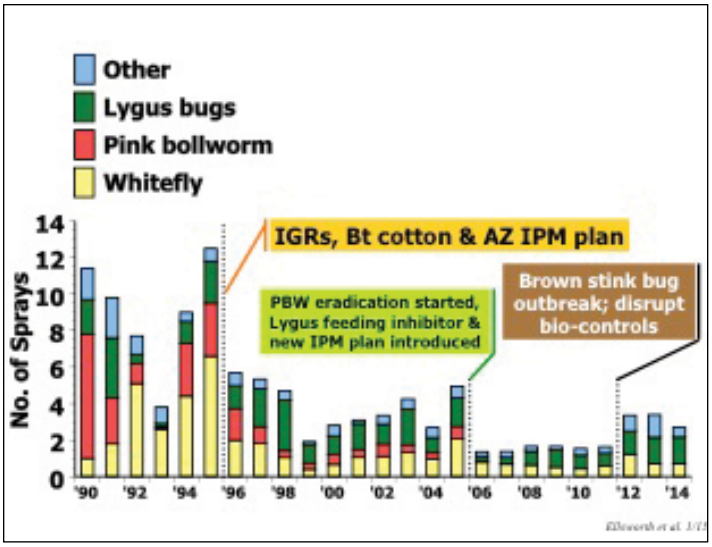

Figure 7. Number of insecticide applications per season per insect pest in Arizona cotton from 1990 to 2014.

In 2011, Sujaya Rao at Oregon State University received funding for a project titled "Development of integrated approaches for clover crown borer management." Rao determined that kairomones reported to be potential attractants for clover crown borer monitoring traps based on lab experiments do not work in the field. She also identified a potential biocontrol fungus. The outputs of the project contributed to an increase in scientific knowledge through three scientific presentations and an increase in grower knowledge through one extension publication and three presentations at grower meetings to 295 attendees.

In 2006, Robert Stougaard at Montana State University received funding for a project titled "Wheat seed quality effect on competitive ability with wild oat." Stougaard determined that larger wheat seed size results in greater wheat seedling competitive ability with wild oat in the field. The outputs of the project contributed to an increase in grower knowledge through six presentations at grower meetings. Seed size is now part of the selection criteria used in the development of winter wheat varieties.

In 2008, Patrick Hatfield at Montana State University received funding for a project titled "Using sheep in grain fallow management to control weeds and insect pests and reduce use of pesticides and fossil fuels." Hatfield determined that sheep grazing in recently harvested fields reduced cheatgrass and wild oat biomass in the subsequent season. The outputs of the project contributed to an increase in

scientific knowledge through three scientific articles and four scientific presentations. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 11 times. In addition, the project led to an increase in grower knowledge through one trade publication.

In 2008, Shaojin Wang at Washington State University received funding for a project titled "Non-chemical postharvest insect control in lentils using radio frequency energy." Wang determined that radio frequency heating raised the temperature of three kilograms (6.6 lbs.) of dried lentils, chickpeas, black-eyed peas and mung beans to 60C (140F) in five to seven minutes. That temperature was sufficient to kill cowpea weevil and Indian meal moth larvae and pupae, which are key storage pests of these crops. The outputs of the project contributed to an increase in scientific knowledge through nine scientific articles and 10 scientific presentations. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 82 times.

In 2009, Levan Elbakidze and Sanford Eigenbrode at University of Idaho received funding for a project titled "Management of virus disease epidemics in lentils via prescribed conditional pea aphid control: evaluation of economic effectiveness and feasibility." They developed an economic model to determine whether to manage pea aphid for only direct damage to lentils or more aggressively for the ability of the aphid to transmit pea enation virus and bean leafroll viruses to lentils. They determined that current dimethoate application restrictions make the difference in aphid management approaches unimportant. The outputs of the project contributed to an increase in scientific knowledge through one scientific article and five scientific presentations.

In 2005, Frank Peairs at Colorado State University received funding for a project titled "Yield losses for Western bean cutworm and European corn borer among site-specific management zones." Peairs determined that site-specific management was not practical for European corn borer and spider mites but was possible for Western bean cutworm. The project outputs contributed to an increase in scientific knowledge through three scientific articles.

Perennial Crop IPM Projects

In 2003, Virginia Stockwell at Oregon State University received funding for a project titled "Refining iron-enhanced biological control of fireblight." Stockwell documented that addition of chelated iron (trade name Sequestrene 138) to *Pseudomonas fluorescens* A506 (trade name Blightban A506) applications improved the control of fireblight of pear and did not burn flowers or russet fruit. Skin russeting of smooth-skinned pear varieties is not commercially acceptable for fresh pears. Applications of other iron compounds would burn flowers and russet fruit. A program of chelated iron and *Pseudomonas fluorescens* A506 followed by oxytetracycline gave equivalent control to two applications of streptomycin. These results are important for managing resistance to streptomycin in the fireblight pathogen population. The outputs of the project contributed to an increase in scientific knowledge through three scientific articles and two scientific presentations. The scientific articles have been cited by subsequent peer-reviewed scientific articles 68 times. Based on this research the Pacific Northwest Disease Handbook recommends the use of BlightBan A506 and Sequestrene.

In 2006, Virginia Stockwell received funding for a project titled "Integration of a modified strain of Blightban A506 with conventional fireblight management." Stockwell determined that the bacterial biological control agents *Pantoea agglomerans* C9-1 (trade name BlightBan C9-1) and *Pseudomonas fluorescens* A506 (trade name Blightban A506) applications could be integrated into fireblight control programs with the antibiotic streptomycin. The outputs of the project contributed to an increase in scientific knowledge through one scientific article and three scientific presentations. The Pacific Northwest Disease Handbook and University of California Integrated Pest Management (UC IPM) recommends these biopesticide products for fireblight of pear. California pear growers' use of bio-pesticides for control of fireblight has decreased since 2003 (Figure 8). Nufarm Limited has the fireblight biological pesticides BlightBan A-506, BlightBan C9-1, and BloomTime Biological FD. Nufarm has gone through chapter 11 bankruptcy and reorganization in the last several years, which may have impacted use of the products.

In 2008, Ken Johnson at Oregon State University received funding for a project titled "Development of a rapid detection protocol for the fireblight

pathogen of pear and apple." Johnson developed a loop-mediated isothermal amplification of DNA (LAMP) method to easily and rapidly detect the firelight pathogen (*Erwinia amylovora*). The outputs of the project contributed to an increase in scientific knowledge through two scientific articles and five scientific presentations. The outputs contributed to an increase in grower knowledge through 10 presentations at grower meetings. The extension diagnostic labs in Utah and Oregon adopted the LAMP detection assay for routine fireblight diagnosis. In addition, the Oregon diagnosis lab developed two more bacterial pathogen diagnostic assays based on the same technology. The fireblight LAMP detection assay was used in a collaborative project with Rachel Elkins, pomology farm advisor in Lake and Mendocino counties in California, to demonstrate the efficacy of delayed dormant copper applications for control of fireblight. The number of delayed dormant copper applications in California went from zero in 2009 to 40 in 2012.

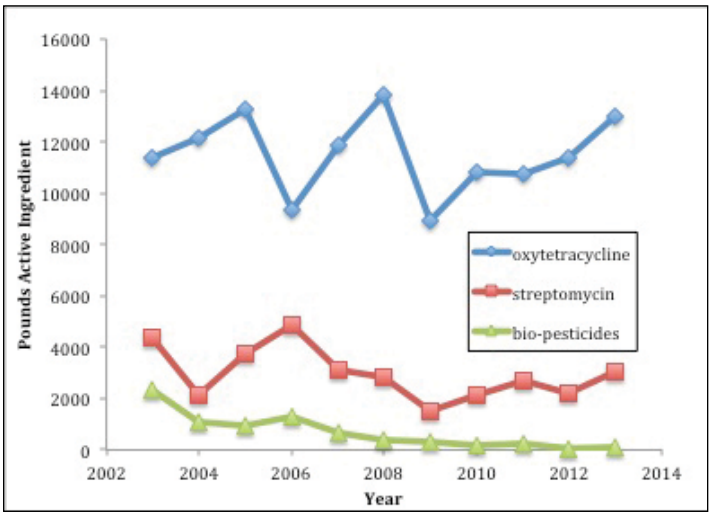

Figure 8. Total pounds active ingredient of oxytetracycline, streptomycin and bio-pesticides to control fireblight of pear in California from 2003 to 2013.

In 2005, Cindy Ocamb at Oregon State University received funding for a project titled "Reduced fungicide use for hop downy mildew management." Washington, Oregon and Idaho produce 98% of U.S. hops on approximately 38,500 acres. Ocamb validated a weather-based disease forecasting method for hop downy mildew in Oregon and Washington. She also determined the number of fungicide sprays and economic value of sprays that could be avoided while maintaining disease control at a level equivalent to standard grower practice at the time. The hop downy mildew model is available on the www.uspest.org site. The outputs of the project contributed to an increase in scientific knowledge through two scientific articles. The medium-term impact of project is the continued use of the downy mildew forecasting model on the uspest.org site. The number of model runs from the uspest.org site has increased from 2010 to 2014 (Figure 9). County extension agents and pest management consultants may conduct model runs and therefore each individual model run may impact large areas. Assuming the downy mildew model runs support decision-making on 50% of hop acreage, then the project reduces fungicide applications by about 15,000 pounds per year and saves hop growers about $900,000 annually.

Year	Model Runs
2010	148
2011	1,060
2012	392
2013	57
2014	236

Figure 9. Number of individual model runs per year for the hop downy mildew model at uspest.org

In 2007, James Barbour at University of Idaho and Jocelyn Millar at University of California Riverside received funding for a project titled "Development of a female-produced sex pheromone for managing *Prionus californicus* in hop." Barbour and Millar identified the sex pheromone produced by female *Prionus californicus* beetles to attract males. The outputs of the project contributed to an increase in scientific knowledge through five scientific articles and to an increase in industry knowledge through one extension publication. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 46 times. *Prionus californicus* monitoring traps using the pheromone are marketed by Alpha Scents. Additional research using the monitoring traps is being conducted in cherry orchards in Utah. The pheromone is the subject of IR-4 trials to generate the data necessary to support EPA registration for use in mating disruption dispensers for protection of hops. Furthermore, with assistance from collaborators, the team found that the same pheromone is used by other Prionus species in North America and Europe. Jim Dutcher in Georgia and Art Ag-

nello in New York state are using the pheromone in research projects for monitoring and mass trapping Prionus root borers in tree fruit and nut crops.

In 2010, Doug Walsh, Tom Marsh and Jennifer Sherman at Washington State University received funding for a project titled "IPM adoption: Motivations, barriers and subjective risk assessment in contract agriculture." The project directors determined that Maximum Residue Levels in the United States and its trading partners had the greatest effect on large-scale hop growers' choice of active ingredients for control of diseases and arthropods pests. The outputs of the project contributed to an increase in scientific knowledge through five scientific articles and four scientific presentations.

In 2007, Glenn Fisher at Oregon State University received funding for a project titled "Integrated management of mite pests and powdery mildew diseases on perennial hosts." Fisher determined that stopping sulfur applications for hop powdery mildew in mid- to late-spring conserved predatory mites later in the season and reduced the need for mid- to late-season miticide applications. In grapes, rotating synthetic fungicide applications with sulfur applications did not decrease predatory mite levels and resulted in adequate pest mite control. Fisher also examined the influence of mites on grape short shoot syndrome and determined the most effective products and timings to reduce losses by 66%. The outputs of the project contributed to an increase in scientific knowledge through nine scientific articles and six scientific presentations. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 43 times. The outputs contributed to an increase in grower knowledge through 16 trade publications and 40 presentations at grower meetings. The following medium-term impacts were based on a survey of hop growers. Among respondents, 68% indicated that their use of sulfur had been modified in some way compared to their previous practices. Sixty percent of growers reported applying sulfur less often, 36% changed the time of year when sulfur was applied, and 8% reduced rates. Respondents in the pre-survey indicated they made 1.99 miticide applications per hop yard on average, whereas average miticide use was reported as 1.76 applications per hop yard in the post-survey.

In 2004, John Brown at Washington State University received funding for a project titled "Development of an IPM program against wood burrowing insects in poplar plantations." Brown determined efficacy of pheromone mating disruption for control of poplar clearwing moth in poplar tree plantations. The larvae are important wood-boring pests of poplar. The outputs of the project contributed to an increase in scientific knowledge through one scientific article and 12 scientific presentations. The sex pheromone for Western poplar clearwing moth was registered with EPA for use in mating disruption. The medium term impact is that mating disruption programs are used to protect all of the approximately 60,000 acres of poplar plantations in eastern Oregon and Washington from Western poplar clearwing moth.

In 2004, Beth Grafton-Cardwell at University of California Riverside received funding for a project titled "Citrus IPM mobile teaching lab." The citrus IPM mobile teaching lab is a fifth-wheel trailer renovated with computerized presentation equipment, four stereo dissecting microscopes, insect collection equipment, and insect preservation supplies. Grafton-Cardwell gave 21 presentations to 250 citrus growers and state-licensed pest control advisors (PCAs) over a six-year period. The project increased grower and PCA knowledge of identification, monitoring and management strategies for nine citrus pests as determined by an average of 74 to 93% correct answers on post-training quizzes.

In 2006, John Hu at the University of Hawaii received funding for a project titled "Environmental-friendly strategies for management of mealybugs, ants, ampeloviruses and mealybug wilt of pineapple." In this system, mealybugs on pineapple are tended by ants for their honey-dew secretions. The mealybugs also vector Pineapple Mealybug Wilt-associated Virus (PMWaV). Hu determined that AmdroPro ant bait reduced the ant population, which resulted in lower mealybug population. Therefore, the amount of diazinon needed to control mealybugs was reduced while maintaining control of PMWaV. The outputs of the project contributed to an increase in scientific knowledge through five scientific articles and two scientific presentations. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 14 times. The outputs contributed to an increase in grower knowledge through two presentations at grower meetings. In the last few years, all pineapple processing plants in Hawaii

have closed due to economic factors. The acreage of pineapple in Hawaii has dropped significantly and there is currently only small acreage of pineapple production for the local fresh market.

In 2010, Mark Hoddle and Daniel Jeske at University of California Riverside received funding for a project titled "Sampling plan development and spatial analysis for Persea mite in avocados: A model system for pests of tree crops." Mites are very small arthropods and monitoring by counting mites with a hand lens is challenging and time consuming. Hoddle and Jeske developed a presence-absence method for sampling leaves to determine Persea mite populations and treatment thresholds in avocado. The method is posted in the avocado pest management guidelines on the University of California Integrated Pest Management (UC IPM) website. The outputs of the project contributed to an increase in scientific knowledge through five scientific articles and three scientific presentations. The outputs contributed to an increase in grower knowledge through five presentations at grower meetings to an audience of 120.

In 2011, Koon-Hui Wang, Cerruti Hooks and Jari Sugano at University of Hawaii received funding for a project titled "An integrated disease management program for banana industries in the Pacific Islands." They determined that banana plants infected with Banana Bunchy Top Virus (BBTV) could be rogued without additional risk of aphid transmission of the virus to neighboring plants by injecting the banana plant with glyphosate and then spraying the leaves with imidacloprid. The herbicide injection and insecticide application reduced the populations of aphids on the BBTV-infected plants and reduced aphid transmission of BBTV to neighboring banana plants. They also documented the disease-control and economic benefits of the use of disease- and nematode-free banana planting material derived from tissue culture. The outputs of the project contributed to an increase in scientific knowledge through two scientific presentations and two banana mini-conferences. The outputs contributed to an increase in grower knowledge through six fields days for 164 growers and publication of the Banana IPM Handbook. The medium-term impact is a change in grower information-seeking behavior. Hawaiian banana growers continue to actively seek out the IPM program information. The banana IPM website has had 315 hits and banana IPM training materials website 335 hits. Unfortunately, the Banana Bunch Top Virus-free and nematode-free tissue culture plantlets operation closed in 2012 due to lack of state funding. Since then the Wang and colleagues have demonstrated the use of macropropagation techniques to propagate banana in sterile potting media. This allows the farmers to continue to propagate virus- and nematode-free banana planting material distributed from this research and extension team.

Natural Area IPM Projects

In 2003, Jorge Vivanco at Colorado State University received funding for a project titled "Integrated management of *Centaurea maculosa* (spotted knapweed) in the Western United States while utilizing its allelochemical properties." Spotted knapweed secretes an allelopathic chemical called catechin, which inhibits the germination of native plant seeds thereby altering the plant population and community structure in range and native areas. Vivanco identified eight native grassland species that are resistant to catechin and may be useful for revegetation. The outputs of the project contributed to an increase in scientific knowledge through eight scientific articles. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 1,511 times.

In 2005, Mark Paschke at Colorado State University received funding for a project titled "Integrated control of spotted knapweed: Utilizing spotted knapweed resistant native plants to facilitate revegetation." Paschke determined that catechin-resistant plants can increase diversity and abundance of native plants in knapweed-infested areas but are not effective nurse crops for catechin-sensitive native plants. The outputs of the project contributed to an increase in scientific knowledge through nine scientific articles and 17 scientific presentations. The scientific articles have been cited by subsequent peer-reviewed scientific articles 11 times.

In 2005, Stephen Enloe at University of Wyoming received funding for a project titled "Mechanisms and impacts of integrated pest management for sustainable Dalmatian toadflax control in the Western U.S." Enloe determined that a combination of reduced herbicide rate and biocontrol with Dalmatian toadflax stem mining weevil did not result in sufficient control of Dalmatian toadflax. Subsequent

research has documented that Dalmatian toadflax stem mining weevil is actually two closely related species and that Dalmatian toadflax can hybridize with yellow toadflax. Both of these factors may have contributed to the lack of control. The outputs of the project contributed to an increase in scientific knowledge through two scientific presentations, and an increase in industry knowledge through two presentations to 210 audience members.

In 2010, Sarah Ward and Sharlene Sing at Colorado State University received funding for a project titled "Assessing long-term impacts of yellow toadflax invasion." They resurveyed 109 yellow toadflax- infested plots surveyed in 1999 and 2000. Yellow toadflax was still present in most plots.

In 2012, Fabian Menalled at Montana State University received funding for a project titled "Optimizing the efficacy of downy brome (*Bromus tectorum*) biocontrol in crops and rangelands: Integration and implementation." Menalled determined that the seed rot fungus, *Pyrenophora semeniperda*, reduces downy brome and non-target grass seed germination and emergence. The outputs of the project contributed to an increase in scientific knowledge through one scientific article and three scientific presentations. The outputs contributed to an increase in industry knowledge through 12 presentations to 500 audience members.

In 2010, Jodie Holt at University of California Riverside received funding for a project titled "Integrated approaches for management of giant reed and restoration of riparian habitats." Holt determined that active restoration of giant-reed-infested sites required early dense native cover sufficient to produce extreme shade (less than 5% light) that would suppress giant reed growth. Results have also demonstrated that mulefat (*Baccharis salicifolia*), a native riparian shrub, is an excellent competitor with giant reed that can rapidly form a dense canopy to shade out giant reed propagules. Results from this research are informing decisions about best management practices for giant reed control and revegetation of riparian sites in order to promote healthy, diverse, sustainable native riparian communities and restore natural ecosystem function. For example, one consideration for land managers who do not have funding for whole-site active restoration is to replant small patches, or islands, of native woody species randomly throughout the landscape, which create native propagule sources, reduce native recruitment distance, and increase the rate of native establishment.

In 2012, Adam Lambert at University of California Santa Barbara received funding for a project titled "Evaluating the efficacy and impacts of *Teramesa romona*, a wasp introduced for biological control of *Arundo donax* (giant reed)." Lambert determined that the wasps are not sufficient to control giant reed. The outputs of the project contributed to an increase in scientific knowledge through one scientific article and three scientific presentations. The outputs contributed to an increase in stakeholder knowledge through three presentations to industry and public workshops.

In 2011, Jane Mangold at Montana State University received funding for a project titled "Developing a statewide invasive plant early detection and rapid response (EDRR) program: the foundation of effective integrated pest mgmt." Mangold utilized the already-existing INVADERS database and EDDMapS (Early Detection and Distribution Mapping System) online system as platforms for volunteers to report weed occurrences. During the course of 21 workshops, she trained 436 people to identify invasive weeds and upload reports to INVADERS database or EDDMapS. The outputs contributed to an increase in industry knowledge through two extension publications. The medium-term impact is a change in stakeholder behavior. From October 2012 to April 2014, 400 new invasive reports were submitted to INVADERS or EDDMapS from people trained by this project.

In 2004, Monica Pokorny at Montana State University received funding for a project titled "Restoration Case Study Information Delivery System." Pokorny developed 118 case studies of on-the-ground projects to add to the restoration database at the Center for Invasive Plant Management. The outputs contributed to an increase in industry knowledge through 30 industry presentations.

In 2011, Carolynn Culver at University of California-Santa Barbara received funding for a project titled "Minimizing impacts to urban, agricultural and natural water systems: Evaluating biocontrol agents for invasive Eurasian mussels." Culver determined that bluegill sunfish can greatly reduce quagga mussel infestations by feeding on both larval and small juvenile quagga mussels. She also found that redear sunfish could reduce mussel infestations, albeit not as effectively as bluegill,

by consuming juvenile and adult mussels. The biocontrol fish can be contained in areas where mussels are abundant to enhance their feeding on the mussels and reduce concentrations of mussels in areas where the fish normally do not feed. Also, if used in combination, they could help reduce already attached (settled) mussels, in addition to those getting ready to or just settling. The outputs of the project contributed to an increase in scientific knowledge through two scientific presentations. The information continues to be provided to water managers in the West, with evaluations of its potential use in water bodies ongoing. The project will continue to increase scientific knowledge through its publication as a Sea Grant fact sheet and more broadly as a chapter in a book on the use of IPM for aquatic invasive species.

Animal Agriculture IPM Projects

In 2004, Bradley Mullens at University of California Riverside received funding for a project titled "Cultural control of poultry ectoparasites." Mullens determined that hens of docile chicken varieties housed at lower cage density can control ectoparasites without pesticides if their beaks are not trimmed. The ectoparasites examined in the project were Northern fowl mite, chicken body louse and chicken mite. In 2006, Mullens received funding for a project entitled "Economic analysis of host-based poultry ectoparasite control." Mullens documented the economic benefits of untrimmed beaks in a docile variety of egg laying chicken hens in terms of feed conversion and pest damage. The outputs of the project contributed to an increase in scientific knowledge through four scientific articles and two scientific presentations. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 13 times. The medium-term impact is a change in organic egg producer behavior. Allowing docile hen varieties without trimmed beaks to manage body mite and louse infestations through self-grooming has been adopted by some organic egg producers. In addition, there is renewed interest in the ability of hens to manage ectoparasites due to the potential to integrate this tactic with the new, less drastic, precision laser trimming which removes less of the beak.

Community IPM Projects

In 2006, Patricia Stock and Dawn Gouge at University of Arizona received funding for a project titled "Assessment and implementation of native insecticidal nematodes: An alternative for control of urban pests." They determined the effects of typical Arizona environmental conditions (high temperatures, low relative humidity and high solar radiation) on the viability of entomopathogenic nematodes and their efficacy in controlling urban insect pests. The outputs of the project contributed to an increase in scientific knowledge through two scientific articles and three scientific presentations. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 15 times. The outputs of the project contributed to an increase in community knowledge through eight urban presentations to 600 audience members.

In 2009, Robert Peterson and David Weaver at Montana State University received funding for a project titled "Improving IPM of mosquitoes by addressing scientific uncertainty and public concerns." They experimentally derived actual environmental concentrations of ultra-low volume mosquito adulticides in California, Montana, and Louisiana over three years and developed MULV-Disp 1.0: A Spreadsheet Program for Predicting Concentrations of Insecticides Sprayed from Ground-Based Ultra-Low-Volume Equipment used for Management of Adult Mosquitoes. The spreadsheet is available for free download at http://landresources.montana.edu/wnv/. The outputs of the project contributed to an increase in scientific knowledge through nine scientific articles and to an increase in end-user knowledge through 17 presentations. The scientific articles from this project have been cited by subsequent peer-reviewed scientific articles 32 times. The medium-term impact is a stakeholder suggestion that EPA adopt the model. The American Mosquito Control Association in a public comment to the U.S. EPA regarding the Biological Opinion issued by the National Marine Fisheries Service mentioned the mosquito adulticide dispersal model. In the comment, the American Mosquito Control Association suggested that EPA use MULV-Disp model when estimating environmental exposures to mosquito insecticides applied via ground ultra-low-volume equipment.

Impacts of the Regional Integrated Pest Management Competitive Grants Program in the Western United States

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