BUILDING RESILIENCE OF NORTHWEST TREE FRUIT TO CHANGING PEST PRESSURES UNDER CLIMATE CHANGE

Submitted in response to

Funding Opportunity Notice-Fiscal Year 2017
U.S. Department of Agriculture-Northwest Climate Hub

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Project Title:

Building resilience of Northwest tree fruit to changing pest pressures under climate change.

Lead Agency:

Center for Sustaining Agriculture and Natural Resources (CSANR), Washington State University

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Partnerships:

- WSU-Tree Fruit Research & Extension Center (TFREC), Washington State University
- Center for Interdisciplinary Statistical Research and Education (CISER), Washington State University
- WSU-Decision Aid System for Tree Fruits (DAS), Washington State University
- Department of Civil Engineering (CE), Washington State University

Additional Investigators:

- Vince Jones, TFREC and DAS, Washington State University
- Ute Chambers, TFREC and DAS, Washington State University
- Todd Coffey, CISER, Washington State University
- Mingliang Liu, CE, Washington State University
- Sonia A. Hall, CSANR, Washington State University
- Georgine Yorgey, CSANR, Washington State University
- Chad Kruger, CSANR, Washington State University

We are an interdisciplinary group of investigators with expertise and prior experience in decision support for agriculture (Jones, Chambers, Rajagopalan), modeling (Jones, Liu, Rajagopalan), integrated pest management (Jones, Chambers), statistical analysis (Coffey), and stakeholder engagement (Hall, Kruger, Yorgey) in the Northwest U.S.

Collaborative Partnerships:

We are creating an advisory group of stakeholders for the project, and will be collaborating with them throughout the project. The advisory group is representative of tree-fruit producers, integrated pest management consultants, industry leaders, and extension leaders. We have ongoing relationships with these stakeholders as part of other projects, and this project provides an additional cycle of collaborative work in those relationships. Individuals who have agreed to be advisory group members include:

- Mike Willett, Manager of the Washington Tree Fruit Research Commission (WTFRC). One of the primary missions of WTFRC is to solve problems faced by the tree fruit industry. The Commission is comprised of active tree-fruit growers or those who have a substantial interest in the industry. **Support letter attached. [Tree-Fruit Industry Leader]**
- Nicholas H Stephens, President of Columbia IPM Inc. Columbia IMP provides integrated pest management advising for the tree fruit industry, and Mr. Stephens is an agricultural consultant who advises producers and is a current user of the WSU-Decision Aid System for Tree Fruit (DAS). **Support letter attached. [Tree-Fruit Integrated Pest Management Consultant]**
- Jim McFerson, Director of WSU-Tree Fruit Research and Extension Center, previously Manager of the WTFRC. **Support letter attached. [Tree-Fruit Extension Leader]**
- Mike Robinson, General Manager of Double Diamond Fruit in Quincy, WA. He is also the owner of BMR Orchards LLC, in Quincy, WA. These companies have apple, cherry and apricot orchards. **Support letter attached. [Tree-Fruit Producer]**

We have identified one additional tree-fruit producer, based on our ongoing relationships. Although we do not have a signed support letter, we received a verbal confirmation to be part of the advisory board.

- Bill Warren, Manager of Warren Orchards in Dayton, WA. Warren Orchards in Columbia County is a 100-acre farm growing several varieties of apples and pears. **Verbal agreement received. [Tree-Fruit Producer]**

Project Objective:

Codling moth is a primary pest of several tree fruits that makes the fruit unmarketable. Climate change can significantly alter this pest's lifecycle, resulting in pest management implications. Given that the pest currently occurs—and is managed—under a wide range of climatic conditions across the continental U.S., a rich body of location and climate-specific management knowledge already exists. ***Our objective is to tap into this existing historical context through the concept of spatial analogs, and gain insights into potential codling moth pest-management adaptations in the Northwest U.S. under climate change. We also aim to communicate the results in a way that leads to increased use of the information, ultimately contributing to enhanced resilience of the Northwest tree-fruit industry to changing pest pressures.***

Pest management adaptations under a changing climate directly target the Hub's funding objective. The focus on a high-priority pest (codling moth) for specialty crops (tree fruit) directly addresses priorities 1 and 2 of this funding opportunity. This proposal was informed by conversations between CSANR, TFREC and our stakeholders, and we will partner with them to create useful and usable products and tools. This is therefore a science-driven, and stakeholder-centered proposal, meeting the criteria of Hub-eligible activities.

Project Description:

Tree fruit (apples, pear and cherries) are a primary contributor to the Northwest economy (USDA NASS, 2015), with the apple industry alone contributing an estimated $7.5 billion/year in Washington State (Globalwise Inc., 2014). One of the primary pests affecting tree fruit production is the codling moth (Barnes, 1991; Alford, 2007) as its feeding makes the fruit unmarketable. Consumers have a low tolerance to cosmetically imperfect fruit, making management of this pest key to a viable and successful regional tree-fruit industry. Without management, damage can lead to fruit loss in excess of 90%. Management includes integrated chemical, biological and cultural controls, and there are multiple interventions in a given season. Timing and type of interventions are both key to efficiently and sustainably managing this pest.

Given that insect occurrence and growth are primarily temperature driven (Wagner et al., 1984), future warming is expected to affect their physiology, phenology, and spatial distribution (Hughes, 2000), increase codling moth pest pressures on tree fruit (Stoeckli et al., 2012), and require adaptations to current pest management strategies. These adaptations will be key to a tree fruit industry that is resilient to changing pest pressures. Increased future pest pressures could necessitate increased chemical control (in terms of number of interventions and range of chemicals used). This can potentially increase overall pest management costs, which then make alternate sustainable management options (with higher initial investment dollars) more economically viable. Therefore, although we expect increased pest pressures in a warmer future climate, there is opportunity to explore management solutions for the Northwest tree-fruit industry that provide incentives for sustainable, cost-effective, integrated pest management strategies.

Codling moth currently occurs under a wide range of climatic conditions all over the continental U.S., with associated regional differences in the codling moth life cycle (Jones et al., 2013; Chappel et al., 2015), and these differences translate to practically important differences in pest management. This includes the type, timing and overall cost of effective interventions. In addition, different tree-fruit species and within-species varieties show varying susceptibility to infestation (Davis et al., 2013; Joshi et al., 2015). Therefore, a rich body of location-specific knowledge already exists, and we can mine it to

inform pest management strategies best suited for specific climatic conditions. Codling moth growing conditions and phenology characteristics under a warmer Northwest future climate may already exist within historical conditions in other parts of the U.S (analog locations), especially along the West Coast's north-south temperature gradient. **The first objective of the proposed work is to draw on these historical regional pest-management differences to inform codling moth management strategies in the Northwest U.S. under a warmer future climate, and thereby build resilience of the Northwest tree-fruit industry to changing pest pressures.** Given that the majority of Northwest tree-fruit production is in Washington state, the main focus of our efforts will be Washington state. We will however include preliminary work in tree-fruit growing regions of Oregon and Idaho, and include these states in our outreach efforts.

As a second objective, we will explore potentially impactful approaches to climate change extension in the Northwest. Climate change extension for agriculture faces challenges of skepticism (Prokopy et al. 2015), and reluctance or inability of users to include this information in decision making (Wilke and Morton, 2016). Traditionally, climate impacts have been presented as expected changes on biophysical factors. This has not led to increased utility of the information in decision making (Palmer, 2012), and we need to rethink extension strategies to ensure our products provide actionable information that gets used. This project has components designed to address some of these extension challenges, including:

- *An approach that emphasizes viewing climate-risk through a lens of historical experiences in analog regions, and using these experiences to chart realistic courses of action* (Dilling and Lemos, 2011). Recent research has indicated that communicating future climate-change risk with a historical context has potential to vastly improve the perceived usefulness of the information (Matthews et al. 2016; Wilke and Morton, 2016), and increase use of products. This is consistent with our experience in the Northwest, where analog-based visualizations have been perceived as impactful by stakeholders.
- *Introduction of climate change information through decision-support tools already in use* (Lemos et al., 2012) *by our intended user-group*. By leveraging and piggybacking on the WSU-Tree Fruit Decision Aid System—which is used for Integrated Pest Management in over 90% of Washington tree-fruit acres (DAS Survey, 2013)—we hope to increase the likelihood of continued use of the project's products.
- *An iterative, two-way communication process with a group of advisors* with whom we have ongoing trust-based working relationships, allowing us to strive for co-production of knowledge (Lemos et al., 2012; Beier et al., 2016).

The two objectives outlined above will be achieved through three specific aims, leveraging existing work.

Specific Aims

Aim 1: Extend current work characterizing climate change impacts on the codling moth life cycle in Washington State to the continental U.S.

The WSU-Tree Fruit Decision Aid System (DAS) (Jones et al., 2010; Chambers, Petit, and Jones, 2011) provides science-based tools that disseminate information for managing tree fruit in Washington State. These include degree-day based phenology models (Brunner and Hoyt, 1982; Beers and Brunner, 1992) that are used to provide recommendations for timing of codling moth pest management interventions based on short-term temperature forecasts. With previous Climate Hub support, we drove these phenology models with historical meteorological observations and future climate projections in tree-fruit growing areas of Washington State. This helped characterize the impacts of future climate on the

codling moth's life cycle and phenological events, which indicated increased pest pressures, earlier emergence, longer season of pest impacts, higher number of pest generations per year, higher probability of overwintering, and other changes.

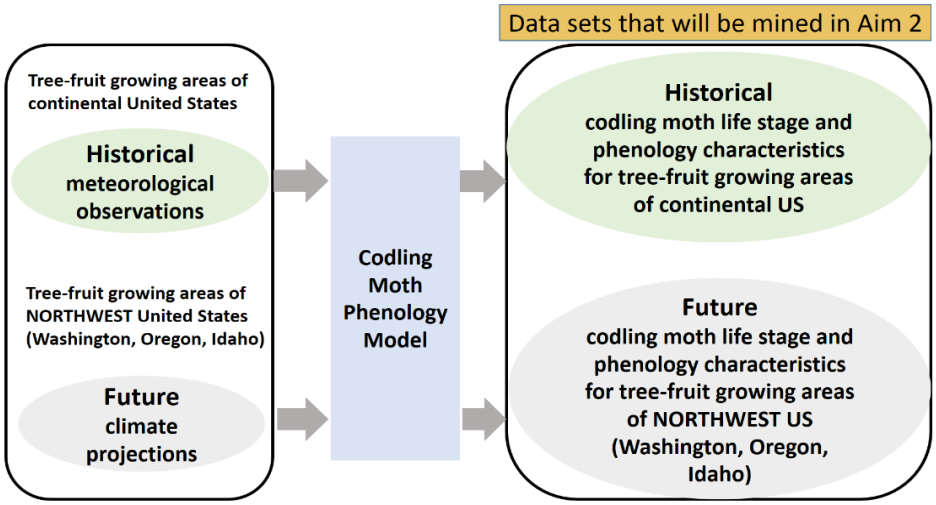

Figure 1: Schematic representation of Aim 1, with inputs to the phenology model and output datasets that will be used to achieve Aim 2.

We will extend this model framework to the tree-fruit growing areas across the continental U.S. (based on USDA CDL, 2017), characterizing codling-moth growing conditions and phenology characteristics for a wide range of historical climatic conditions (see Abatzoglou, 2011 for details of the gridded historical meteorological observations at 4-km resolution from 1979 to present). Future-climate based characterization will be extended to include Oregon and Idaho in addition to Washington State (Figure 1). Future climate projections are modified Multivariate Adaptive Constructed Analog (MACA) based (Abatzoglou and Brown, 2012), downscaled global climate model (GCM) data from the Coupled Model Intercomparison Project 5 (CMIP 5, Taylor et al., 2012). This data is available at a 4-km resolution and projected to 2100 for multiple GCMs and two concentration pathways.

Aim 2: Explore analogs for future projections of codling moth growth and phenology characteristics in the Northwest (Washington, Oregon and Idaho). Identify potential pest management adaptation needs, focusing on Washington State.

Analogs (CGIAR, 2011; Matthews et al. 2016; Wilke and Morton, 2016) provide an approach to building resilience to climate change by mining existing historical experiences under a wide range of conditions. Analogs are historical timeframes or locations that closely match a future projection for our location of interest. Knowing that the projected future manifestation of the codling moth in a Northwest sub region is similar to the current manifestation in a different part of the continental U.S. has a two-fold advantage:

- It allows stakeholders to immediately relate to the impacts as real experiences of peers, which creates a higher likelihood of perceived utility and use (Matthews et al. 2016; Wilke and Morton, 2016).
- It identifies the right network of locations that can benefit from information related to best practices for managing the pest.

We will use the Mahalanobis statistical distance measure (De Maesschalck et al., 2000) or the propensity scoring methodology (Caliendo et al., 2008) for codling moth growth and phenology analog identification and determine what (if any) regions of the continental U.S. we can learn from, to build resilience of the Northwest tree-fruit industry to changing codling moth pressures under climate change. This task will include tree-fruit growing areas of Washington, Oregon and Idaho.

This similarity between current manifestations in different areas of the U.S. and future manifestations expected for the Northwest, along with input from stakeholders (see Aim 3 below) will inform location-specific potential pest management adaptations, such as timing, type, cost and sustainability of interventions. We will describe these potential adaptations. The primary focus area for this task will be Washington State, in order to narrow the project scope.

Aim 3: Stakeholder engagement and climate change extension and outreach

Figure 2: Schematic for stakeholder engagement and climate change extension and outreach.

We will engage with stakeholders to ensure products are useful, accessible, and have an increased likelihood of ongoing use. A collaborative partnership will be formed with our advisory group of stakeholders, many of whom have partnered in previous efforts that provided the basis for this proposal. The advisory group is representative of tree-fruit producers, integrated pest management consultants, industry leaders and extension leaders (see **Collaborative Partnerships** above for details). In the final stages of the project, we will extend interactions to the broader Northwest tree-fruit industry (Figure 2).

Stakeholder engagement in co-production

We will ask the advisory group for (a) input on how to make our science-based products and visualizations most useful for informing their decisions, (b) guidance on broadening awareness and use of products, and (c) input on translation of spatial analog information to potential changes to pest management strategies under climate change. Interactions with the advisory group will occur on an ongoing basis, both informally and through meetings.

We will have three formal meetings—early stage, mid stage, and late stage of project—with the advisory group. Likely approaches are half-day workshops (two planned) or individual interviews. The early-stage meeting will help us better understand factors affecting their pest management decisions, how they fit within proposed products, and establish shared expectations for process and products. The mid-stage meeting will be geared towards feedback on preliminary results and products, pest management adaptation needs, and ideas for useful, usable, and impactful visualization and communication to the broader tree fruit industry. The late-stage meeting will focus on feedback on the final products and associated training materials, how they can be improved, and identifying extension and outreach needs. It will also be an opportunity for us to understand the benefits and challenges of communicating climate risk and adaption needs through an analog approach. Lastly, it is an opportunity for us to get an understanding of additional needs in terms of science-based products, training materials, and extension approaches, which will inform future efforts.

In addition to the three formal meetings, we will have regular ongoing interactions throughout the project timeline though phone calls and email exchanges.

Climate change extension and outreach

The products will be made available as part of two existing online tools—CSANR's Climate Visualization Tool for Ag (that was partly funded by the Northwest Climate Hub), and the WSU-Tree Fruit Decision Aid System (DAS). Screen shots of these tools are provided in the product mock-ups section. Given that DAS is extensively used by the Washington tree-fruit industry for current-year pest management decisions, piggybacking on it will help us reach the target audience and improve the likelihood of these climate-change related products being used on an ongoing basis. Providing access through CSANR's Climate Visualization Tool for Ag will provide free access to the tool for producers who are not currently subscribers to DAS, including producers in Oregon and Idaho, and small-acreage producers.

The product will be shared with the Northwest tree-fruit industry through a multi-media approach, including:

- A webinar, or video training material, that accompanies the product.
- Short layperson articles describing results and products. WSU Decision Aid System's News (https://www.decisionaid.systems/), the WSU tree fruit web site (http://treefruit.wsu.edu/), and Good Fruit Grower (www.goodfruit.com), are potential outlets targeting the regional tree-fruit industry. Agclimate.net or CSANR's blog Perspectives on Sustainability are additional venues for these articles.
- Presentations at relevant regional and local grower meetings, such as the Washington State Tree Fruit Association Annual Meeting, Pear and Apple Day, or various extension meetings throughout the state.
- Information will be shared through the WSU Irrigated Ag Extension Team's email notification system, and list-serves for the tree-fruit industry.

We will work with the Climate Learning Network and the Northwest Climate Hub to develop, present and archive a webinar sharing the results of this project. Webinars are a cost-effective and efficient process for this (Allred and Smallidge 2010; Yorgey et al. 2013). Finally, we will also share our results with the scientific community more broadly, submitting the results for publication in an open-source, peer-reviewed journal.

Project Expected Outcomes

The products and training materials developed, stakeholder engagement, and outreach though the extensively used WSU-Tree Fruit Decision Aid System, are expected to result in the following outcomes:

For the Northwest Tree-Fruit Industry

- *Improved understanding of implications of climate change on codling moth pest management, and potential adaptation needs and solutions. Greater awareness of the products and a higher likelihood of product use.*
- *Climate change implications uncovered in this study can help the Washington State Tree Fruit Research Commission plan for future research needs for the industry.*
- *An approach generalizable to other pest management challenges associated with climate change. Lessons learned from this codling-moth based case study, can inform broader pest management issues.*
- *Enhanced resilience of the Northwest tree-fruit industry to changing pest pressures.*

For This Project Team and Broader Climate Change Extension

- *Products and information with a higher likelihood of use.*

- *Increased awareness of the value and challenges in using spatial analogs in climate change extension, and insights on whether the approach leads to an improved perceived usefulness and use of products.*
- *Improved understanding of the decision-making context of end users, allowing us to be better positioned to shape future ideas for actionable science-based products for climate change extension. Strengthened relationships with stakeholders.*

Timeline:

The proposed timeline for this project is 18 months. The chart below describes the timing of the various tasks and project deliverables. This timeline assumes the project starts in the Fall semester of 2017, and may need adjusting depending on when funding becomes available.

<----------18 months---------->

Specific Aims	Tasks	Fall 17	Spring 18	Summer 18	Fall 18
AIM 1	Extend future-climate phenology model simulations to Idaho and Oregon				
	Extend historical phenology model simulations to continental US				
	Articulate pest-management implications for NW due to climate change				
	Process datasets as input for AIM 2				
AIM 2	Run simulations to identify analogs				
	Translate knowledge to relevant for pest-management adaptation needs				
	Release final product in WSU-DAS and CSANR's online tool				
AIM3: Co-production	Formal advisory group meetings/worshops				
	Informal interaction with advisory board				
AIM3: Extension and Outreach	Create and refine products/training material				
	Develop and refine articles, publications				
	Regional/local conferences/meetings presentations				
	Develop and deliver webinars				

Communication:

Aim 3 above describes the communication strategy with partners, including three formal meetings with the project's advisory group, with specific objectives for each. In addition, we will have informal interactions with the advisory group throughout the project, and the project team will have monthly conference calls that the advisory board will be invited to join as their time permits, and as discussion needs arise. At the advisory group's recommendation, we will also reach out to other partners as appropriate.

Resulting products and associated training materials will be available through two existing online tools, as described under Aim 3. One makes the product freely available to all stakeholders in Washington, Idaho, and Oregon, and the second is widely used for yearly pest-management decision making in Washington State, and allows us to directly reach the target audience. Outreach and awareness will be through a multi-media approach consisting of webinars, recorded powerpoints, lay-person articles, conference presentations, and communication via email list serves for the tree-fruit industry (see details under Aim 3, above).

Project Products:

We will create a product that lays out region-specific climate change related changes in Northwest codling-moth pest pressures, maps spatial analogs of pest pressures, describes implication for future pest management (in terms of timing, type and cost of interventions), and articulates adaptation possibilities. The visualization details of these maps and graphics will be finalized in coordination with the advisory group. The products will be made available as part of two existing online tools, described under Aim 3 above.

With input from our advisory group, we will also create a training webinar, recorded powerpoint, or video that complements and helps explain the products. Other supporting project products are listed below.

- Presentations at a minimum of two conferences/meetings pertaining to the tree-fruit industry
- Short online lay-person outreach articles in at least three avenues
- Webinar focusing on the Northwest tree-fruit industry
- One peer-reviewed, open-source publication submission

Product Mock-up:

Sub-region specific information that will be available in the product, include:

- Historical codling-moth pest pressures in the Northwest U.S.
- Expected changes to codling-moth pest pressures in the Northwest U.S. at different future time frames (eg. 2020s, 2040s, 2060s, 2080s)
- Potential codling moth pest-management implications of these changes
- Spatial analogs to future expected codling-moth pest pressures in the Northwest U.S.
- Pest-management adaption needs for the Northwest U.S. (focused on Washington State), and what we can learn from analog locations?
- Compilation of a list of potential useful resources from analog locations

The project's product will be made available in CSANR's Climate Visualization Tool for Agriculture (see Figures 3 and 4 for screen shots from the tool), and WSU's Tree Fruit Decision Aid System (see Figure 5 for a screen shot). Visualizations (maps and other graphics as appropriate), along with text will be provided for each section listed above. The visualizations will likely build on the look and feel of weather-based visualizations that the WSU-DAS user-base is familiar with, but with a climate change context. The look and feel of graphics will finalized based on interactions with stakeholders.

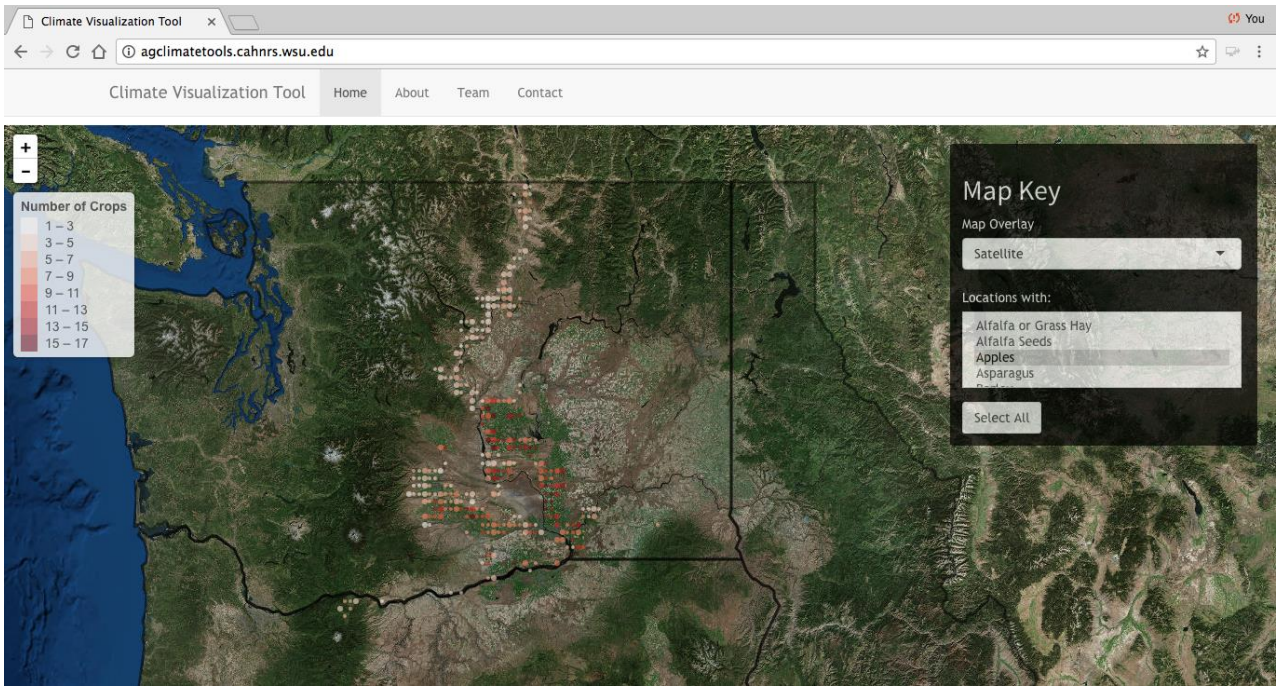

Figure 3: Map interface of CSANR's Climate Visualization Tool for Agriculture (partly funded by the NW Climate HUB). The user can select a location of interest, which pulls up a list of crops that grow in the location. The user can then select the crop of interest and go to crop-specific visualization tabs.

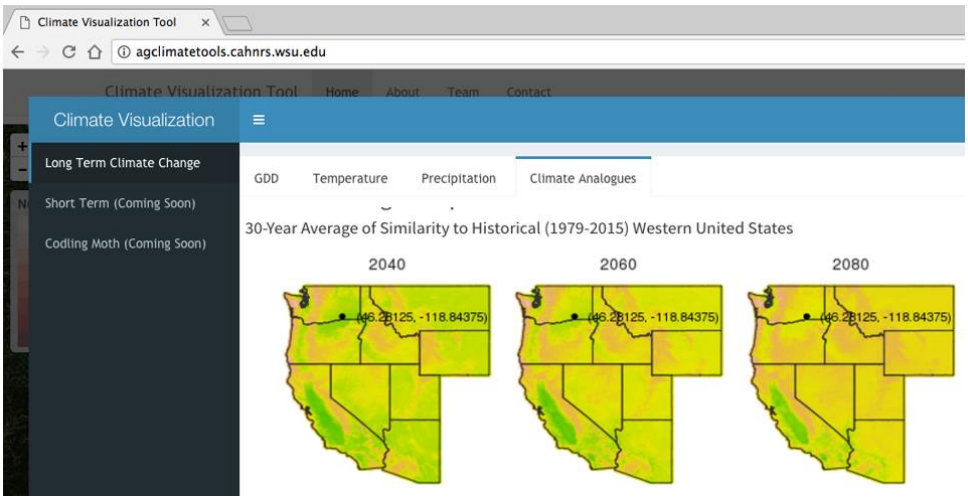

Figure 4: This figure shows the spatial analog tab in CSANR's Climate Visualization Tool for Agriculture. Locations with historical crop growing-conditions most similar (in green) to projected future growing conditions in the user's location of interest are shown (black dot). This image corresponds to spatial analogs calculated based on crop-relevant variables derived from temperature and precipitation - including growing degree days, cooling degree days, heat stress, growing season length, and seasonal precipitation patterns. For this proposed project, we will start with a similar process of analog identification and visualization - but for pest-pressure characteristics instead of crop growing-condition characteristics. Visualizations will be revised based on stakeholder input. Proposed project's product will be an additional tab on this website.

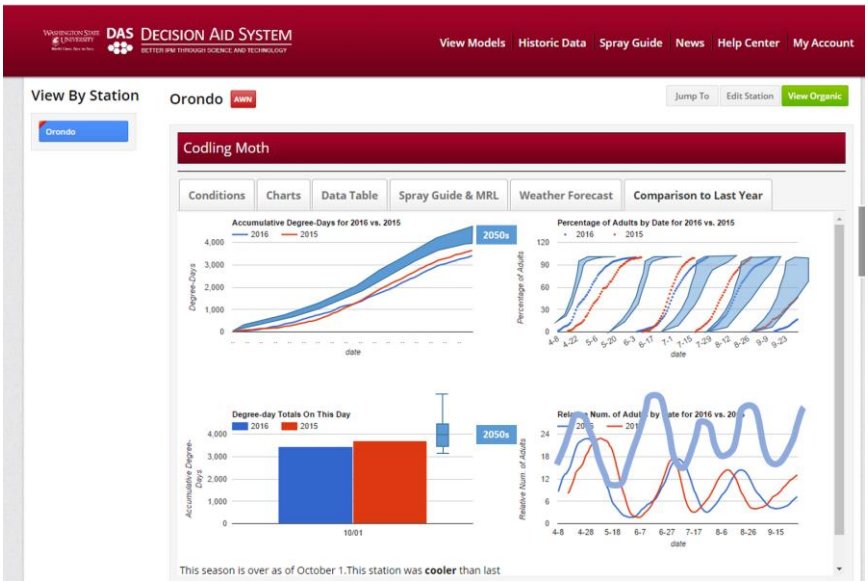

Figure 5: This is a screen shot from the WSU-DAS tool to aid current-year forecast based codling-moth integrated pest management. This image corresponds to the expected distribution of the adult moth population through the season, and shows a comparison of current year's expectation to the previous year. Visualizations of several other variables related to the Codling Moth's phenology and growth characteristics are available in this tool. We will add our project's product (with climate-change instead of current-year focus) to this website, so that it reaches the target audience.

Budget Form:

The project has an estimated total cost of $123,781 that includes a **WSU requested budget of $70,000 from the NW Hub**, WSU matching funds of $49,002, and a Forest Service budget of $4778 for the Northwest Climate Hub's participation in the project. The budget form is attached as an excel file separately. ***The WSU requested budget of $70,000 includes $64,124 in direct labor, $3426 in travel, $800 in equipment, and $150 in goods and services costs.***

State approved contract rates were considered where applicable, eg. overnight stay, per diem, and mileage. Analogy and recent past experience were used to estimate each direct cost work element. Recent travel and stakeholder meetings of similar nature are the basis for travel cost estimates. WSU's indirect rates (to estimate WSU matching funds) are based on the most current agreement dated 12/6/1015.

Budget Narrative:

NW Climate Hub's participation ($4778)

The Northwest Climate Hub will help to develop and produce a recorded webinar that will be made widely available through the Climate Learning Network. The eXtension Climate Learning Network is a powerful platform that connects professionals in the Land Grant University System and the USDA Climate Hubs. The Hub will also bring expertise on social outreach to help in planning meetings, workshops, and interview sessions with the project's advisory group. The Northwest Climate Hub will assist in disseminating the data and tools created by the project by helping to plan engagement at workshops, collaborating in the development of recorded and internet-available webinars, and providing information on the tools through existing Hub communications (periodic news briefs, internet links with the Hub website). This is particularly important for bringing the regional information from this project to the attention of stakeholders from across the US who are dealing with codling moth impacts on fruit trees.

WSU-Direct Labor ($64,124)

	Personnel	Responsibilities	TC (days)	Salary	Benefits
1	Kirti Rajagopalan (PI)	Kirti will oversee all aspects of the proposed work. She will lead Aims 1 and 2, and support Aim 3. She will coordinate inclusion of the product in CSANR's online tool.	86	$24,208	$7,650
2	Sonia Hall (Co-I)	Sonia will lead Aim 3, and coordinate stakeholder engagement and outreach.	28	$7,026	$3,611
3	Vince Jones (Co-I)	Vince is the Entomologist. He will support Kirti in interpreting and translating results for pest-management implications, and adaptation needs.	14** (6)	$3,507	$901
4	Chad Kruger (Co-I)	Chad will support Aim 3, through his industry connections, and vast stakeholder engagement and outreach experience.	9** (1)	$575	$136
5	Ute Chambers (Co-I)	Ute will help coordinate with WSU-DAS.	6	$1,718	$551

6	Mingliang Liu (Co-I)	Mingliang will support Aim 1's data processing needs.	19	$4,185	$1,339
7	Todd Coffey (Co-I)	Todd will support Kirti in the statistics piece of Aim 2.	19	$5,934	$1,739
8	Georgine Yorgey (Co-I)	Georgine will support Aim 3, through her stakeholder engagement and outreach experience.	3	$764	$283
	TOTALS			**$47,915**	**$16,209**

**Vince Jones and Chad Kruger have time commitments with funding requests, as well as time commitments provided as a WSU match. The number of days in parenthesis is the time commitment for which funds are requested, and the salary and benefit number in this table correspond to that. For example, Vince Jones commits a total of 14 days of work to this project, of which funds are requested for 6.

WSU-Travel ($3426)

These costs relate to the stakeholder engagement and outreach components (AIM 3 of the proposal).

- Travel to one half-day workshop is budgeted at $1574. Workshop cost of $1574 includes
  - $1121 as mileage calculations of $.575 per mile for a 395 mile round trip for 5 people (although we expect 13 attendees, some will be local), and
  - $453 as $51 per day per diem, and one night hotel stay at the state contracted rate of $89 plus taxes ($100 approx) for 3 people (most of the expected 13 attendees should be be close enough to make a day trip, and not require overnight stay)
  - The workshops will likely be at Pullman, WA or Wenatchee, WA.

- Travel to two conferences/meetings for one person is budgeted for $1852 @ $926 per conference/meeting. The per conference cost of $926 includes
  - $224 as mileage calculations of $.575 per mile for a 395 mile round trip for one person
  - $352 as two days of $51 per day per diem, and two nights of hotel stay at the state contracted rate of $89 plus taxes ($100 approx) per night for one person
  - registration costs of $400 (based on recent charges for meetings in the area)
  - conference options we are considering include the WA State Tree Fruit Association (Nov/December at Kennewick), or the Pest and Orchard Disease Management Conference (January at Portland). The first is grower focused and the second pest management consultant focused.

WSU- Goods/Services and Supplies ($150)

These costs relate to the stakeholder engagement and outreach components (AIM 3 of the proposal)

- This includes poster printing costs of $150 for conferences/workshops

WSU-Equipment ($800)

These costs relate to the high performance computing resource needs associated with AIMS 1 and 2 of the proposal.

- Cost of $800 is requested for buying time allocation and storage on the high-performance computing cluster in the Civil Engineering department. This is for use specific to this project.

WSU -Other expenses ($1500)

- Open source journal publication cost estimated at $1500, based on current rates for PloS one.

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Letter(s) of Support from Stakeholders:

Three letters of support are attached.

Columbia IPM, Inc.
2452 NW Columbia Ave. #10
East Wenatchee, WA. 98802

Dr. Kirti Rajagopalan
Center for Sustaining Agriculture and Natural Resources
Washington State University

February 22, 2017

Dear Dr. Rajagopalan,

I would like to show my support of your project, "Building resilience of Northwest tree fruit to changing pest pressures under climate change." Codling moth management has been a priority concern for most managers and IPM consultants for the past 50+ years. The long-standing problem of codling moth management is a result of a complex interaction of its biological interactions with the host plants and the complex interaction of the temperature-driven population growth. Any tools that can help conceptualize and visualize the risks and how they might change or be mitigated in the future would be a big help to the industry in general and to IPM practitioners such as myself in particular.

I particularly like the approach that your group is taking, because it doesn't just point out potential problems that might occur, but also shows that we may be able to understand how to deal with the problems by focusing on tree fruit growers in warmer climatic areas and how they are dealing with problems that we will likely face in the future. In addition, I appreciate your efforts to involve those of us already using decision-support tools like WSU's Decision Aid Systems from the inception of the project. Your openness to advice will improve my understanding of the products and how I can use them as I make pest management decisions.

I am interested in being part of this project's advisory group. I will participate through informal conversations, conference calls, or workshops, to provide the input to the research team on (a) decisions that would benefit from an understanding of codling moth dynamics and impacts under future climate, (b) how to make the products and visualizations most useful for informing those decisions, and (c) how to broaden awareness of these products and tools.

I recognize that my collaboration in this effort does not provide, include, nor request any grant funding for myself or for my organization.

Sincerely,

Nicholas H Stephens

President

Columbia IPM, Inc.

Dr. Kirti Rajagopalan
Center for Sustaining Agriculture and Natural Resources
Washington State University

February 21, 2017

Dear Dr. Rajagopalan,

I would like to share my support of your proposed project, "Building resilience of Northwest tree fruit to changing pest pressures under climate change." Managing codling moth and its impact on tree fruit production and marketability is an ongoing priority concern for the Washington Tree Fruit Research Commission and our industry. Such management occurs in the context of many other risks, including biological factors, climatic and weather-related factors, and market factors. Research and tools that help visualize how these risks may change in the future are valuable to our industry, especially when accompanied with how to most efficiently and effectively address those changes.

Your proposed approach would not only allow producers to understand what changes in codling moth dynamics may occur over the next few decades, but would also identify where we might look for tree fruit producers who are currently facing similar situations, thereby providing guidance on pest management strategies that might effectively address emerging codling moth management challenges. In addition, I appreciate your efforts to involve our organization from the inception of the project, and your openness to advice from the Commission, which is composed of active fruit growers, or others who have a substantial interest in the production of tree fruit.

The Washington Tree Fruit Research Commission is interested and willing to work with this project's advisory group to ensure that industry input is available to the research team on (a) decisions that would benefit from an understanding of codling moth dynamics and impacts under future climate, (b) how to make the products and visualizations most useful for informing those decisions, and (c) how to broaden awareness of these products and tools.

I recognize that my collaboration in this effort does not provide, include, nor does it envision any funding for myself or for my organization from the proposed project.

Sincerely,

Mike Willett
Manager, Washington Tree Fruit Research Commission

WASHINGTON STATE UNIVERSITY
World Class. Face to Face.

Wenatchee Tree Fruit Research and Extension Center

28 Feb 2017

Kirti Rajagopalan
Center for Sustaining Agriculture and Natural Resources
Washington State University
Pullman WA 99164

Dear Kirti:

I appreciate the opportunity to represent and actively involve the WSU Wenatchee Research and Extension Center in your proposal: "Building resilience of Northwest tree fruit to changing pest pressures under climate change." Work by our researchers and extension professionals over the past decades has contributed considerably to the management programs that provide our growers with effective and sustainable options to control codling moth, our key pest for apple. I believe this proposal is far-sighted and a necessary effort to address the threat posed by climate change, which will challenge all the pest management strategies we have developed and the industry has implemented. I am glad the Climate Hub is sponsoring such a program.

I am willing to commit the necessary time to be an active participant in your advisory panel member and provide my input on proposal objectives, activities, metrics and deliverables. I am also willing to contribute to the critical extension activities you outline in the proposal without any expectation for funding from the proposed project.

Thank you again for your outreach and best of luck with this proposal.

Sincerely,

James R. McFerson

James R McFerson
Director - WSU Research & Extension Center
Professor of Horticulture

1100 North Western Avenue, Wenatchee, WA 98801
509-663-8181 • Fax 509-662-8714

BMR Orchards LLC
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509-797-5969

Dr. Kirti Rajagopalan
Center for Sustaining Agriculture and Natural Resources
Washington State University

March 1, 2017

Dear Dr. Rajagopalan,

I would like to show my support of your project, "Building resilience of Northwest tree fruit to changing pest pressures under climate change." From my perspective as a grower in North-Central Washington, codling moth management is perennially one of the most important issues faced by the industry. While WSU's Decision Aid System has helped mitigate the problems by clearly providing management recommendations based on models and real-time weather and forecast data, we are always looking for ways to help reduce the risks both now and in the future.

The idea of using climate analogs to help explain potential changes in codling moth phenology and management is very appealing as it builds on the knowledge we have currently as well as knowledge from areas that currently face the problems we might face at different times in the future. Working with the WSU-Decision Aids System is an excellent way to make sure your research and extension efforts reach the industry decision makers and give the best use of the grant funding. As with that system, being able to provide advice on the design and implementation of the products will help our management programs improve and be used by industry.

I am interested in being part of this project's advisory group. I will participate through informal conversations, conference calls, or workshops, to provide the input to the research team on (a) decisions that would benefit from an understanding of codling moth dynamics and impacts under future climate, (b) how to make the products and visualizations most useful for informing those decisions, and (c) how to broaden awareness of these products and tools.

I recognize that my collaboration in this effort does not provide, include, nor request any grant funding for myself or for my organization.

Sincerely,

Mike Robinson

Mike Robinson
BMR Orchards LLC

Data Management Plan:

The data generated as part of this project will be archived. Products will be available as part of two existing online tools – CSANR's Climate Visualization Tool for Agriculture, and WSU- Tree Fruit Decision Aid System (DAS). Although DAS allows us to reach the target audience efficiently, access to DAS is available only as paid subscriptions. Also, DAS's geographical scope is restricted to Washington State. Hosting the product on CSANR's Climate Visualization Tool addresses these issues by providing free access to all, access to audience in Idaho and Oregon, and there are no data access or sharing restrictions.

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