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Photo by Steve Garrity

6th Annual Northwest Climate Conference

3 – 5 November 2015 | Coeur d'Alene, Idaho

Conference Abstracts

*Abstracts are organized by session then listed in order of presentation as found in the conference program. *Denotes presenter.*

Plenary Sessions

Water Year 2015: A prototype year for the future climate of the Northwest?

Causes and Effects of the Recent Warming in the NE Pacific

Nicholas Bond, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington

Strongly positive sea surface temperature (SST) anomalies have prevailed in the NE Pacific Ocean since 2013. The causes and effects of these anomalies, sometimes referred to as the "blob", are summarized. Anomalous air-sea interactions associated with a strong and persistent ridge of higher than normal sea-level pressure (SLP) resulted in reduced seasonal cooling of the upper ocean (Bond et al. 2015) during the winter of 2013-14. The ridge itself, at least in part, appears to have been part of a large-scale remote response to conditions in the far western tropical Pacific. Warm SSTs in the latter region, and the enhanced deep convection, has been implicated in as standing-wave pattern in the atmosphere from the tropics to higher latitudes in a manner similar to that associated with ENSO, but with roots farther west (Seager et al. 2014; Hartmann 2015). This connection is indicated both in the observations and numerical model experiments. The pattern of anomalous SST in the NE Pacific has evolved during the past year. These changes are due to transports associated with the mean ocean circulation and the weather during the past year, which during the winter of 2014-15 featured lower than normal SLP over virtually the entire NE Pacific. As of early summer 2015, a wide strip of relatively warm water is present along the entire west coast of North America (Fig. 1), in a pattern projecting on the positive phase of the Pacific Decadal Oscillation (PDO). The warm ocean temperatures have had major and wide-ranging impacts on the marine ecosystem. It will be interesting to see how the recent event plays out in terms of both the physics and biology.

Water Year 2015: Summary of climate, hydrology and snowpack observations

Ron Abramovich, USDA Natural Resources Conservation Service Snow Survey

Water year 2015 was very unique in terms of climate variability in Idaho and the Pacific Northwest. We'll discuss fall precipitation, the November arctic cold spell and how Christmas brought the best powder skiing conditions for the year. Development of the 'Snow Drought' and impacts from two Atmospheric River events that produced early runoff before the typical snowmelt runoff forecast period even started. A dry and warm March and April closed ski areas early and produced record high early irrigation demand. May's rains provided some relief for southern Idaho irrigators. Record high June temperatures gave way to more reasonable July temperatures as the summer fire season grew in intensity. After the past unique year and several since 2011, everyone is looking and wondering what the winter of 2016 will bring to the Pacific Northwest.

Mote Abstract

Philip Mote, Oregon Climate Change Research Institute

In a year when the Northwest has been plagued by terrible snowpack, drought, low river flows, and forest fires, some have said that this is "the new normal". Indeed, some aspects of this year's climate resemble what climate models foretell for the future - but how far in the future? Other aspects of this year's climate are different from the "new normal". And although the picture is gradually becoming clearer, many important aspects of how climate change will affect the region are still poorly known.

The Oregon Story: Living through the new drought of record

Kathie Dello[*], Oregon Climate Change Research Institute; John Stevenson, Oregon Climate Change Research Institute

The 2015 drought in Oregon found its way into history as the new drought of record, besting the tough years of 1977 and 1992. While the media intently focused on California's drought, the situation in Oregon was just as dire. The notoriously wet state of Oregon now feared severe water shortages and increased wildfire danger. The most notable years of this drought are the last two, though drought has persisted in eastern Oregon for four years. The winter of 2013-2014 was pretty near normal in terms of temperatures, but low precipitation in the winter months meant that snowpack struggled to accumulate. One winter with low snowpack is survivable; two is not. The winter of 2014-2015 was abnormally warm. So warm, that ski resorts struggled to open, flowers bloomed early, and snowpack was at record lows. The drought was set into motion early in the winter and the worst case scenario played out: a dry spring, and a very hot and dry summer. We will tell the tale of Oregon's struggles, perseverance, and successes during this challenging year. From the urban water utilities to the irrigation districts, every Oregonian was touched by the drought in some way. We will discuss how this year looks like our future, and how this has opened up a new conversation around climate adaptation in the state.

Climate Change in the Inland Northwest

How Temperature and Precipitation Trends Have Affected Mountain Hydrology and Ecology

Charles Luce, US Forest Service; John Abatzoglou, University of Idaho; Zachary Holden, US Forest Service*

While modeling the pathways to increased temperature are clear with respect to increased atmospheric CO_2, precipitation changes are more uncertain. Nonetheless, precipitation changes can have tremendous influences on hydrologically mediated outcomes of climate change, including many ecological changes in forests. Interpreting many hydrological and ecological trends over the last several decades requires understanding both the temperature and the precipitation contexts underlying the change. Recent work has shown that there has likely been a trend in precipitation in the mountains of the northwestern U.S. associated with changes in winter westerly winds. Although it presents, on the one hand, an opportunity for a discussion about whether precipitation might decline further, a more important discussion exists in deciphering how precipitation variations and temperature variations over the past 60 years have influenced a number of hydrological and ecological outcomes, including: snowpack, low flows, floods, and wildfire. We will discuss the historical trends in temperature and precipitation and relate them to trends and sensitivities of outcomes to explore where and how precipitation uncertainty contributes, or does not contribute, to uncertainty in hydrological and ecological outcomes.

Through a glass darkly: evaluating the effects of future climate change on wildlife

Kevin McKelvey, US Forest Service; Polly Buotte, US Forest Service*

Historically, determining the fate of wildlife populations was largely a function of intensive autecological studies to establish vital rates, food habits, and habitat correlates. These understandings were assumed temporally static and thus projectable in a straightforward way. With anticipated directional climate change, this approach has become increasingly untenable. However, attempts to project dynamic and changing conditions and their effects on wildlife are subject to vast uncertainties. We illustrate this both generally and using as an example Canada lynx, one of the better studied species with obvious adaptations to cold climates. Though these uncertainties are large and daunting, we argue against methods that mask them for 3 reasons. First, a great deal of useful information is obtained by examining the full range of future projections. Secondly, simplified projections based on a single or consensus model are likely to lead to excessive consideration of low likelihood future landscapes at the expense of alternative futures. Lastly, formal evaluation of uncertainties facilitates the collection of appropriate information to improve future projections.

What Do Cities and Utilities Need from Climate Research?

Cyndy Bratz, Tetra Tech

How should we all use climate research? For the past four years, members of the Pacific Northwest Clean Water Association (PNCWA) have been hearing from climate researchers – Dr. Philip Mote, Dr. John Abatzoglou, Dr. Charles Luce and others. PNCWA is a member association of the Water Environment Federation – city public works staff, utility staff, treatment plant operators, consultants, academics and regulators. This presentation describes PNCWA, our membership, and what some cities and utilities are doing regarding climate change-related planning. It also describes the state of understanding and action in this area across the Pacific Northwest. Some who understand climate change still ask how it will affect them next year and want to plan for the near term. Some are planning further out into the future, but largely for adaptation. Some have a goal to get completely carbon neutral. Some deny that climate change is happening. As some cities and utilities begin climate change-related planning, what do we need to know to plan properly? Climate change has a big effect on stormwater, rivers (receiving water bodies for wastewater treatment plants) so effluent permits will be affected - river flows and river water quality both affect effluent permits, sea level rise is affecting infrastructure like pump stations, treatment plants, stormwater detention basins, etc, and snowpack/water supply/water resources will drive reclaimed water projects. But how do we plan for all this? In the past we've used historical data. But that will be inadequate in the current era. This presentation describes the intersection between infrastructure planning, integrated watershed management and climate change. It describes what cities and utilities need from climate research.

Climate, Grapes and Wine: Understanding Terroir Influences in a Variable and Changing Climate

Gregory Jones, Southern Oregon University

Climate is a pervasive factor in the success of all agricultural systems, influencing whether a crop is suitable to a given region, largely controlling crop production and quality, and ultimately driving economic sustainability. Climate's influence on agribusiness is never more evident than with viticulture and wine production where climate is arguably the most critical aspect in ripening fruit to optimum characteristics to produce a given wine style. This talk will provide an overview of regional to global research on 1) aspects of terroir that influences optimum quality and production characteristics, 2) the suitability of different winegrape cultivars to different climates, 3) how climate variability influences production and quality variations, and 4) how climate change has and will likely continue to alter the global wine region map.

Climate Change Adaptation Across Disciplines

Climate change, migration, and the Puget Sound region: What we know and how we could learn more

Alison Saperstein, University of Washington
Lara Whitely Binder, University of Washington Climate Impacts Group[*]

This study responds to the interests of Climate Impacts Group and its stakeholders in the claim that climate change will cause an unanticipated surge of newcomers to move to the Puget Sound region. This systematic literature review of media coverage, peer-reviewed social science research, and agency reports assesses the "climate refugee hypothesis" in light of what is known about both the influence of climate change upon migration and the nature of Puget Sound's existing migration system. A synthesis of this information suggests that a sudden and dramatic population increase is unlikely to occur, given the nature of anticipated climate impacts in Puget Sound's migration system and the fact that migration into Puget Sound is driven primarily by economic factors. However, climate change could have some effect on population flows, both directly and indirectly through its economic impacts, and population forecasting currently does not fully account for these possible consequences. Many researchable questions remain about the influence of climate forces upon migration into the region both now and in the future. Pursuing one or more of these investigations could better prepare regional public service providers for demographic changes that could result from climate change.

Adapting to Climate Change: Science, Decision-Making, and Practice Cultures

Johanna Wolf, Royal Roads University

Climate change adaptation involves myriad micro- and macro-level adjustments to address and prepare for the effects of shifting climate conditions and increasing extreme weather events. A growing body of research suggests that culture plays an important role in adaptation yet there is very little evidence as to how culture may be shaping the science, policy and practice of adaptation itself. As a dynamic system of shared meanings and practices, culture subsumes knowledge, beliefs, norms, and values—and this is as true of 'institutional cultures' as any others. Scientists, decision-makers (those in various levels of government able to advance programmatic decisions), and practitioners (those involved in adaptation implementation) are important shapers of knowledge and policy processes and outcomes, with each group bringing its own unique ideas and perspectives. This study examines whether there are distinct institutional cultures in adaptation science, policy, and practice, and if yes, how these affect the relationships between the three domains. Based on semi-structured interviews and a questionnaire that involved decision-makers at various levels of government (local, regional, provincial, and federal) in Canada, adaptation scientists working within Canada, the US, and abroad, and practitioners in British Columbia (N=30), the findings characterize science, decision-making, and practitioner cultures to illuminate the boundaries and overlaps of each culture. Specifically, we compare how each culture defines the expectations that guide their production, consumption and interpretation of information, frame risks and impacts, and inform the setting, prioritization, and implementation of adaptation goals. The results suggest there are distinct cultures in science, policy, and practice, and that these cultures influence the goals, interactions, and processes of adaptation within and across the three domains. We discuss the most important points of connection and disconnection among the three domains in terms of knowledge, beliefs, norms and values. These findings highlight an urgent need to build on points of connection to increase the overall connectivity between the three domains more broadly in order to advance adaptation as a whole.

Seeking Climate Resilience: Twenty years of applied climate science in the Northwest
Amy Snover, University of Washington Climate Impacts Group
The Northwest is generally considered rich in assessments, localized data, tools, and resources for assessing and reducing climate risks. El Nino has entered the common lexicon, and information about El Nino/Southern Oscillation (ENSO) conditions is routinely considered in resource management decision-making. Climate change adaptation efforts are underway in many parts of the region, and stakeholders routinely advise federally-funded applied climate research and outreach efforts aimed at supporting the development of regional climate resilience. These efforts benefit from over twenty years of applied climate science in the Northwest. Drawing on a review of the assessment and adaptation literature, historical climate impacts tools and datasets, and the archives of the University of Washington Climate Impacts Group, this talk will chronicle the development and refinement of climate impacts projections since the early 1990s, and highlight significant knowledge advances. What lessons can we draw from an early focus on climate variability for advancing climate literacy and engagement in an era of continued ambivalence towards the issue of climate change? As the focus of many Northwest practitioners moves from problem identification ("What does climate change mean for my interest area?") to decision making ("What am I going to do about it?"), what are the challenges and opportunities for regional climate scientists?

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Concurrent Sessions

Adaptation and Working Across Boundaries

Sea level rise and coastal flood risk probabilities: Improving risk communication to support community resilience

Ian Miller, University of Washington Sea Grant; Sascha Petersen, Adaptation International; Matt Fougerat, Adaptation International; Kate Dean, NOPRCD; Cindy Jayne, NOPRCD; Jake Bell, Adaptation International*

Presenting sea level rise information to decision makers in ways that are accurate, understandable, and useful has always been challenging. Visual depiction of annual coastal flood risk probabilities that incorporates sea level rise has been an elusive goal until now. The presentation presents an approach developed as part of the North Olympic Peninsula Climate Adaptation project that builds fully probabilistic relative sea level and extreme coastal flood projections for the region.

The projections rely on previously published data and supplemental information from Kopp and others (2014), but incorporate higher resolution local information on factors that can alter relative sea level patterns. The coastal flood risk is incorporated using publicly available water level data fit to a Generalized Extreme Value Distribution, and incorporated into the sea level rise projections using a Monte Carlo approach. The presentation will cover the process for developing the probabilities along with the GIS-based maps created to visually communicate those probabilities for selected focus areas on the North Olympic Peninsula. This approach takes into account locally varying factors that can lead to differences in anticipated community impacts due to sea level rise and/or coastal flooding. We will also assess the efficacy of this approach, relative to a more traditional scenario-based sea level planning approach, based on presenting preliminary data and maps to communities on the Strait of Juan de Fuca in Washington State. Overall, it provides communities with more flexibility and increased understanding relative to scenario-based sea level rise planning approaches.

The available science assessment project: Evaluating the supporting science behind climate adaptation actions

Rachel Gregg, EcoAdapt; Lisa Gaines, OSU Institute for Natural Resources; Whitney Reynier, EcoAdapt; Jeff Behan, OSU Institute for Natural Resources*

Climate change is one of the most pressing issues facing natural resource management. The disruptions it is causing now and projected to cause in the future require that we change the way we consider conservation and resource management in order to ensure the future of habitats, species, and human communities. Practitioners often struggle with how to identify and prioritize specific adaptation actions used in response to climate-induced stresses. Management actions may have a higher probability of being successful if they are informed by available scientific knowledge and findings; a systematic mapping process provides a mechanism through which to scientifically assess management-relevant questions. By evaluating specific actions on scientific knowledge and findings, we may be able to increase resource management effectiveness and efficiency. The goal of the Available Science Assessment Project is to synthesize and evaluate the body of scientific knowledge on specific, on-the-ground climate adaptation actions to determine the conditions, timeframes, and geographic areas where particular actions may be most effective for resource managers. We have derived a methodology that utilizes interviews, systematic mapping, scientific expert elicitation, and extensive engagement with natural resource managers throughout the Northwest Climate Science Center region. For this pilot project, we are evaluating the science behind specific actions used in response to climate-induced fire regime changes in national forests in the region.

Assessing climate change effects on natural and cultural resources of significance to tribes

*Samantha Chisholm Hatfield***,** *Oregon Climate Change Research Institute*[*]*; Philip Mote, Oregon Climate Change Research Institute; Kathie Dello, Oregon Climate Change Research Institute; Elizabeth Marino, Oregon State University*

This research documented the responses of Native American cultural traditions to climate change in the Northwest and Great Basin areas of the United States, primarily using Traditional Ecological Knowledge. There are aspects of tribal culture, such as songs, stories, prayers, and dances that include fish, wildlife, or plants as central images or main symbolic figures. Visible expressions of culture are usually connected to certain species and habitats which might be expected to change as climate changes. In addition to such visible expressions, which indeed show evidence of adapting to climate change, interviewees identified several common themes that extend to fundamental, largely invisible aspects of culture and even identity. In particular, the most important cultural consequence of climate change is how it affects the definition of time, in both seasonality, and the manner in which time is determined. In addition, we detected a very clear a sense of imbalance, confusion, or unknowing because new environmental conditions do not match the traditional information that has been passed down through generations. Because climate change affects the presence, abundance and patterns of distribution of animals and plants, it was hypothesized that such changes would in turn influence tribal cultural aspects connected to those resources. Native American people are affected disproportionately by climate change compared to non-Natives. The intimate connections that tribes have maintained with the natural environment are more spiritually rich and complex than non-Native consumptive views of natural resources. The research involved three Northwest tribes, and two Great Basin tribes. Tribes were selected after careful consideration of tribes' size, level of cultural activity, strength of ties to the environment, and connection to culturally significant and aboriginal geographic regions.

Water, salmon, cous, and climate: Assessing climate vulnerabilities for the Confederated Tribes of the Umatilla Indian Reservation

Sascha Petersen, Adaptation International; Patrick Mills, CTUIR; Ellu Nasser, Adaptation International; Darrin Sharp, OCCRI*

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is a union of three tribes and lies on the western boundaries of the Blue Mountains in Northeast Oregon. Integral to tribal culture is a deep connection to the land, particularly through harvesting of "first foods"—salmon, roots (Cous), berries (Huckleberry), and game (deer and elk). The CTUIR is already experiencing the impacts of climate change and is proactively planning for its future. In partnership with Adaptation International, a small mission driven organization focusing on helping communities build resilience, and the Oregon Climate Change Research Institute (OCCRI), the CTUIR has completed a Vulnerability Assessment for their ceded lands to better understand their vulnerabilities to climate change. The CTUIR started their climate vulnerability assessment process by creating a Climate Change Committee comprised of 15 people representing a variety of Tribal government departments; from Science and Engineering to Planning, and Human Health to First Foods and Natural Resources. Adaptation International led this Committee through a series of two workshops to refine and then prioritize a list of 15 "Key Items of Concern", spanning climate related impacts to first foods, the built environment, the agricultural economy, and public health that were particularly important to the CTUIR. In support of this assessment, OCCRI generated locally specific climate projections for the CTUIR ceded lands using Multivariate Adaptive Constructed Analogs (MACA) downscaled Coupled Model Intercomparison Project v5 (CMIP5) model output. Climate parameters analyzed for three time periods (2010-2039, 2040-2069, 2070-2099) included: mean seasonal daily maximum temperature; mean seasonal total precipitation; mean number of days/Season > 90 degrees Fahrenheit; and mean number of days/season with no precipitation. Temperatures for the domain are projected to be warmer across the board, with a noticeable increase in days > 90°F. There is a suggestion of increased seasonality in precipitation (wetter winters; drier summers), but the range in precipitation projections is large. This presentation will provide a summary of the vulnerability assessment results and the public engagement materials. This rapid assessment, completed over seven months, lays the foundation for the CTUIR's continued action on climate change. It proves that climate vulnerability assessment and adaptation planning isn't limited to coastal communities, and the framework used here can provide a model that other communities can follow.

***Pop-up*: Data visualizations for the combined effects of projected sea level rise, storm surge, and peak river flows on water levels in the Skagit floodplain**

Jonathan Kemp, Environmental Science Associates

See Tools Café abstracts in the Poster Session section below.

The importance of climate on the benefits and economic viability of the Yakima Basin Integrated Water Resource Management Plan

Jonathan Yoder, *Washington State University*[*]; *Jennifer Adam, Michael Brady, Stephen Katz, Keyvan Malek, Qingqing Yang, Washington State University; Joseph Cook, Shane Johnston, University of Washington*

The Yakima River Basin Integrated Water Resource Management Plan ("IP") has been proposed for the management of drought risk and salmonid recovery, and includes several surface and groundwater storage projects, fish passage projects, fish habitat enhancements, water conservation, and reservoir management changes including instream flow augmentation, and water market development. The plan as a whole is estimated to cost between $2.7 and $4.4 billion. We report methods and results of a benefit-cost (B-C) analysis of the IP, focusing on how the irrigated agriculture benefits of the plan projects are affected by CMIP 3 climate scenarios through their effects on simulated water curtailment distributions. The benefits of the new water storage under the plan are higher under more adverse climate scenarios because they partially offset predicted declines in snowpack, which acts as a water storage mechanism for late summer irrigation. For example, based on the historic climate regime and curtailment scenarios (1925-2009), the expected net present value of agricultural benefits from IP water storage is about $84 million under moderate market conditions. Under the most adverse climate scenario considered (HADGEM1, A1B), the expected net present value of IP water storage projects for agriculture is about $384 million under intermediate market conditions. Further, we find that the cost of providing the proposed instream flow augmentations without investing in additional storage are higher in terms of foregone agricultural production value, ranging from $158 million (expected net present value) given the historical climate regime to $490 million under the most adverse climate regime we consider. However, the agricultural production cost of providing IP instream flows given that implementation of proposed storage augmentation under the IP is significantly lower. Overall, we find that because of their high cost, none of the water storage projects satisfy a B-C criterion (such that benefits are larger than costs) except in two cases under the most extreme climate and most restrictive market assumptions. Fish passage projects are found to be most likely to pass a B-C test, and uncertainty surrounding habitat and instream flow benefits precludes useful inference about the economic efficacy of these activities. In contrast to 2012 study commissioned by the U.S. Bureau of Reclamation and the Washington State Department of Ecology Office of Columbia River, we find that the IP as a whole is unlikely to satisfy a B-C criterion.

City of Tacoma climate change resilience study: Infrastructure, ecosystems and social systems

Nora Ferm, Cascadia Consulting Group[*]*; Jim Parvey, City of Tacoma*[*]*; Jeanne Walter, City of Tacoma; Steve Winter, ESA; Matt Fontaine, Herrera Consulting; Lara Whitely Binder, UW Climate Impacts Group; Andrea Martin, Cascadia Consulting Group, Inc.*

Changes in temperature and precipitation are projected to have wide-ranging impacts on the Puget Sound region in the coming decades, exacerbating other stresses such as those caused by urbanization and shoreline alteration. These impacts can affect the reliability and performance of local government infrastructure, programs, and services while increasing risks to property, public safety, and economic activities. In 2015, the City of Tacoma is conducting a Climate Change Resilience Study to inform decisions that will promote sound investments and protect local residents in the years ahead.
The study is being carried out by a multi-disciplinary team comprised of Cascadia Consulting Group, ESA, Herrera, and the UW Climate Impacts Group. It details key climate impacts and vulnerabilities specific to Tacoma, and provides a shortlist of adaptation strategies and further study needs that consider the probability and consequences of projected impacts, City priorities, resource constraints, the local regulatory and policy environment, and unique windows of opportunity for adaptation action. To make the findings actionable, we use an analytical framework consistent with the City's existing methods and planning processes. We are exploring the holistic interactions between infrastructure, natural systems, and social systems to identify opportunities for actions that have multiple benefits. Study sites where infrastructure, natural systems, and social systems interact include the tideflats at Commencement Bay, Marine View Drive, transportation infrastructure along the downtown waterfront, the sanitary sewer and storm drainage systems, the Puyallup River, and Ruston Way (including stormwater assets, treatment facility, habitat, restoration sites, and public spaces). The team is identifying assets and resources that are able to accommodate anticipated changes in climate during the asset's lifetime, and those that are at higher risk for failure. The social systems component of the assessment also considers poverty, education, age of housing, and other factors that affect residents' adaptive capacity. Recognizing the importance of local experience as well as the need to build support and capacity for long-lasting resilience efforts, we make effective stakeholder engagement central to our approach. By the time of the NW Climate Conference, our study will be nearly complete. We will share our methodology and results. The City will speak to its plans for using the findings to inform a resilience roadmap.

Planning for Climate Change Across a Rural Two County Geography

Cynthia Jayne, North Olympic Development Council; Kate Dean, North Olympic Development Council; Sascha Petersen, Adaptation International; Jake Bell, Adaptation International; Ian Miller, Washington Sea Grant*

Bringing together a diverse group of stakeholders and building a participatory approach to climate planning is critical in many settings, but particularly challenging in a large geographic region with a diverse set of organizational interests spanning from agricultural producers and timber harvester to tribal government and urban water managers. The North Olympic Development Council (NODC) provides a unique perspective as a regional planning entity focused on economic development and sustainability on how to unite these groups and move climate planning forward.

In this presentation, we will discuss a project that brings together economic industries like paper mills, agricultural producers, timber harvesters, and tourism-focused industries, along with city and county planning departments for two counties and three cities, emergency services, three tribal governments, watershed management groups, and other environmental groups to assess climate vulnerabilities and develop an adaptation plan for the Jefferson and Clallam Counties of Washington State.
From July 2014 – October 2015, the NODC partnered with Adaptation International and Washington Sea Grant to conduct a project that used a collaborative approach to bring together the best available science with the local stakeholder knowledge. The project focused on broad adaptation planning across the entire geography. Addressing the unique challenges created by a region that is spread over 3,500 square miles and a project that included more than 30 partner organizations required proactive communication, a combination of in-person meetings and webinars, leveraging engagement and outreach through existing organizations, and utilizing a core team with representatives from a variety of the partner organizations to guide and focus the project. This presentation will include the approaches utilized, the challenges and lessons learned, and the final prioritized vulnerabilities and adaptation strategies identified.

Climate change adaptation and resilience in our built environment: Green infrastructure policy integration with Puget Sound municipalities

Erin Ryan-Peñuela, Edmonds Community College; Thomas Murphy, Principal Investigator EdCC; Kacie McCarty, Research Assistant, EdCC; Darin Molnar, Research Associate, EdCC; Alicia Kelly, Research Assistant, EdCC*

What is so difficult about installing a raingarden in our city center? Pervious concrete in the local parking lot? Or a bioswale along main street? Cities and counties are at the forefront of addressing climate change resilience and adaptation now and into the future. Green infrastructure builds resiliency and can be a key adaptive response to a wide variety of climate change impacts that threaten current infrastructure, water quality, and human health. Infrastructure like rain gardens, vegetative shorelines, green roofs and pervious surfaces, can reduce flooding, urban heat, coastal erosion, coastal damage and slow down and clean stormwater, among other benefits. Local and national policy is in the midst of changing to encourage and even require green technologies for new development in our cities and counties. Municipalities face serious barriers related to public and private buy-in, design, construction and maintenance of these new technologies. An ethnographic research project led by the Anthropology Department at Edmonds CC on behalf of the Puget Sound Partnership sheds light on the depth, spectrum, and patterns of green infrastructure barriers across a twelve county region in Western Washington. The study addresses barriers categorized as physical and technical; institutional and community; financial; and legal and regulatory. By using interview, survey, participant observation and document analysis the study has gleaned an in-depth understanding to the context of barriers for employees working in a host of roles within the municipality including but not limited to administrative, public works, planning and operations and maintenance. The presentation will share the methodology, results and recommendations from this study. This presentation will inform citizens, non-profits, industry, government employees and elected officials to the barriers and gateways that our cities and counties must tackle in order to incorporate green infrastructure and build climate resilient communities.

Agriculture

Biochar soil amendments as a tool for drought adaptation in PNW agriculture

Claire L. Phillips, USDA-ARS; Kristin Trippe, USDA-ARS; Stephen Griffith, USDA-ARS; Gerald Whittaker, USDA-ARS; Gary Banowetz, USDA-ARS; David Gady, Farm Power LLC; Bailey A. Murphy, USDA-ARS; Anthony V. Beovich, USDA-ARS*

Loss of snow pack, changing hydrographs, and increased temperatures and irrigation demands as a result of climate change all threaten to create transformational drought for growers in the Pacific Northwest. One approach for adapting to drought is to improve moisture retention through soil management practices. Recent efforts at the FSCRU to develop on-farm power have produced a biochar from gasification of seed mill waste that may prove useful as a tool for drought adaption. Testing of this biochar revealed that it contains no toxic elements, making it suitable as a soil amendment, and additions of ~8 tonnes acre-1 in dryland wheat system showed improved soil moisture and yield increases of 250%. Persistent but weaker impacts were observed in growing years 2 and 3 following the biochar amendments. Here we present results from a series of laboratory and field studies characterizing how grass seed screening biochar, which is produced from a regionally abundant feedstock, impacted soil moisture, temperature, and plant growth. Because of the liming qualities of gasified biochar, the greatest benefits are likely to be realized in acidified soils, a common and growing problem in the PNW. Although the persistence of biochar impacts in soil is still unknown, our results indicate that gasified biochar, particularly when utilized as part of a system of on-farm power production, waste reduction, and nutrient recycling, can improve agricultural sustainability in the context of climate change.

Projected regional shifts in Pacific North West dry land agriculture in response to climate change

Tina Karimi, Washington State University; Nelson Roger, Biological system Engineering, Washington State University; Abatzoglou John, Department of Geography, University of Idaho; Huggins Dave, USDA-ARS / Adjunct Faculty at WSU; Stöckle Claudio, Washington State University.*

The dryland agricultural region of the PNW includes northern Idaho, eastern Washington and northern Oregon. These areas are classified based on the distribution of major cropping systems in the region that have emerged as a consequence of biophysical and socio-economic drivers. PNW wheat dryland area is comprised of 3 main systems (Agro-ecological classes or AEC): a) grain/fallow, b) annual crop/fallow transition, and c) continuous cropping, which are aligned with precipitation amounts (low, intermediate and high rainfall zones, respectively). AECs attempt to specify land use into relatively homogeneous areas that result in common production systems. Although there is an interest on sustainable intensification of cropping systems, the question remains if climate change impacts on the region will preclude intensification and shift the borders of AECs. This question can be addressed using two different methodologies, one based on climatic indices, and another based on cropping systems simulation. In the first method, bioclimatic variables found to be good estimators of land use are combined with future climate scenarios to predict future shifts in AECs. The other method is to study projected yields through crop simulation modeling that includes the effect of bioclimatic, soil and management drivers on crop growth. The cropping system with the highest grain production in future scenarios would be the desired system. Preliminary results point towards an increasing prevalence of grain/fallow in the future especially in 2030s (2015-2045) period, with a concurrent decrease of annual crop/fallow transition and some decrease of the continuous cropping.

Impacts of climate change on irrigated agriculture in the Columbia River basin through water rights curtailment.

Kirti Rajagopalan, Washington State University; Kiran Chinnayakanahalli, AIR Worldwide; Roger Nelson, Washington State University; Georgine Yorgey, Washington State University; Keyvan Malek, Washington State University; Claudio Stockle, Washington State University; Michael Brady, Washington State University; Chad Kruger, Washington State University; Jennifer Adam, Washington State University*

Irrigated agriculture is impacted by climate change both directly and indirectly. Warmer temperatures and elevated CO2 levels directly impact the plant growth cycle and potential crop yields. In addition to this, indirect effects include factors such as changes in water availability for irrigation, particularly in snowmelt dominated regions. This is especially relevant in regions that exercise irrigation water rights curtailment in times of shortages, e.g., to maintain environmental flows. The relative magnitudes and directions of both the direct and indirect effects will determine the net impact climate change on agricultural production in such regions. We examine the indirect impacts of climate change in the 2030s on irrigated agricultural production in the Washington state part of the Columbia River basin, using a coupled crop-hydrology model in conjunction with a water management model that includes an approximation of water rights curtailment in the region. The indirect effects are also considered relative to the direct impacts of climate change on agricultural production. Results indicate that although future curtailment rates are expected to be higher than historical conditions, the effects of curtailment on crop yields are not correspondingly larger in the future. Impacts are crop dependent and depend on the timing of curtailment in relation to crop growth stage. Earlier onset of crops and accelerated growing degree day accumulation under warmer future climate alter the crop growth cycle leading to interesting impacts of curtailment on agricultural production.

REACCH Decision Support Tools for NW Wheat/Grain Farmers

Katherine Hegewisch, University of Idaho; John Abatzoglou, University of Idaho; Edward Bechinski, University of Idaho; Erich Seamon, University of Idaho; Paul Gessler, University of Idaho; Sanford Eigenbrode, University of Idaho*

Wheat and other small grain production in the Northwestern US encompass 4 million acres and contribute approximately $2 billion annually to the economy. Inter-annual variability in climate directly impacts crop yield in parts of the NW through energy and moisture constraints. These crops are also subject to indirect yield reductions caused by insect pests, weeds and pathogens that if managed appropriately can be minimized. The Regional Approaches to Climate Change in Pacific Northwest Agriculture (REACCH) project has developed a set of mobile decision support tools that can assist farmers with timely decisions regarding crop planting, fertilizing, spraying and harvesting to maximize theoretical yield. We highlight a set of tools that use a 4-km gridded real-time weather monitoring dataset to aid decision-making on when to plant or treat crops. Historical datasets and seasonal climate forecasts for the next 6-months are also incorporated for contextualizing conditions of the current growing season and providing outlooks tailored to specific locations, respectively. Finally, phenological models for several pests, weeds and pathogens have been incorporated into the decision support tool enabling multi-species comparisons. By placing weather monitoring and forecast tools on a mobile app accessible to farmers, we aim to improve decision-making for managing key pests and weeds, as well as to improve grower understanding of organism biology and responses to climate drivers.

An agricultural producer learning tool for the Columbia River basin.

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A primary factor affecting risk management for agricultural producers is weather and its variability. At key decision points throughout the year, producers use the information available to them to make the best possible decisions in spite of uncertainties. Decision support tools can help producers make better informed short-term decisions about their operations, such as what to plant, when to plant and how to manage crops under variable weather conditions. Such tools can be adapted to be used as “learning tools”. Learning tools can help producers evaluate past operational decisions, or explore the possible future impacts of long-term strategic decisions before they are actually made. For example, drawing on historical and future climate projections, a producer might explore what the future climate normal and extremes might be, look at historical analogs for a specific scenario, or explore adaptation strategies.

Based on existing data, tools, and methods that are useful for agricultural producer decision making, a prototype learning tool has been assembled for the Columbia River Basin in the Pacific Northwest US. The primary goals are:

- Visualize historical climate and crop yield data in a format that is relevant for producers.
- Provide access to short-term and seasonal weather forecasts that can be viewed in the context of historical data.
- Provide a learning tool that gives producers the flexibility to evaluate "what if" scenarios with respect to operational decisions made in the recent past.
- Provide a learning tool for producers to visualize what future climate projections look like, identify historical analogs and evaluate adaptation alternatives.

Although the current prototype focuses on weather and climate-based visualizations, the framework can be expanded to include other aspects that impact producer decisions. There is also potential to integrate what we learn through on-going regional earth system modeling partnerships in the Columbia River basin to enrich the toolkit and help producers make informed decisions that prepare them to adapt to a changing climate.

Communication

Conveying Climate Change Vulnerability at the Local Level

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Conveying climate change vulnerability of local watersheds is advanced through the use of data-driven, interactive virtual worlds. The Managing Idaho Landscapes for Ecosystem Services (MILES) project has developed a virtual environment as a decision support tool for Fernan Lake (Idaho) stakeholders to: (1) assist in the prediction of climate and management induced system shifts in order to mitigate or prevent declining ecosystem services prior to conflict, (2) better communicate ecosystem complexity to disparate communities of interest, and (3) help identify social heterarchies competing for ecosystem service provisions. Fernan Lake is challenged by recurrent toxic blue-green algae blooms of increasing historical incidence and duration. The risk of fire vulnerability due to intensified heat, and drought forecast by downscaled climate models, and consequent increased loading of nutrient precursors to the lake, exacerbates this condition. Management activities focused at minimizing phosphorus loading to Fernan Lake will benefit from a better understanding of phosphorus sources and sinks in this watershed and how they will respond to a changing climate. The Virtual Fernan environment employs a regression relationship between fire occurrence and the Keetch-Byram Drought Index (KBDI) correlated with the total soil water (TSW) predicted from the Water Erosion Prediction Project (WEPP) model for historical climate conditions as its baseline condition. Future scenarios in Virtual Fernan are developed using WEPP-predicted TSW as an indicator of the likelihood of future fire occurrence and resultant algae blooms using the Coupled Model Intercomparison Project Phase 5 for the four

Representative Concentration Pathways scenarios. Users of Virtual Fernan explore the effects of user-selected climate change induced wildfire regimes and management scenarios on the incidence of blue-green algae blooms in Fernan Lake. Social data and models are incorporated in the Virtual Fernan decision support tool, advancing the understanding of social ecological system response to climate change. Ongoing research using a novel application of network analysis and the Virtual Fernan prototype is testing how sensitive managed ecosystems are to human decision-making relative to climate change and continued urban growth, and the associated ecological and social tradeoffs.

Tell Me When I Start Talking Climate and I Will Tell You When You Start Talking Management

Gregg Servheen, Idaho Department of Fish and Game

State fish and wildlife agencies have the primary management authority for fish and wildlife inside their state boundaries. They implement this responsibility primarily through actions related to regulation of fishing and hunting, habitat protection and management of their own properties, collecting, assessing, and maintaining scientific information on fish and wildlife and their habitats, providing technical assistance to land management and use decisions in relation to their impacts on fish and wildlife, and collaborating with partners of all kinds to do all of the aforementioned. Although much of their management would appear supportive of climate change adaptation, it may be necessary to change how their management decisions are made rather than the management actions themselves to insure the conservation of fish and wildlife resources is adapted to climate change. This is because in Idaho, the Department of Fish and Game's authority and primary constituency focus on the regulation of hunting and fishing through the sale of licenses and tags. And their many work and planning processes are focused on management outcomes that serve these drivers. So their authority and its cycle of processes are on an annual or bi-annual cycle and driven primarily to perpetuate the status quo of the existing management system. Conversely, climate change knowledge is provided in terms of predictions of impacts to environmental resources from changes in temperature and precipitation at coarse scales and in terms of decades. Applying such predictions and science within a state fish and wildlife agency, at the very least, is often a mismatch of data and spatial scales. Fish and wildlife empirical data that provides for management action through the existing state agency paradigm is missing for the majority of species. As a result, there is a disconnect between climate adaptation and management action at a state fish and wildlife management scale. Not the least of which are language and communication barriers caused by differences in spatial scales, decision cycles, science, and relevant outcomes. We examine these differences, provide some ideas on how to build linkages among and between these mismatches, and offer some process, language and collaboration improvements to help make "adaptation" a verb and fish and wildlife management a climate adaptation.

So you have data, now what?

Dominique Bachelet, Conservation Biology Institute; Melanie Brown, Conservation Biology Institute; Mike Gough, Conservation Biology Institute; Tim Sheehan, Conservation Biology Institute; Ken Ferschweiler, Conservation Biology Institute*

Pacific Northwest ecosystems contribute to the economic, social, and ecological stability of the region by providing sustainable timber production, high carbon sequestration potential, unique wildlife habitat, and high water quality. Climate change may jeopardize these ecosystem services through increased temperatures and reduced snowpack, exacerbating the influence of disturbance such as fire and pest/pathogen outbreaks. Furthermore heat waves and declines in water availability in the rest of the country will likely cause human population migrations to the Northwest which means increased demand for services but also amplified need for effective carbon sequestration measures that could partially mitigate human-caused disturbances. The combination of projected climate change and land use adds uncertainty to the long-term effectiveness of current management strategies. Managers need reliable information to adjust their strategies as population density increases. However they are currently overwhelmed by the diversity of available information and the multiplicity of sources. Our goal is to centralize and package effectively the usable information for land managers and for the general public in order to increase awareness and promote preparation for the challenges ahead. We are designing conservation planning atlases in Data Basin for a number of landscape conservation cooperatives to address this need. We are adding some user-friendly tools to specifically serve the available climate projections and land use data in a meaningful way. By working closely with a group of managers, our goal is to understand how consideration of these projections figures into the decision-making process and refine the ways we can deliver relevant metrics. We have been holding interviews to gather information and critical feedback on existing climate-related web pages and tools, providing us with benchmarks for improvement. Through an iterative process we hope to continue this collaboration and address the variety of issues managers continually have to face to maintain healthy ecosystems.

An Indigenous Approach to Adapting to Climate Change: Lessons to be Shared

Rodney Frey, University of Idaho; Leanne Campbell, Coeur d'Alene Tribe; Brian Cleveley, University of Idaho*

The Indigenous peoples of the Americas have proven successful, since time immemorial, in adapting to numerous environmental changes threatening their ways of life. In the example of the Schitsu'umsh (Coeur d'Alene) of Idaho, they have engaged the physical changes in their world by relying upon their traditional knowledge and practices, called hnkhwelkhwlnet "our ways of life in the world." The Schitsu'umsh offer invaluable insights and lessons that can contribute to better policies and practices addressing climate change. Acknowledging the unequivocal relationship between the content, the "what" of hnkhwelkhwlnet, and the means of accessing and disseminating that content, the "how," if Indigenous ways of knowing and engaging the world are to be understood and appreciated, consideration must also be given to the manner of approaching, presenting and teaching it, the "how" of understanding hnkhwelkhwlnet. For the Schitsu'umsh, the act of re-telling the oral traditions, 'me'y'mi'y'm (the "how") has been and continues to be essential to disseminating their hnkhwelkhwlnet from generation to generation. It is a form of education based upon attentive listening, stmi'sm, and active participation, 'itsh'u'lm. We will demonstrate that an interactive 3-D Landscape (based virtual world technology) as means of accessing and disseminating hnkhwelkhwlnet closely aligns with the structure and dynamics of 'me'y'mi'y'm, and is thus more effective means of communicating Indigenous knowledge and practice to the scientific community. We will discuss the nature and key attributes of hnkhwelkhwlnet, and how it is similar and distinct from other forms of Traditional Ecological Knowledge. And we will focus on one particular attribute of hnkhwelkhwlnet that offers specific insights for climate change, what is called snukwnkhwtskhwts'mi'ls ł stsee'nidmsh – "empathic adaptability."

Ecological Adaptation

Capturing subregional variability in regional-scale climate change vulnerability assessments of natural resources

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Climate change vulnerability assessments that span large climatological or ecological gradients need to incorporate the potential for variability in species or resource vulnerability. Here we present a framework for incorporating this variability in vulnerability to climate change as implemented in the first regional-scale assessment led by the U. S. Forest Service. During the course of this assessment, five subregional workshops were held to capture variability in vulnerability and develop adaptation tactics. Our framework consisted of a questionnaire to address three objectives: 1) identify species, resources, or other information missing from the regional assessment; 2) describe subregional variability in exposure, sensitivity, and adaptive capacity and; 3) determine additional information needed to either assess vulnerability or develop adaptation options. This framework was used in eight natural resource areas; in our results and discussion we focus on wildlife resources. Participants identified three habitat types and 13 species as important in subregions that were not included in the regional assessment. Participants also described multiple instances of subregional variability in exposure, sensitivity, and adaptive capacity. A better understanding of the mechanisms of climate influence on wildlife populations was an information need common across all subregions. We provide recommendations, including a revised framework, for improving the process of capturing subregional variability in a regional vulnerability assessment. Our revised framework is structured around pathways of climate influence and population characteristics, each with separate rankings for exposure, sensitivity, and adaptive capacity. This structure allows for a quantitative ranking of species, pathways, exposure, sensitivity, and adaptive capacity. These rankings can be used to direct the development and implementation of future regional research and monitoring programs. Our framework can be extended to natural resources other than wildlife. In conclusion, we find that regional assessments can capture subregional variability and this process will continue to improve with repetition and careful evaluation of the process.

Future drought vulnerability in tree stands: Understanding soil moisture dynamics to develop resilience strategies for climate change in the Pacific Northwest

Ryan Niemeyer, University of Idaho; Timothy Link, University of Idaho; Gerald Flerchinger, USDA ARS; Sherri Johnson, Oregon State University; Mark Seyfried, USDA ARS; Bend Soderquist, University of Idaho*

Soil water content (SWC) exerts a primary control on vegetation, nutrient cycling, and net primary productivity in the U. S. Pacific Northwest (PNW). Both the amount and timing of SWC depletion can change due to shifts in either climate or vegetation cover. A warmer climate in the future could increase the days tree stands experience a soil moisture deficit. To reduce SWC competition in seasonally arid tree stands and promote tree stand health, land managers and forest owners are thinning tree stands. No studies we are aware of have assessed how thinning could reduce drought vulnerability at a stand scale across an elevational gradient within a watershed, and across the diverse climates that characterize the PNW. Our objectives are to understand potential tree stand vulnerability to drought across elevational and climatic gradients and assess how stand thinning could potentially reduce this vulnerability. Our study sites represented two end member PNW sites: conifer stands in the wetter H.J. Andrews Experimental Forest (HJA) in western Oregon and conifer and aspen stands in the drier Reynolds Creek Experimental Watershed (RCEW) in southwestern Idaho. We simulated hydrological fluxes in tree stands at HJA and RCEW respectively, at three sites spanning an elevational gradient from a rain-dominated to snow-dominated precipitation regime. We simulated hydrological fluxes with the Simultaneous Heat and Water (SHAW) model that simulates fluxes in one-dimensional space. We first simulated hydrological fluxes from 1999 to 2014 at all six sites (three at HJA, three at RCEW). We optimized saturated hydraulic conductivity and rooting depth with measured SWC as the response variable. The best fit model parameters were then used to simulate future SWC under current and thinned tree stands. We simulated future climate with the Multivariate Adaptive Constructed Analogs (MACA) data set across 20 global climate models (GCMs) in the mid-century (2046-2065) warming under the 8.5 representative concentration pathway. To simulate thinned stands, we simulated reduced leaf area index and rooting density. Drought vulnerability was assessed based on the number of days with the soil water potential below -1.5 MPa. This information presented will help land managers locate stands that are likely to be most vulnerable to drought and where thinning could potentially offer the largest benefit.

Engaging transboundary science-management partnerships to address climate impacts on wildlife connectivity in Washington and British Columbia

Meade Krosby, University of Washington Climate Impacts Group

Maintaining and restoring ecological connectivity is the most frequently recommended climate adaptation strategy for biodiversity conservation. Despite the ubiquity of this recommendation among state and federal climate adaptation plans, specific management strategies and tactics for connectivity conservation under climate change remain underdeveloped. How should we design corridor networks to best facilitate climate-driven shifts in species ranges, and how can we address potential climate impacts to existing habitat linkages? The Washington-British Columbia Transboundary Climate-Connectivity Project is a collaborative effort to address such questions, and produce specific, actionable strategies for managing habitat connectivity under climate change. This work is being led by science-management partnerships tasked with using the best available science around climate change and connectivity to inform the decision-making of participating agencies, tribes, and NGOs. We will describe the history of the project, which was developed as a direct response to feedback from regional managers. Next, we will explain our project approach, which addresses the significant conceptual and technical challenges around adapting connectivity conservation to climate change, while accommodating the diverse management scales, objectives, and activities of project participants. Finally, we will share insights gained from our efforts to overcome the institutional and political barriers to adaptation presented by an international border. This case study demonstrates the power of science-management partnerships to translate general adaptation principles into specific management actions, and the importance of bridging international borders to address climate impacts on wildlife connectivity.

Climate-Change Vulnerability in the Pacific Northwest: A Comparison of Three Approaches

Julia Michalak, University of Washington; Michael Case, University of Washington; Scott Rinnan, University of Washington; Joshua Lawler, University of Washington

Climate change has had a significant impact on the distribution and ecology of many species already, and these impacts are projected to increase in the future. Because individual species respond to climate change differently, some will be more adversely affected than others. Successfully managing species in a changing climate will require an understanding of which species will be most and least impacted. Several approaches have been proposed for assessing the vulnerability of species to climate change. However, it is unclear how these approaches compare to one another and whether they produce similar results. Here, we used three different approaches to rank 76 species of birds, mammals, amphibians, and plants by their vulnerability to climate change. The approaches we compared included: 1) projected range loss based on climatic niche model projections; 2) a trait-based assessment, which combined expert-knowledge based sensitivity scores with projected climatic changes; and 3) a measure of species climatic niche breadth based on the climatic conditions within species' current ranges. We found that the species vulnerability rankings differed substantially depending on the approach used. Some species were ranked as highly vulnerable by one approach but only moderately vulnerable by the other two approaches. Only one species, the woodland caribou (Rangifer tarandus caribou), was consistently ranked in the top ten most vulnerable species by all three approaches. The disparity in results is not entirely surprising given that the three measures assess different aspects of vulnerability and are based on different types of information. Nonetheless, these results are important because they indicate that more than one approach may be needed to adequately assess vulnerability. Basing management decisions on a single approach may lead scientists and managers to underestimate vulnerability.

Ecology

Integrating mechanistic and empirical model projections to assess climate impacts on tree species distributions in northwestern North America

Michael Case, University of Washington; Joshua J. Lawler, University of Washington*

Empirical and mechanistic models have both been used to assess the potential impacts of climate change on species distributions and each modeling approach has its strengths and weaknesses. Here, we demonstrate an approach to projecting climate impacts on species distributions that draws on both empirical and mechanistic models by integrating projections from a dynamic global vegetation model (DGVM) that simulates the distributions of biomes with empirical niche models for seven tree species in northwestern North America. These integrated models incorporate important biological processes, such as species competition, physiological responses of plants to changes in atmospheric CO2 concentrations, and disturbances as well as what are likely to be species-specific climatic constraints. Our integrated modeling results projected less suitable environmental space than our unrefined models for the majority of modeled species. The two modeling approaches also projected similar trends of expansion and contraction for most species, but the locations of expansion and contraction differed by modeling approach. The results of this study demonstrate that integrating mechanistic model output with empirical niche models can reduce the likelihood of over predicting suitable environmental space. Although there is a clear need to improve the understanding of the current drivers of species' distributions, growth, reproduction, and survival, future projections from these integrated modeling approaches offer insight into the location of environmentally suitable areas. These results also highlight which species may be better able to persist in a changing climate.

The possible futures of PNW ecosystems

Tim Sheehan, Conservation Biology Institute; Dominique Bachelet, Conservation Biology Institue; Ken Ferschweiler, Conservation Biology Institute; John Abatzoglou, University of Idaho*

Using the MC2 dynamic global vegetation model we simulated vegetation shifts and concurrent changes in carbon stocks and fluxes in the PNW using climate projections from 20 CMIP5 climate models downscaled using the MACA method. Simulations were run under two representative concentration pathways (RCP 4.5 and 8.5) for potential natural vegetation with and without fire suppression. Results were summarized for three subregions: the western Northwest (WNW), from the crest of the Cascades westward; the Northwest plains and plateau (NWPP), non-mountainous areas east of the Cascades; and the eastern Northwest mountains (ENWM), mountainous areas east of the Cascades. Over most of the WNW, large fires facilitate rapid vegetation shifts from conifer to mixed forests as temperatures warm. In the NWPP, fire risk increases but effective fire suppression enhances carbon sequestration because of woody expansion. In the ENWM, alpine ecosystems are replaced by conifer forests, increasing carbon capture but fire risk increases.

Projecting the dependence of aspen productivity on redistributed snow in a warming climate

Ben Soderquist, University of Idaho; Kathleen Kavanagh, Texas A&M University; Timothy Link, University of Idaho; Mark Seyfried, Agriculture Research Services, USDA; Ryan Neimeyer, University of Idaho; Eva Strand, University of Idaho*

Precipitation occurring in the form of snow is an important resource to aspen (Populus tremuloides) stands in many semi-arid ecosystems across the intermountain west. In mountainous regions, the redistribution of snow by wind can increase the effective precipitation available to vegetation and provide prolonged periods of increased soil moisture and forest productivity. With increasing temperatures, the distribution of soil moisture may become more uniform as precipitation regimes become dominated by rainfall. Understanding the ecohydrological interactions between aspen and the heterogeneous distribution of soil moisture is essential for predicting and mitigating future losses in ecosystem diversity and productivity in regions characterized by snow dominated precipitation regimes. To address the dependence of aspen productivity on redistributed snow, we simulated the net primary production (NPP) of aspen stands spanning a precipitation phase (rain:snow) gradient in the Reynolds Creek Experimental Watershed and Critical Zone Observatory (RCEW-CZO). Within the RCEW-CZO, the total amount of precipitation has remained unchanged over the past 50 years, however the percentage of the precipitation falling as snow has declined by approximately 4% per decade at mid-elevation sites. The biogeochemical process model Biome-BGC was used to simulate aspen NPP at three stands located directly below snowdrifts that provide melt water late into the spring. After adjusting precipitation inputs to account for the redistribution of snow, historic annual aspen NPP at the driest site was increased by as much as 70% relative to simulations assuming a uniform precipitation layer. To assess climate change impacts on future aspen productivity, mid-century (2046-2065) aspen NPP was simulated under several warming and emission scenarios using the Multivariate Adaptive Constructed Analogs (MACA) data set. Projected simulations indicate that aspen stands at the driest sites with the largest snow drifts will experience drier soils and prolonged periods of drought stress with warming temperatures and associated decreases in the proportion of precipitation falling in the form of snow. Future increased soil moisture limitations subsequently result in decreased aspen NPP. The loss of the soil moisture subsidy stemming from prolonged redistributed snow water resources is one process that directly influences ecosystem productivity in the rain:snow transition zone. Therefore, identification and future management of vulnerable aspen stands should account for shifts in the timing and phase of precipitation.

Coupled response of grassland biomass to changes in climate and grazing management using an ecohydrologic model

Julian Reyes, Washington State University; Christina Tague, University of California Santa Barbara; Chad Kruger, Washington State University; Kris Johnson, Washington State University; Jennifer Adam, Washington State University*

Grasses in rangeland ecosystems cover a large portion of the contiguous United States and are used to support the production of livestock. These grasslands experience a wide range of precipitation and temperature regimes, as well as management activities like grazing. Assessing the coupled sensitivity of biomass to both climatic change and human activities is important to decision makers to ensure the sustainable management of their lands. The objective of this study is to examine the sensitivity of biomass under co-varying conditions of climate and grazing management. For this, we used the Regional Hydro-ecologic Simulation System (RHESSys), a physically-based model that simulates coupled water and biogeochemical processes. We selected representative grassland sites using the Köppen-Geiger climate classification system and information on major grass species. Historical precipitation and temperature data were incrementally perturbed to simulate climatic change (i.e. warmer and/or wetter conditions). We collected information on historical grazing patterns – intensity, frequency, and duration – at each of the sites. Similar to climate data, we perturbed the historical grazing patterns to mimic possible changes in management. To visualize this multi-dimensional parameter space (i.e. factorial design), we created surface response plots of varying climate and grazing factors for biomass. Additionally, forage quality information was incorporated into calculations of grazing intensity. Changes in climate or grazing management alone produced shifts in the sensitivity of grassland biomass. However, co-varying climate conditions (temperature and precipitation) with either grazing intensity, frequency, or duration revealed different biomass responses. For example, some changes in grazing duration could be mediated by changes in climate. Effects of high intensity grazing could be buffered somewhat depending on the duration or timing of grazing (i.e. start and end date). This research employs process-based modeling with simple, incremental changes in both climate and grazing management. By doing so, we can provide information that is useful for land managers and ranchers for future planning.

Northwest Climate

Land surface interactions in a changing climate

Eric P Salathé Jr., University of Washington Bothell

Observations of global land temperatures suggest that the warming trend on the hottest days exceeds the overall rate of global warming. One plausible explanation for this amplification is the effect of surface moisture feedbacks, which are becoming increasingly positive as the climate warms. In regions of high soil moisture, evapotranspiration increases directly with energy inputs to the surface so that warm anomalies result in higher evaporative cooling. However, in a warmer drier climate, decreasing soil moisture limits evapotranspiration, resulting in a positive feedback during heat events. Thus, regions can undergo a shift in the sign of the soil moisture-temperature feedback as a result of climate change. Where this occurs, the impacts could be substantial, affecting the intensity and duration of heat waves, plant ecosystems, and the risk of wildfire. This talk will present simulated projections of the land surface interactions during climate change using a high-resolution regional climate model. Regional differences in the coupling among soil moisture, evapotranspiration, and temperature are diagnosed using the interannual correlation between summertime-mean surface temperature and moisture flux. Where this is positive, moisture flux increases during warm years and the increased latent heat transport from the surface provides a negative feedback to surface heating. Where the correlation is negative, surface moisture is depleted and latent heat flux from the surface is suppressed during warm periods resulting in a positive feedback to temperature. Future regional projections for the Northwest indicate large regions where the correlation between moisture flux and temperature changes sign. The correlation decreases over much of the region, indicating a shift from negative to positive feedback during warm extremes. The largest response is on the western slopes of the Cascades, the high desert of western Oregon, and mid-elevation slopes of the Rockies across southern Idaho. Global climate model results show a similar but spatially diffuse decrease in this diagnostic over the western United States. However, the result from the regional model is substantially amplified and clearly related to terrain, possibly through changes in snow cover or associated with specific vegetation classifications. An analysis of the simulated surface water and energy budget provide will be presented to provide insight into the processes controlling the climate response. This analysis will provide better guidance on the areas most likely to experience this projected shift in soil-moisture feedback.

Temperature Trend Biases in Gridded Climate Products in the Western U.S.

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In the mountainous western U.S., temperatures from high-resolution gridded climate products are often used to assess climate impacts on local hydrology, ecosystem processes, and biotic communities. However, there has been little formal analysis on the ability of these products to accurately capture temporal variability and trends in local climate. Here, we summarize and expand upon recent assessments of trend biases in the widely used PRISM and Daymet data products. Throughout the western U.S., we find that PRISM and Daymet contain spatially structured cold and warm trend biases. Most notably, we show that the products have propagated an extreme warm bias from the SNOTEL station network across large areas of mountainous terrain. Depending on the spatial and temporal scale of a specific climate analysis, these biases could have a substantial impact on climate attribution studies and possibly lead to erroneous conclusions. Further improvements in gridded climate products are needed to quantify temporal variability and trends in local climate.

Analysis of Intensity-Duration-Frequency Curves in British Columbia

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Intensity Duration Frequency (IDF) curves define probabilities of experiencing various intensities of short-term precipitation for given durations at individual sites. Projected trends in precipitation, specifically in extreme events, suggest current IDF curves will be insufficient for accurately assessing flood risk in a changing future climate. Reliable estimates of future sub-daily precipitation events require a better understanding of scaling relationships between short-term precipitation events and how trends in extreme precipitation alter these existing links. We evaluate the performance of IDF curves in past and future periods for sub-daily precipitation drawn from weather stations, gridded reanalyses and global climate model simulations across British Columbia. We find a strong spatial dependence of IDF curves in the observations that is poorly replicated by both gridded reanalysis and historical sub-daily climate model simulations. Using Generalized Extreme Values estimates of return periods instead of standard Gumbel-based values results in minimal improvement of fitted distributions. Employing an exponential form of interpolating equation yields poorer agreement with estimated return values for sub-daily precipitation at stations but is nearly as effective as a power law interpolation for sub-hourly station and sub-daily reanalysis precipitation. Future climate projections of sub-daily precipitation indicate a shift in the scaling relationship between precipitation amounts for different sub-daily intervals, however there is substantial bias between models. The projected scaling relationship changes follow similar works indicating a super Clausius-Clayperon scaling in response to increasing temperature is possible for sub-daily precipitation.

Timing is Everything: Prioritizing adaptation using information about the "Time of Emergence" of climate change

Cary Lynch, UW Climate Impacts Group; Joe Casola, UW Climate Impacts Group; Amy Snover, UW Climate Impacts Group; Eric Salathé, UW-Bothell STEM program*

Given limited resources, strategic prioritization of climate change adaptation efforts is essential. A key consideration is information about when and where climate change is likely to matter first – yet such information is surprisingly difficult to come by. Although information about the "time of emergence" of climate change can be gleaned from existing climate change scenarios, it has not been explicitly characterized for variables and spatial scales relevant to local decision-making. Multiple local climate change projections, based on different emission scenarios, global climate models and downscaling methods, increase the difficulty of identifying when and where the effects of climate change could matter. This presentation will describe a new approach to climate change decision support that identifies when and where climate change is expected to cause local, management-relevant conditions to deviate significantly from the past. Designed to support adaptation prioritization across sectors, this approach has been implemented in the PNW by the UW Climate Impacts Group, in partnership with the Environmental Protection Agency and US Army Corps of Engineers. The project combined stakeholder interviews, new analysis of the "time of emergence" of climate change for a variety of management-relevant parameters, and development of a prototype web-based platform for user exploration of results. This presentation will describe how climate change "time of emergence" information can inform climate change-related risk assessment and decision making for both sophisticated and novice practitioners, discuss insights derived from this approach for PNW adaptation priorities, and explore implications for climate change communication more broadly.

Water Resources

Seeing the Future? Hydrologic Impacts of a Record Warm Winter and Dry Spring in the Oregon Cascades

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Snow is a crucial moisture source for forests, aquatic ecosystems, and communities in the Pacific Northwest and across the western US. The winter of 2014-2015 was the warmest winter on record followed by an anomalously warm, dry spring resulting in historically low streamflows and early declarations of drought conditions across western Oregon. We present an overview of the hydrologic impacts of this extraordinarily low snow year. Our study region includes (a) surface-flow dominated Western Cascades watersheds, representing a flashy streamflow regime with rapid baseflow recession and very low summer flows; and (b) the spring-fed High Cascades watersheds, representing a slow-responding streamflow regime with a long and sustained baseflow recession that maintains late summer streamflow through deep-groundwater contributions to high-volume coldwater springs. We model the effects of increasing winter temperatures on snowfall using SnowModel, a physically based and spatially distributed snow hydrology model. We measure the streamflow recession behavior in both spring-fed and surface-flow dominated watersheds using repeat measurements of flow dynamics and channel characteristics. We hypothesize that in surface flow dominated streams, the location of channel heads will migrate downstream, contracting the network longitudinally; the wetted channel width and depth will contract laterally, as summer recession proceeds and flows diminish. In spring-fed streams, channel heads "jump" downstream longitudinally to the next downstream spring when upper basin spring flow diminishes to zero; while downstream of flowing springs, wetted channel width and depth contract laterally as flows recede. We analyze and interpret our modeled snow data by empirical data by plotting time series of key statistics characterizing the response of the stream network. A year like 2015 is more than an outlier meteorological year. It represents a unique opportunity to test fundamental hypotheses for how montane hydrologic systems will respond to anticipated warmer winters, declining snowfall, and dramatic changes in amount and timing of recharge.

Impact of 2015 warmth on glacier mass balance across the Pacific Northwest

Mauri Pelto, Nichols College; Christopher McNeil, USGS; Ben Pelto, University of Northern British Columbia; Justin Wright, USGS*

The 2015 hydrologic year has been posited in terms of temperature as an analog for the future for the Pacific Northwest (PNW). Glacier mass balance in the PNW is highly affected by accumulation season temperatures. Here we will present the results of 2015 mass balance investigations across the PNW including glaciers in Alaska and Washington with a focus on the regional variation of mass balance gradients. End of accumulation season observations in the spring of 2015 at lower elevations indicate a snowpack thickness much below average, but closer to normal snowpack thickness at higher elevations. Additionally, above average ablation season temperatures across the PNW have further reduced snowpack at all elevations. These conditions should result in steeper than normal balance gradient and negative mass balance on all glaciers; however, possibly less negative in some regions than the climate community would assume. How negative the mass balance is will depend on the elevation of the winter snow/rain line in the vicinity of each glacier. We will contrast our snowpack observations with the freezing level tracker (ISU) results. In the North Cascades it is immediately apparent that freezing levels were elevated throughout the accumulation season, which generally begins in late September. Freezing levels were highest relative to the median in the key winter accumulation months of January through March. The snowline on glaciers across the region in early June exhibit levels typically observed 1-2 months later in the melt season. Our results will elucidate the magnitude of regional and local variability observed in glacier mass balance gradients during 2015 hydrologic year, allowing an understanding of how the warmer winter temperatures affect regional snowpacks.

Modeled crop yield response to various types of drought events in the Pacific Northwest

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Climate change is projected to increase frequency and severity of water availability during the growing season over the U.S. Warming results in an earlier spring peak runoff shifting water availability away from the irrigation season. Droughts in the Pacific Northwest (PNW) are generally triggered by individual or a combination of conditions such as low winter precipitation, low summer precipitation, and warm temperatures during winter. For instance, while precipitation totals for the winter of 2014-2015 were near normal in the PNW, warm temperatures during these months limited the accumulation of mountain snowpack reserve for adequate summer water supply, resulting in drought emergency in the State of Washington. In drought years, dryland agricultural areas experience increased water stress and irrigated areas experience increased competition with competing needs (such as instream flows for fish) for available water resources. How irrigated and dryland cropping systems respond to various types of drought events, i.e. meteorological (less precipitation), hydrological (lower water storage in reservoirs), agricultural (lower soil moisture), and snowpack drought (lower snowpack), is not just a scientific question, but an understanding useful for optimizing water management and developing adaptation strategies. We hypothesize that the response of crops to drought varies under different cropping systems, type (and magnitude) of drought events, and management practices. This study uses a coupled hydrologic and cropping systems model, VIC-CropSyst, to simulate changes in crop yields during historical and future periods in response to various drought events and corresponding temperature and precipitation conditions. All drought events are classified and characterized with multiple drought indices, such as the Standardized Precipitation Index (SPI) for meteorological drought, soil moisture anomaly index (SMAI) for agricultural drought, and total water deficit (TWD) for hydrological droughts. Simulated results indicate that the response of crops in the PNW to droughts is sensitive to its location, timing, length, and magnitude. This explicit drought study can help decision makers to develop event-oriented and location- specific adaptation strategies for reducing vulnerabilities of the PNW agriculture to drought.

A retrospective economic impact assessment of the 2005 drought in Washington State under alternative industry aggregation schemes

Michael Brady, Washington State University; Timothy Nadreau, Washington State University; Jonathan Yoder, Washington State University*

Economic impact studies of droughts are motivated by the reasonable assumption that economic harm extends beyond the farm through reduced demand for intermediate inputs and reduced income. Therefore, developing widely accepted estimates is an important part of evaluating drought mitigation policies. This is an important time to fill these need given the similarity between the 2015 drought and predicted droughts under climate change in future decades. A significant challenge in conducting an economic impact study that attempts to inform policy is the tradeoff the researcher faces in terms of aggregating industries. The advantage of a highly disaggregated input/output model (I/O) is that one achieves a more accurate representation of the intermediate inputs and final demand for a particular industry. For example, a single industry for 'energy' production would combine wind power generation and oil extraction, which use very different amounts of types of inputs including labor. On the other hand, a highly disaggregated model that has hundreds of industries requires assumptions on many thousands of parameters within the social accounting matrix. This makes it very challenging to be transparent and conduct robustness checks that can satisfy concerns about the sensitivity of results. The common implication of this is the perception that economic impact studies are manipulated to achieve a particular outcome. In this paper we discuss results of a retrospective economic impact assessment of the 2005 drought in Washington State using a highly aggregated model with fewer than twenty industries. We discuss advantages and drawbacks to the aggregated model in this context. In particular, we consider these tradeoffs when there is uncertainty over how water curtailments to agriculture affect farm-level production decisions.

A climate change risk assessment for water quality and salmon recovery; South Fork Nooksack River, WA

Steve Klein, Environmental Protection Agency; Jon Butcher, Tetra Tech Inc.; Hope Herron, Tetra Tech Inc.; Bruce Duncan, EPA Region 10; Laurie Mann, EPA Region 10; Teizeen Mohamedali, Washington Department of Ecology; Steve Hood, Washington Department of Ecology; Oliver Grah, Nooksack Indian Tribe; Treva Coe, Nooksack Indian Tribe; Mike Maudlin, Nooksack Indian Tribe; Ned Currence, Nooksack Indian Tribe; Tim Beechie, NOAA Fisheries*

The U.S. Environmental Protection Agency (EPA) Region 10 and EPA's Office of Research and Development (ORD) and Office of Water (OW) have launched a Pilot Research Project (EPA Region 10 Climate Change and TMDL Pilot) to consider how projected climate change impacts could be incorporated into a Clean Water Act (CWA) 303(d) Temperature Total Maximum Daily Load (TMDL) and influence restoration actions in the Nooksack River Basin (WRIA 1) Endangered Species Act (ESA) Salmonid Recovery Plan. The Pilot Research Project uses a temperature TMDL being developed for the South Fork

Nooksack River (SFNR), in Washington, as the Pilot TMDL for Climate Change Adaptation. An overarching goal of the pilot research project is to ensure that relevant findings and methodologies related to Climate Change Adaptation are incorporated into the SFNR Temperature TMDL. This project is structured as a stakeholder-centric process.

Instrumenting a glacier served watershed to establish baseline conditions and evaluate climate change impacts on the hydrology of the Nooksack River system and salmon

Oliver Grah, Nooksack Indian Tribe; Jezra Beaulieu, Nooksack Indian Tribe; Mauri Pelto, Nichols College*

The Nooksack Indian Tribe relies on sustainable harvestable surplus of salmon in the Nooksack River for subsistence, commercial, and ceremonial uses. The Nooksack River watershed has a substantial area of valley and alpine glaciers, primarily on Mount Baker at the head of the watershed. Glacier melt in the late summer season, a time of substantial limiting factors for salmon survival caused by low flows and high temperatures, provides a very important source of flow and lower temperatures. Measurement of ablation and discharge immediately below Sholes Glacier on Mount Baker quantifies the volume of glacier runoff to the North Fork Nooksack River, which provided more than 40% of total river runoff in August and September, 2014, peaking at 80% of total flow in mid-September (Pelto, Grah, and Beaulieu, in review). Increased glacier discharge during this time period largely offset the impact of increased air temperature on stream temperature leading to a mean change of 1.1°C in glacier sub-watersheds of the Nooksack River. A paucity of field data exists that addresses the issue of the impacts of climate change on glacier melt and the hydrology of the Nooksack River and subsequently survival of salmon. To this end the Tribe has implemented glacier watershed instrumentation that establishes a baseline of water and air thermal regimes, glacier mass balance and melt contribution, snowmelt contribution, sediment loading, and subsequent influences on the hydrology of the Nooksack River watershed. We have collaborated with Drs. Mauri Pelto (Nichols College, MA; glacier field studies), Christina Bandaragoda (University of Washington; glacier modeling), and Robert Mitchell (Western Washington University, river basin hydrologic modeling) to effectively assess the likely impacts of climate change on the river system. This information is used in assessing impacts to nine species of Pacific salmon in the watershed and inform fish habitat/watershed restoration planning taking climate change into direct consideration. We will present our preliminary results on establishing baseline conditions and our team's glacial and river basin modeling that incorporates climate change projections into Nooksack River hydrology. In addition, we will present results of applying our field data in the climate change model calibration and verification being conducted by the University of Washington and Western Washington University.

Developing a spatially explicit stream temperature model to assess population vulnerability of native trout to future climate change in the Crown of the Continent ecosystem, USA and Canada

Leslie Jones, University of Montana; Clint C. Muhlfeld, U.S. Geological Survey, Northern Rocky Mountain Science Center; Lucy A. Marshall, University of New South Wales*

Assessing the thermal dynamics of stream systems across space and time is fundamental for understanding hydro-ecological interactions and predicting species response to future climate change. Here we assembled a database of over 289,000 mean daily stream temperature records throughout the Crown of the Continent Ecosystem (CCE) in the Rocky Mountains of USA and Canada and used a Random Forest (RF) modeling approach to evaluate spatio-temporal patterns and processes and the relative importance of environmental drivers influencing seasonal stream temperature variation. We then applied this RF model to two cold-water, ectothermic species - bull trout and westslope cutthroat trout - to assess thermal habitats capable of supporting these species under future climate change scenarios. Specifically, we (1) evaluate use of RF models in predicting monthly stream temperatures, (2) use a RF model to identify seasonal climatic, geomorphic, geographic, and ecological processes influencing seasonal stream temperature variation, (3) interpolate stream temperature predictions across 104,600 km of stream habitat in the CCE, and (4) assess relative vulnerabilities of bull trout and westslope cutthroat trout populations to future climate warming. This stream temperature model will provide a useful tool for identifying areas of potential refugia for aquatic organisms under future climate change and informing conservation programs for freshwater species in one of the most biodiverse and intact ecosystems in North America.

The evolving contribution of glacier melt to summer streamflow in the Pacific Northwest: 1960-2099

Chris Frans, University of Washington; Erkan Istanbulluoglu, University of Washington; Dennis P. Lettenmaier, University of California Los Angeles; Andrew Fountain, Portland State University*

Many water resource and sensitive ecological systems in the Pacific Northwest are located downstream of partially glacierized headwater catchments. Glacier melt is a key component of hydrologic systems when other sources (rain, snowmelt) are at in minimum. Thus glacier recession can result in significant consequences to downstream systems during the dry season. Partially glacierized river basins display complex multi-phased patterns of hydrological response to increasing air temperature and reductions in glacier mass. These patterns of response vary greatly as a function of the rate of change in climate, particulars of the local climatology, the initial relative glacier cover, and the topographic setting of a river basin. To describe how partially glacierzed PNW river basins have changed historically and to predict the trajectory of these changes into the future we use an advanced glacio-hydrological simulation model, constrained with historical glaciological and watershed observations. We developed a sample of river basins used in

this analysis (Cascade-WA, Thunder-WA, Stehekin-WA, Hoh-WA, Hood-OR, and Nisqually-WA) to (1) characterize how hydrological response varies within the region, (2) to identify vulnerable downstream locations in space and time, and (3) to quantify at which spatial scales glacier melt is a significant contributor to streamflow. Our results show that despite ubiquitous declines in glacier area, discharge from glacier melt is predicted to increase and decrease depending on the topographic setting of the individual river basin. In river basins that originate at the highest elevations in the region, glacier melt and its relative contribution is projected to increase for some time, partially buffering negative trends in late summer streamflow driven by decreased seasonal snowmelt. In river basins at lower elevations glacier melt is projected to decrease with glacier recession, further exacerbating negative trends in summer streamflow.

Predicting the hydrologic response of the Columbia River System to climate change: Calibration and sensitivity analyses

Oriana Chegwidden, University of Washington; Mu Xiao, University of California, Los Angeles; David Rupp, Oregon State University, Oregon Climate Change Research Institute; Matt Stumbaugh, University of Washington; Joseph Hamman, University of Washington; Bart Nijssen, University of Washington*

The streamflow regime of the Columbia River Basin (CRB) is largely driven by the seasonal pattern of winter snow accumulation followed by spring snowmelt. As a result, anthropogenic climate change, and in particular its effect on snow, is expected to affect the timing, and potentially overall volume, of streamflow in the Columbia River. Anticipating these changes will be critical for flood control, hydropower generation, fisheries, navigation, and recreation. In this project, we aim to assess the effects of methodological choices in the hydrologic modeling process on streamflow projections and other hydrologic fluxes under climate change. To this end, we are implementing three independent hydrologic models, forced by output from ten global climate models (GCMs) depicting two representative concentration pathways (RCPs), downscaled in three unique ways. All three hydrologic models are implemented at 1/16th degree (~5km) resolution across the CRB and run at a sub-daily time step. The hydrologic model calibration was conducted independently for each grid-cell. The reference dataset of spatially-distributed runoff time series was derived from naturalized flows at gage locations using a Kalman filter technique. We will show validation results from the calibrations of the three models at sites throughout the basin in the form of routed streamflow time series and spatial maps of hydrologic fluxes. Then, we will discuss the resulting spatially-distributed parameter fields, which offer insights into the structure of the individual hydrologic models. In addition, we will discuss hydrologic sensitivity analyses, which provide a preliminary estimate of the effects of climate change in the CRB.

A bottom-up approach to identifying flood risks and climate change vulnerabilities

Julie Vano, Oregon Climate Change Research Institute

Extreme weather events have the biggest impact on society, yet are often the climate phenomena we understand least, especially in GCMs. Even though these understandings are limited, there are opportunities from a hydrologic perspective to use past weather events to better quantify conditions (e.g. extent, duration, and intensity of precipitation, snow pack, soil moisture) that caused those events. This will help identify how the character of simulated future events, as they continue to evolve, differs from those of the past. To explore this, this research works to develop an impacts-focused method that uses the same modeling framework as past climate change studies (global climate models, hydrological models, and impact assessment tools), but reverses the typical direction of information flow: first, resource managers identify a metric of concern, e.g., flow above X cfs at a certain gauge, then hydrologic factors that lead to the metric are diagnosed, and finally connections to climate drivers are quantified. This presentation will discuss the opportunities and challenges of this approach in the Pacific Northwest. Floods in the Skagit River in western Washington, selected after numerous meetings with stakeholders throughout the region, will be highlighted as a test case for this bottom-up approach.

High-resolution, intermediate-range forecasting for water resource management in Southern Idaho

Matt Masarik, Boise State University[*]*; Lejo Flores, BSU; Katelyn Watson, BSU; Eric Rothwell, USBR*

The water resources infrastructure of the Western US is designed to buffer variability in precipitation and snow storage, deliver reliable water supply to users, afford flood control for communities, and provide recreation opportunities for the public. Thus water resource management is a balancing act of meeting multiple objectives while trying to anticipate and mitigate natural variability of water supply. Currently, the forecast guidance available to management personnel is lacking in two ways: the spatial resolution is too coarse, and there is a gap at the intermediate time range (10-30 days). To address these shortcomings we explore the effectiveness of using a mesoscale numerical weather prediction (NWP) model as a means to generate high-resolution model guidance out to 30 days. A state of the art regional NWP model, the Weather Research and Forecasting (WRF) model, will be used for this work. To investigate the skill of WRF at predicting high-impact weather we use it to conduct a case study of a heavy precipitation event, occurring June 2-4, 2010, that produced flooding in the Payette River Basin of Idaho. The case study involves first running WRF using input from the Climate Forecast System version 2 (CFSv2) Reanalysis data to create a fine resolution simulation containing the episode. Next, we run WRF with CFSv2 Reforecast data, initialized at several different lead times, and use this to evaluate WRF's ability to capture the event. The next phase is to implement an operational forecast product designed for water resource management personnel at the Bureau of Reclamation. For this we use CFSv2 forecast data as input and will run WRF at a spatial resolution of 1 km, and temporal resolution of 1 hr. The forecasts will be generated bi-weekly for a lead time of 30 days. The product will be available to the Bureau of Reclamation, as well as the general public, via an online interface. To conclude we present the analysis of the June 2010 modeling case study by comparing the results of the Reanalysis forced run with those of the Reforecast simulations. Preliminary observations from the operational forecasts will be given. Lastly, an assessment of the usefulness of the WRF guidance to water resource managers is discussed.

Improved technology for Western water supply forecasts

Danny Marks, *USDA Agricultural Research Service Northwest Watershed Research Center*

As the climate in mountainous regions continues to warm, operational snow models based on unreliable statistical relationships to temperature are much less effective than in the past. ARS scientists in Boise, Idaho are now in the process of extending the use of the processed-based iSnobal model into operational management of water supply and streamflow forecasting. In the Boise River basin of Idaho, ARS is working with the US Bureau of Reclamation (BoR) to provide information on the state of snow volume, the thermal state, and any surface water input from melt or rain on bare ground throughout the winter and spring. In addition, current efforts are coupling iSnobal to a modified version of the University of Washington's Distributed Hydrology Soil Vegetation Model (DHSVM) to provide streamflow forecasts to BoR and other water managers. ARS scientists have also initiated evaluation of using the NCAR Weather Research and Forecasting (WRF) meso-scale model to generate forcing data so that the modeling tools could be applied in more remote or data limited locations.

Wildfire

Effects of climate change on snowpack and fire risk in the Western United States

Diana Gergel, University of Washington; Matt R. Stumbaugh, University of Washington; Dennis P. Lettenmaier, University of California at Los Angeles; Bart Nijssen, University of Washington*

Climate change is projected to result in declining snowpack, earlier snowmelt and a shorter snow season in the Western United States, which may affect fire risk. In this study, the impact of climate change on snowpack and soil moisture is evaluated for five mountain ranges in the Western United States: the Sierra Nevada, Cascades, Northern and Southern Rockies, and the White Mountains. Snow water equivalent (SWE) and soil moisture (SM) are simulated at a 1/16th degree resolution for the historical period (1950-2005) and the future period (2006-2099) using the Variable Infiltration Capacity (VIC) model, driven by ten Global Climate Models (GCMs) from the Coupled Model Intercomparison Project 5 (CMIP5) archive. The GCMs were downscaled using the Multivariate Adaptive Constructive Analogues (MACA) method, a statistical downscaling method that uses a training dataset of meteorological observations. For the future period, two Representative Concentration Pathways (RCPs), 4.5 and 8.5, are used. The multi-model ensemble average is computed over the selected GCMs. A second set of hydrologic simulations was done using historical gridded observations, simulated over grid cells surrounding Snow Telemetry (Snotel) sites, to validate simulated SWE with observed SWE. A pronounced decrease in SWE occurs in all mountain ranges and across all models. Decreases in SWE relative to historical climatology (1970-1999) are statistically significant (using a Welch's t-test) for all mountain ranges and all future periods (2010-2039, 2040-2069, 2070-2099) except for the Southern Rockies in 2010-2039. By the 2070-2099 period, SWE is projected to disappear during most years in lower elevations of the White Mountains. Earlier snowmelt and a shorter snow season also occur. Grid cells in each mountain range are classified as snow-dominant, transient or rain-dominant according to average winter temperature. The transition of grid cells from snow-dominant to transient, and transient to rain-dominant, is projected to occur throughout the Western US, as average winter temperature increases. Soil moisture shows an increase in March (driven by earlier snowmelt) and a strong decline in August (driven by reduced streamflow from snowmelt). Although the relative increases/decreases differ across models, the trends are robust for all models. This timing shift in soil moisture may affect the occurrence of fire, particularly at lower elevations that experience a stronger shift in snowmelt and soil moisture timing. Consequently, we evaluate the extent to which fire risk is affected and differences in fire risk projections for the 21st century across models.

Hindcasting climatic water balance scenarios in the Clearwater Region

Bridget Guildner, University of Montana; Solomon Dobrowski, University of Montana*

The Nez-Perce Clearwater Forest functioned as a refuge for a variety of herbaceous and amphibian species through the Last Glacial Maximum, and this refugium has been suggested as a possible explanation for the disjunct ranges of key inland wetbelt tree species such as western redcedar (Thuja plicata) and mountain hemlock (Tsuga mertensiana). While these wetbelt species may have migrated from the coast following warming, they could also have persisted in glacial refugia, or areas where the local climate decoupled from glacial regional climate enough to allow survival. Determining whether these species might have persisted at the Last Glacial Maximum requires multiple lines of evidence, including hindcasting of bioclimatic factors that drive tree establishment and survival. However, global climate model outputs are too coarse to capture the microclimatic variability of this region's complex topography and do not include information about the climatic water balance, which is a key driver of plant distributions. To hindcast the fine-scale climatic water balance at the mid-Holocene (6 kya) and the Last Glacial Maximum (21 kya) at an 800m resolution, I used broad-scale global climate model reconstructions for those periods from the Paleoclimate Model Intercomparison Project (PMIP) and compared those outputs to 800m current climate normals from TopoWX and PRISM to generate a set of climate anomalies for each time period. Anomalies were applied to current-day fine-scale climate inputs to generate distributions of plausible climate scenarios at 6kya and the LGM. I sampled conditions randomly from these distributions to drive a simple water balance model based on mean monthly temperature, dewpoint, and precipitation, wind speed, and soil water capacity, while accounting for evaporative demand and snowmelt dynamics. Finally, I used these water balance scenarios as inputs to boosted regression tree niche models built from Forest Inventory Analysis plot data to determine whether conditions could have allowed the survival and establishment of western redcedar and mountain hemlock. Work is ongoing, but preliminary results suggest that the LGM climate may have been able to support mountain hemlock, but not western redcedar, while the mid-Holocene appears to have been too inhospitable for both species. Work is underway to incorporate 250m temperature inputs for even finer-scale analysis suitable for juvenile niche models, and I will present these results as well.

The distribution and occurrence of wildfire refugia under a changing climate

Arjan Meddens, University of Idaho; Crystal Kolden, University of Idaho; Jim Lutz, Utah State University; John Abatzoglou, University of Idaho*

Refugia are important landscape elements by which ecosystems can maintain biodiversity and potentially recolonize areas that have become temporarily uninhabitable from disturbance events. Refugia are key to conservation ecology, especially given recent rapid climate change. Wildfire is an important driver that determines spatiotemporal patterns of the landscape. By burning at different severities (from unburned to severe burning), wildfires create a mosaic of landscape elements that vary in time and space. Areas that are minimally impacted by fire (i.e., unburned islands) can function as refugia for a diverse range of biota. Our project objectives are to (1) evaluate methods for detecting un- (or minimally) burned areas within fire perimeters using Landsat imagery, (2) hindcast our best classification method to the entire Landsat image archive (1984-2015) to detect the distribution of past unburned areas, and (3) link changes of occurrences, distributions, and sizes of these unburned islands within the inland northwest to a changing climate. Locations within fire perimeters that were unburned or slightly burned in 2012 and 2014 were visited in the field one-year post fire. We collected fire severity information and related these observations to Landsat satellite data. We used a variety of Landsat band and acquisition time combinations, and classification techniques to separate burned from unburned areas. We discuss initial results on the detection, evaluation, and distribution of unburned islands within a single fire year. In addition, we discuss strategies on linking the occurrence of these unburned islands to changes in climate. Quantifications on the size and distribution of unburned areas will lead to better understanding and improved management strategies maintaining important wildfire refugia over the entire landscape.

Fire refugia: The physical and hydrologic basis

Zachary Holden, U.S. Forest Service; Marco Maneta, University of Montana*

Stand-replacing wildfires play a fundamental role in the persistence of species at local scales. We examine the climatic and physical factors that could mediate the severity of wildfires in mountainous terrain using high resolution topographically resolved meteorological inputs and a spatially distributed ecohydrology model. We examine separately the sensitivity of modeled evapotranspiration and late season soil moisture to wind, radiation, soil depth, minimum temperature and humidity. A suite of physical factors including lower wind speeds, cold air drainage solar shading and increased soil depth reduce evapotranspiration and increase moisture availability in valley bottoms. Evapotranspiration shows strong sensitivity to spatial variability in surface wind speed, suggesting that sheltering effects from winds may be an important factor contributing to mountain refugia. Using satellite-derived maps of burn severity for recent fires in the US Northern Rockies and topographically resolved historical climate data, we examine relationships between wind speed, cold air drainage potential and soil depth and the occurrence of unburned and low severity fire. Statistically significant differences in severe fire occurrence suggest that sheltered valley bottoms with high cold air drainage potential have mediated the severity of recent wildfires. Our finding highlight the complex physical mechanisms by which mountain weather and climate mediate fire-induced vegetation changes in the US Northern Rocky Mountains.

Wildlife

Predicting climate change impacts on river ecosystems and salmonids across the Pacific Northwest

Clint Muhlfeld, USGS Rocky Mountain Science Center; Gordon Luikart, University of Montana; Ryan Kovach; Leslie Jones*

Salmonids – a group of coldwater adapted fishes of enormous ecological and socio-economic value – historically inhabited a variety of freshwater habitats throughout the Pacific Northwest (PNW). Over the past century, however, populations have dramatically declined due to habitat loss, overharvest, and invasive species. Consequently, many populations are listed as threatened or endangered under the U.S. Endangered Species Act. Complicating these stressors is global warming and associated climate change. Overall, aquatic ecosystems across the PNW are predicted to experience increasingly earlier snowmelt in the spring, reduced late spring and summer flows, increased winter flooding, warmer and drier summers, increased water temperatures, and expansion of invasive species. Understanding how effects of climate change might influence habitat for native salmonid populations is critical for effective management and recovery of these species. Scientists at the USGS and University of Montana used novel techniques and empirical data to study how climate change may drive landscape scale impacts that affect freshwater habitats and populations of key salmonid species (bull trout, cutthroat trout, and steelhead) throughout the PNW. Results showed strong linkages between climatic drivers – temperature and flow regimes – and the distribution, abundance and genetic diversity of native salmonids across the PNW. Specifically, warming temperatures and shifting flow regimes are expected to fragment stream systems and cause salmonids to retreat upstream to headwater areas, thereby decreasing fish population abundance and genetic diversity – both of which are critical for persistence in a changing landscape. Climate-change-induced periods of decreasing spring snowmelt and increases in stream temperatures are likely to decrease native biodiversity by fostering cross-breeding between invasive and native trout species. The study also developed a new framework for assessing the vulnerability of freshwater species to climate change and other stressors in complex stream networks, which will aid managers in pro-actively implementing conservation programs to increase resiliency and adaptive capacity of aquatic species.

Incorporating climate change into salmon habitat restoration planning in the South Fork Nooksack River, Washington

Treva Coe, *Nooksack Tribe*[*]*; Steve Klein, EPA-ORD; Jezra Beaulieu, Nooksack Indian Tribe*

Evidence is growing that climate change will have significant ramifications for salmon recovery in the Pacific Northwest. The effects of climate change could be particularly profound for Pacific salmon since they are already substantially stressed by legacy impacts and contemporary climate changes. These systems often lack resilience and are strongly dependent on temperature and stream flow regimes that are already impacted by excessive temperatures and low flows caused by past and present land uses. It is critical that watershed management, habitat restoration planning, and regulatory approaches incorporate climate change science and understanding to preserve and restore the natural habitat of sensitive and endangered species. The South Fork Nooksack River (SFNR) is one of three forks of the mainstem Nooksack River located in northwest Washington State. The river supports nine species of salmonids including three species that are federally listed as endangered under the endangered species act. Substantial effort has been expended to recover drastically reduced populations of salmon. The SFNR is listed as a Category 5 water body on the Clean Water Act Section 303(d) list of impaired waters for excessive temperatures. This designation requires that a Total Maximum Daily Load (TMDL) evaluation be conducted that identifies baseline or natural temperature loading, sources of temperature loading due to humans, and methods to bring the river back into compliance with State water quality standards and numeric criteria based on salmonid core summer, spawning, incubation, and migration habitats. The temperature TMDL primarily addresses numeric water temperature standards without directly addressing salmon life requisites, recovery, restoration planning, and climate change. EPA Washington Department of Ecology, and the Nooksack Indian Tribe initiated a pilot research project in 2012 that addresses climate change in the temperature TMDL project for the South Fork Nooksack River. In collaboration with these agencies, the Nooksack Indian Tribe conducted a qualitative assessment of climate change impacts on the watershed, including hydrologic changes, physical and biological limiting factors, fish distributions, and watershed/salmon habitat restoration planning by applying the Beechie et al (Beechie et al. 2012) methods, Restoring salmon habitat for a changing climate. The qualitative assessment evaluates existing stressors and limiting factors that relate to excessive temperatures, reviews and develops salmon habitat restoration plans that facilitate salmon resilience in the face of climate change. This presentation will summarize the results of the qualitative assessment that specifically addresses salmon survival and habitat restoration efforts in the face of climate change and that informs related ESA Recovery Plan and local salmon recovery efforts.

Microclimatic envelopes of terrestrial gastropods

Michael Lucid, Idaho Department of Fish and Game; Sam Cushman, USFS Rocky Mountain Research Station; Andrew Shirk, UW Climate Group; Shannon Ehlers, Idaho Department of Fish and Game; Lacy Robinson, Idaho Department of Fish and Game; Chris Witt, USFW Rocky Mountain Research Station*

Low vagility ectothermic organisms with permeable skin are often thought to be more sensitive to environmental conditions than organisms without these characteristics. However, quantitative analyses which delineate environmental conditions for wide suites of such species are rare. Global temperatures are predicted to rise 2-4°C in the next 20-30 years and it may be possible to manage micro-climates to maintain suitable temperature ranges for species if narrow micro-climatic niches are delineated. From 2010-2014 the Multi-species Baseline Initiative co-located air temperature data loggers with terrestrial gastropod surveys at 879 survey sites across 22,975 km2 in northern Idaho and adjoining mountain ranges. At each site we collected air temperature every 90 minutes for 1-4 years and calculated mean annual air temperatures for each site (-0.242-14.174°C, mean = 6.311°C). We collected 9,391 gastropod specimens representing 58 species. For species detected at ≥15 survey sites (n = 26 species) we determined 19 (73%) showed strong association within a 2-4°C temperature range. These species were classified as having 'warm' (n = 9 species, 35%) or 'cool' (n = 10 species, 35%) climatic envelopes dependent on if the mean detection site temperature was greater or less than the study area mean temperature (6.311°C).

This data-set of air temperature associations for low vagility species will help inform management actions to maintain necessary micro-climate conditions for terrestrial gastropods.

Integrating climate change into state wildlife planning examples from Idaho and Washington

-- This presentation is a collaboration incorporating the two abstracts below --

Leona Svancara, Idaho Department of Fish and Game[*]*; Rita D. Dixon, Idaho Department of Fish and Game*

Idaho's climate is changing and undoubtedly is affecting the range and extent of native species' distributions, abundance, and interspecific interactions, as well as the habitats upon which these species depend. To the best of our ability, the Idaho Department of Fish and Game (IDFG) is adapting management strategies and priorities based on the changing conditions that native species face. One of the primary means for doing so is through the revision of the Idaho State Wildlife Action Plan (SWAP), a plan aimed at identifying Species of Greatest Conservation Need, addressing the most critical threats, and precluding the need to list species under the Endangered Species Act. SWAPs are mandated by Congress to address 8 required elements: 1) species distribution and abundance, 2) locations and condition of key habitats and community types, 3) problems that may adversely affect species or their habitats, 4) conservation actions, 5) monitoring of species, their habitats, and the effectiveness of conservation actions, 6) plan review and revision every 10 years, 7) coordination with conservation partners, and 8) inclusion of broad public participation. The revised Idaho SWAP will be completed by October 1 of this year and we discuss ways in which aspects of climate change are addressed in all 8 required elements, with particular emphasis on the climate data and methods used in the species conservation assessments and ecological section plans. We highlight challenges associated with addressing climate in species management and additional research needs. We hope that our efforts to minimize the risks of climate change and maximize benefits to species and their habitats will help to preserve our native fauna for future generations.

Lynn Helbrecht, Washington Department of Fish and Wildlife[*]*; Jessi Kershner, EcoAdapt*

This presentation will describe the results and lessons learned from a Washington Department of Fish and Wildlife (WDFW) project to integrate climate change considerations into a required State Wildlife Action Plan (SWAP). Our overarching goal was to understand how climate change would affect the conservation status of the species and habitats addressed in the SWAP, and to inform decisions about modifying priorities or specific actions in response. Products from this project include vulnerability descriptions and rankings for each of the 268 species of greatest conservation need (SGCN) identified in the SWAP, as well as 28 ecological systems of concern. Ecological systems were selected as the classification unit for habitats in the SWAP in part because they are mapped across the state and enable spatial analysis. We mapped/plotted species and ecological system vulnerability and confidence to highlight those resources with high vulnerability and high confidence, as well as those with low confidence. Those with high vulnerability and high confidence we placed on a climate watch list and those with low vulnerability we have highlighted for additional research and data needs/monitoring or expert input. Project results are also expected to inform decisions about where landscape actions can be leveraged for long-term benefit to species and habitats. Identifying which ecological systems are most at risk from climate change, and where those systems occur across the state provides an important spatial component to our understanding of the impacts of climate change. Lessons learned include the importance of engaging staff early in project development and product review. The concepts, resources and methodology for assessing climate vulnerability are still new to many, and we experienced reluctance from some staff to embrace the findings, in part due to a lack of understanding about the methodology and underlying concepts. We also recognize the importance of including staff expertise more fully in the assessment content. For these reasons, a series of workshops are planned for Phase II in order to provide an opportunity for WDFW staff and others to review project methodology, add expert input to the vulnerability assessments and create more project buy-in with the aim of having climate related information better incorporated into management actions.

Special Sessions

Northern Rockies Adaptation Partnership

Adapting natural resource management to climate change: Vulnerability of water resources in the Northern Rockies

Charles H. Luce, U.S. Forest Service, Rocky Mountain Research Station

Many consequences of climate change for terrestrial and aquatic ecosystems occur through impacts on the water cycle, including changes to precipitation, snowpack, glaciers, annual water yield, summer low flows, peak runoff, and stream temperature. Some changes are primarily driven by temperature change, for which we have relatively robust predictions. Other changes have substantial dependence on precipitation, which has a very uncertain future in the climate models. Understanding relative sensitivities and historical contexts of changes offers an opportunity to frame the consequent uncertainties in projections. This presentation will cover how changes in precipitation and temperature are expected to manifest in changes to water quantity, timing, and quality across the USFS Northern Region and portions of the Greater Yellowstone Area, along with quantitative and qualitative assessments of the uncertainty.

Adapting natural resource management to climate change: Vulnerability of rangelands in the Northern Rockies

Matt C. Reeves, U.S. Forest Service, Rocky Mountain Research Station

Within the Northern Rockies, rangelands occupy 26 million hectares and provide numerous ecosystem functions. Goods and services derived from rangelands in the region include forage for millions of domestic and wild ungulates, greater sage-grouse habitat, and numerous recreational opportunities. Presently, the sustainability of these goods and services are threatened by land-use change, residential development, energy development and invasive species. These threats, expressed against the backdrop of climate change pose unique challenges for resource managers in the region. Interactions among land-use change, management, and climate change are poorly understood. As part of the Northern Rockies Adaptation Partnership, northern Great Plains, mountain and valley grasslands sagebrush, and montane shrublands were evaluated in terms of their vulnerability to expected ranges of climate change. Those vegetation types supporting non-sprouting taxa and those existing in sites that are susceptible to invasive species are more vulnerable. Droughts of greater intensity and length combined with invasive species and changing fire regimes probably contribute most to vulnerability of these vegetation types.

Adapting natural resource management to climate change: Vulnerability of recreation in the Northern Rockies

David L. Peterson, U.S. Forest Service, Pacific Northwest Research Station; Michael S. Hand, U.S. Forest Service, Rocky Mountain Research Station

Recreation is one of the most important ecosystem services in the Northern Rockies, annually generating 13 million visits to national forests and national parks, and $800 million in expenditures. Summer recreation is expected to benefit from climate change, because less snowpack and warmer temperatures will extend opportunities for access to high-elevation destinations during the "shoulder seasons" in spring and autumn, although very high temperatures may discourage some terrestrial activities and shift them to lakes and streams. Lower snowpack and higher warmer temperatures will have a significant negative impact on snow-based winter recreation, especially downhill and cross-country skiing. Effects on hunting are expected to be neutral to slightly positive, and effects on fishing are expected to be slightly negative. Increased wildfire, a likely secondary effect of climate change, will generally discourage most outdoor activities during the summer. Federal agencies can increase the resilience of recreation to climate change by (1) diversifying activities across multiple seasons in areas that are currently used for winter sports, and (2) increasing flexibility in availability of facilities and employees for expanded summer recreation. Preliminary evidence from 2015 suggests that recreationists are highly adaptable with respect to the availability of recreation opportunities in space and time.

Implementing climate change adaptation in resource management and planning in the Northern Rockies

Jessica Halofsky, University of Washington

Resource managers are struggling to incorporate climate change information into long-term program planning at appropriate temporal and spatial scales to strategically assess which actions may be more appropriate at specific sites. The Northern Rockies Adaptation Partnership (NRAP) climate change vulnerability assessment provides a framework for resource managers to incorporate the best available science into landscape planning. In addition, the development of adaptation options contributes to decision support by applying the assessment information to strategic and on-the-ground tactics for varying management operation levels. NRAP products provide an opportunity for federal agencies to apply best science to develop land management plans, prioritize and evaluate adaptation actions, monitor vulnerabilities and efficacy of adaption actions, and incorporate climate change information in project design and NEPA analysis. Although the vulnerability assessments provide valuable information, additional work may be needed to apply assessment information and adaption strategies. The assessment can be used to develop spatial tools to depict where there are current and projected vulnerabilities. Decision support tools, including summaries of critical questions, can be developed to assess the need and urgency for actions.

Successful Adaptation to Climate Change

Successful Adaptation to Climate Change: Framework, Indicators and Metrics
Amy Snover, University of Washington Climate Impacts Group
The session will focus specifically on the question of what "success" in climate change adaptation might mean, and how one might define and measure it. Against a backdrop of accelerating change, increasingly apparent impacts, tightening budgets and growing competition for available resilience funds, and hostile or ambivalent public engagement, practitioners are under pressure to not just propose adaptation strategies, but defend them in budget negotiations, public hearings, and legal proceedings and to demonstrate their effectiveness and multiple benefits. In this session, participants will be introduced to a framework for defining and evaluating adaptation success developed with scientists, practitioners and stakeholders on the West Coast. Through facilitated discussion, session participants will examine the four key dimensions of success (process, decision, action, outcome) in the context of their own work, collectively working to identify key traits of success, capabilities needed to realize that success, and ways that barriers can be overcome. The session will conclude with a discussion on potential metrics and indicators for each of the four dimensions of success. The active engagement and collaborative approach to the session aims to exchange experiences from examples from across the Northwest and scales of governance (local, regional, state, federal, tribal), while considering multiple interests that need to be integrated in adaptation efforts (e.g., public safety, property rights, ecological integrity, economic activity, culture and community resilience). Session participants will (1) understand the powerful role that explicit attention to defining and tracking adaptation success can play in building resilience and (2) be ready to deepen their attention to success in their own initiatives, using new resources that reflect current state-of-the-art in climate change adaptation practice, science, and scholarship.

World Café style breakout groups

Facilitated by: Amy Snover, Lara Whitely Binder, Joe Cassola, Meade Krosby, University of Washington Climate Impacts Group

Water Crossing Design and Decision Making

Flood Risk Response to Climate Change in Olympic National Park and Implications for Culvert Design

Ingrid Tohver, Climate Impacts Group; Alan Hamlet, University of Notre Dame; Se-Yeun Lee, Climate Impacts Group*

A warmer future climate is expected to change flood risks in the Pacific Northwest, posing considerable challenges to natural resource managers in the Olympic National Forest (ONF) and Olympic National Park (ONP). A key part of management in the ONF and ONP involves maintaining the network of forest roads, and specifically those requiring water-crossing structures present a suite of complications. The sizing of culverts and related infrastructure is a particularly complex aspect of stream crossing design, and climate change impacts introduce additional challenges. Current practice is based on the Northwest Forest Plan aquatic conservation strategy that applies estimates of Q100 (or the peak flow with an estimated 100 year return frequency) extrapolated from historical observations, plus associated debris, as the standard metric for stream crossing design. Simple regression models relating observed annual precipitation and basin area to Q100 are the key metrics used in the design process. Under the projections of a changing climate, these methods for estimating flood risk are inadequate for capturing the complex and spatially varying effects of seasonal changes in temperature, precipitation, and snowpack on flood risk. As an alternative approach, this study applies a physically-based hydrologic model to estimate historical and future flood risk at 1/16th degree (latitude/longitude) resolution (about 32 km2). We downscaled climate data derived from 10 global climate models to the 1/16th degree spatial resolution over the region of the Olympic Peninsula. The downscaled meteorological data are then used as inputs for the Variable Infiltration Capacity (VIC) model, a macro-scale hydrologic model, which simulates hydrologic variables at a daily time step. At each 1/16th degree grid cell baseflow and run-off variables were used to estimate Q100 for the historical period and under two emission scenarios, A1B and B1, at three future time intervals: the 2020s, the 2040s and the 2080s. Results from this analysis show an overall pattern of increased flood risk in mid-elevation basins where projected temperature increases shift the precipitation patterns from snow to rainfall. This overarching trend triggers an increase in instantaneous runoff over an enlarged basin area, rather than snow accumulation at moderate elevations. These ensemble estimates of changing flood risk could serve as a tool for evaluating needed changes in culvert design in the Olympic Peninsula by providing high-resolution maps of changing flood risk over the areas managed by the ONF and ONP.

Geospatial tools for future peak streamflow estimation in culvert management at North Cascades National Park Complex

Ronda Strauch, University of Washington Watershed Dynamics Research Group; Ekran Istanbulluoglu, University of Washington; Regina Rochefort, University of Washington*

The long-term resilience of culverts depends substantially on anticipating the peak streamflows and designing culverts to convey these flows and associated sediment and debris. Conventional estimation of flood magnitudes relies on historical streamflow measurements, but physically-based hydrologic models driven by future climate scenarios simulated by global climate models provide opportunities to assess climate change impacts on flood frequency and magnitudes. In our study area at the North Cascades National Park Complex, where culvert washouts have repeatedly damage roadways and trails, the Variable Infiltration Capacity (VIC) macro-scale hydrology model indicates higher 100-year flood magnitudes in the future. Projected streamflow estimates from the VIC hydrologic model are at daily scale, which underestimates peak flows generated from instantaneous (15-minute) streamflow gage records. Consequently, we examined several approaches to use the spatially-distributed VIC simulations of historic and future streamflow to more closely match the peaks from instantaneous flow records. Additionally, we compared methods of integrating the VIC data into the USGS StreamStats tool readily available to land managers for estimating current peak streamflows. Geospatial and spreadsheet tools were developed to easily integrate the VIC model information on future streamflow into existing culvert assessment and design practices. The additional hydrologic processes captured by the VIC model combined with the rapid estimation of peakflows at any culvert location provides the potential for practical integration of climate change information into current infrastructure management.

An applied case study to integrate climate change into design and permitting of water crossing structures

Timothy Quinn, Washington Department of Fish and Wildlife; Jane Atha, Washington Department of Fish and Wildlife Habitat Science Division; George Wilhere, Washington Department of Fish and Wildlife; Jennie Hoffman, Climate Adaptation Research; Ingrid Tohver, University of Washington Climate Impacts Group*

The Washington Department of Fish and Wildlife (WDFW) provides technical guidance for the design of nearly every one of hundreds of fish passable water crossing structure that are constructed or repaired each year. In addition, WDFW permits fish passage structures on all lands except those covered under Forest Practice rules and designs fish passage structures for its own lands. None of WDFW's actions to ensure culvert designs meet high scientific standards account for changes in hydrology resulting from climate change. We evaluated the current WDFW culvert design and permitting decision process to identify design elements and decision points potentially sensitive to climate change impacts. We identified bankfull width as a primary culvert design criterion that was also sensitive to climate change. To determine how bankfull width might change in the future, we translated fine-scale hydrologic extreme projections across the state into predicted bankfull width estimates. We derived bankfull width estimates at 1/16th grid cell resolution from the Variable Infiltration Capacity (VIC) hydrologic model simulation of historical stream discharge as well as for two times-series, 2030-2059 and 2070-2099, within the A1B climate scenario (a composite of ten climate models). For each grid cell, the agency can multiply the projected ratio of change, averaged over the ten models, to empirically measured bankfull width at a culvert site to determine projected changes in bankfull width. Cumulative distribution graphs illustrating the range of model projections of bankfull width estimates at grid cell resolution also allow the agency to quantify and assess climate-associated risk of fish passage culvert failure at an operational level.

Washington State Coastal Resilience and Collaboration

Building Coastal Community Resilience through Effective Partnerships

Michael Levkowitz, Hershman Fellow, Washington Department of Ecology; Jamie Mooney, Washington Sea Grant; Bobbak Talebi, Department of Ecology*

The Coastal Hazards Resilience Network (CHRN) is comprised of hazards and climate change practitioners from federal, tribal and state government agencies, academic institutions, and nonprofit organizations in Washington State. The CHRN aims to improve regional coordination, integration, and understanding of coastal hazards and climate change impacts through the establishment of effective partnerships. In addition, the network aims to address multi-hazard planning, preparedness, adaptation, response and recovery as critical needs in Washington State. To help strengthen local capacity to reduce risk, FEMA initiated a Risk MAP (Mapping, Assessment, and Planning) program to provide communities with enhanced multi-hazard data and assessment information. This process culminates with a Resiliency Meeting where FEMA-generated data is presented to local communities. Resiliency meetings also offer an opportunity for local governments to provide feedback on FEMA's risk assessment and highlight additional areas of concern. The CHRN has partnered to support FEMA's efforts through the Risk MAP process by further supporting the needs and interests of communities beyond the Resiliency Meetings to move towards implementation. As a result of this work, the CHRN has been able to assist two communities with high priority hazard issues (North Cove and the City of Ocean Shores) and will continue to help address the needs of Washington's coastal communities identified through the Risk MAP process and other forums.
This presentation will highlight the CHRN's role in the FEMA RiskMAP process and will continue with the results of that partnership through two community case studies: Ocean Shores and North Cove. These two coastal communities are facing severe shoreline erosion, one of which has the fastest eroding shoreline on the US Pacific Coast. As a result of the heavy erosion, the land under the homes in North Cove is disappearing, leaving the homes in danger of "falling into" the Pacific Ocean. Due to the heavy storms in December 2014, three separate homes fell victim in one week. The community of

Ocean Shores has historically implemented short-term solutions due to immediate need of preparation and response to severe storms, to protect its condominium development, however those solutions have aged and are now failing. The drastically eroding shorelines in both communitites are jeopardizing the safety and livelihoods of residents. The CHRN's efforts to provide technical assistance and management solutions for each community will be showcased as part of this presentation.

Climate Resilient Floodplains: Assessing Climate Impacts of Concern to Puget Sound Communities

Julie Morse, The Nature Conservancy; Lara Whitely-Binder, UW Climate Impacts Group; Guillaume Mauger, UW Climate Impacts Group*

The low elevation coastal floodplains of Puget Sound are particularly sensitive to changes in climate due to the intersection of sea level rise, increasing peak flows, and changing sediment loads. These changes have consequences for the economic, cultural, and natural resources that communities rely on. Responding to climate change will not be a "one-size-fits-all" approach. It is critical to understand the context of each watershed, so that climate information can be tailored to address the specific needs of stakeholders and decision-makers. This presentation will summarize information gained through a series of climate interviews conducted in the Stillaguamish and Puyallup River watersheds. The goal of this assessment was to identify priority floodplain issues that are affected by climate change, in order to better integrate climate information into watershed planning processes. This assessment will also inform how climate change is integrated into the regional funding programs of Floodplains by Design and the Regional Conservation Partnership Program. This work is part of the larger "Climate Resilient Floodplains" project, funded by NOAA. A companion presentation will describe a synthesis of climate change impacts on floodplains and an evaluation of project-specific information needs for climate resilient planning.

Climate Resilient Floodplains: Bringing Climate Science into Project Design

Guillaume Mauger, University of Washington Climate Impacts Group

Floodplains are home to a wide range of economic, cultural, and natural resources. Recent efforts have emphasized collaborative decision-making across multiple floodplain interests, as well as a more holistic perspective on watershed-scale planning. Although there is a strong desire to include climate change into these planning efforts, very little guidance has been developed to help incorporate climate impacts into risk assessments and project design. This presentation will describe the "Climate Resilient Floodplains" project, funded by NOAA as a first step at addressing this need. In this talk we will discuss two key aspects of the project: (1) a synthesis of climate change impacts on Puget Sound floodplains, developed as a resource for stakeholders, and (2) an evaluation of currently-funded projects to identify the specific climate data and research that is needed to inform project design or implementation. A companion presentation will describe the the results of a series of in-person interviews designed to explore concerns and vulnerabilities of stakeholders and inform local and regional decision-making processes.

Climate Impact Pathways through Sediment to Inform Coastal Resilience Planning

Eric Grossman, U.S. Geological Survey; Chris Curran, Washington Water Science Center; Andrew Stevens, USGS Pacific Coastal and Marine Science Center; Steve Rubin, USGS Western Fisheries Research Center; Chad Stellern, Western Washington University; Abbas Hooshmand, Swinomish Indian Tribal Community*

Ongoing impacts of sediment aggradation in stream channels that affect flood risk and disturbance to essential habitats for salmon recovery (tidal marsh, channels, eelgrass) resulting from channelizing flow are projected to be exacerbated by climate change across the Pacific Northwest. Improved understanding of these impacts and development of metrics and models to detect change and monitor performance of land use actions are intended to help managers implement adaptive management strategies for increased resilience. An expected shift by 2080 to more precipitation as rain, especially on steep mountain slopes exposed by retreating glaciers and snowpack is projected to increase the intensity of floods and fluvial sediment loads in glacier-fed streams by 3-6 times present amounts. As sea level rise inundates coastal environments the extent and frequency that tides and storm surge retard stream flows will increase and promote stream channel sedimentation farther upstream. The current and historical loss of sedimentation on floodplains as fluvial sediment continues to be focused to the nearshore and deeper depths of Puget Sound through levees has led to ~1m of local subsidence across extensive and nationally important agricultural lands and greater flood risk and drainage challenges. New empirical data and models summarizing the extent and frequency of the joint occurrence in stream flows, tidal anomalies, suspended and bedload sediment flux and routing, vertical land movements, and coastal hydrodynamics (currents, waves, and regional sea level rise) that affect water levels and sedimentation across floodplain-estuary-nearshore environments, reveal that legacy land use effects have reduced coastal resilience and will challenge Puget Sound recovery and planning. Models linking climate change downscaling, sediment transport and coastal change help identify opportunities for coordinated investments to reduce coastal hazards while enhancing ecosystem functions that valued wildlife and people depend upon. Lessons learned from the largest estuary restoration in the Pacific Northwest at Nisqually Delta, the March 2014 SR530 (Oso) landslide, and recent avulsions on the Nooksack and Skagit rivers help to highlight information needs, metrics, and priorities for sequencing and implementing ecosystem restoration and adaptation planning across the dynamic floodplains, estuaries, and beaches of the Pacific Northwest. We will also describe research results summarizing the wave and sediment attenuation capacity of several Puget Sound tidal marsh plants, scales of nearshore roughness important to wave dissipation, and sensitivity of wave transformation models to rising sea level that are being integrated into the Puget Sound Coastal Resilience Tool (spatial.wwu.edu/coastal/resilience).

Poster Session

Agriculture: Impacts and Adaptation

P1

How temperature and water potential affect the growth of Fusarium and Rhizoctonia pathogens of wheat

Iqbal Singh Aujla, Washington State University; Paulitz, Tim, USDA-ARS, Root Disease and Biological Control Research Unit, Pullman, WA*

Climate change is projected to shift the temperature regimes and type of winter precipitation in the Pacific Northwest region of the United States. Temperature and moisture are two major factors influencing the activity of soil-borne pathogens like Fusarium culmorum, F. pseudograminearum, Rhizoctonia solani AG-8 and R. oryzae causing crown and root rots of wheat respectively, in the dryland wheat production area. This study has been undertaken to decipher the influence of temperature and water potential on the biological activities of these wheat pathogens. These pathogens were grown on potato dextrose agar, potato dextrose broth, and wheat straw or toothpicks adjusted to different osmotic and matric potentials (-0.13 to -10 MPa) with sodium chloride, potassium chloride, and polyethylene glycol (PEG-8000), and incubated at temperatures ranging from 4 to 35°C. Fusarium spp. grew optimally at 20 - 25°C and -1 to -3 MPa. A decline in growth rate was observed at lower water potentials, but growth rates were 0.07 - 3.34 mm/day even at -9 MPa. Rhizoctonia solani AG-8 was more restricted for optimal growth at 20-25°C and -0.13 MPa. The optimal growth of R. oryzae occurred at 30°C and -0.13 MPa, but the growth rate declined less compared to AG-8 with lower water potential and temperature. R. oryzae was the only pathogen to grow at 35°C where the optimum water potential was -2 MPa, compared to -0.13 MPa at temperatures lower than 35°C. The effect of water potential was independent of salt composition. This study contributes to the knowledge of the biology and epidemiology of these pathogens, and will be used in predicting their potential distribution under future climate scenarios.

P2

Climate drives soil health in the inland Pacific Northwest

Jason G. Morrow, Washington State University; Huggins, David, USDA-ARS; Reganold, John, WSU; Carpenter-Boggs, lynne, WSU; Collins, Hal, USDA-ARS; Gollany, Hero, USDA-ARS; MAchado, Stephen, CBARC OSU, Johnson-Maynard, Jodi, University of Idaho*

Mean annual precipitation (MAP) and mean annual temperature (MAT) are critical drivers of soil organic matter (SOM) levels, influencing both above ground productivity and decomposition rates. SOM is critical to many important soil processes, and subsequently an essential consideration when evaluating soil health. Consequently, climate is an important consideration both in monitoring soil health across regional climate gradients, as well as in understanding how future climate scenarios may impact soil health. Management practices also have the potential to promote SOM aggradation or degradation. For example, tillage facilitates microbial degradation of SOM by promoting crop-residue-soil contact and by placing residues into a moister sub-surface environment compared to surface placement of residue under no-till (NT). Furthermore, studies have found that cropping intensification along with NT is necessary to build SOM levels. In this study, we measured multiple soil carbon (C) and nitrogen (N) properties across four agricultural sites within the wheat-based cropping region of the inland Pacific Northwest (iPNW). These four sites capture a range of tillage and cropping intensities, span a MAP gradient ranging from 26 inches to 16 inches, and a MAT gradient ranging from 51oF to 47oF. The objectives of this study were to, 1) identify how MAP and MAT interact with tillage and cropping intensity to determine soil C and N levels, and 2) based on this present day relationship between MAP, MAT and soil C and N properties, project how future climate scenarios will impact SOM, and subsequently soil health. In a multivariate model that included MAT, MAP, as well as tillage and cropping intensity, MAP explained 57% of SOC variability and 69% of total soil N variability. When MAP was removed from the model, MAT became the dominant variable, explaining 42% and 49%, respectively, of SOC and total N variability. Both the acid hydrolyzable and non-hydrolyzable fractions of SOC were equally sensitive to MAP and MAT, indicating no relationship to chemical recalcitrance and climate sensitivity. A present-day climate ratio (MAT/MAP) was significantly correlated with soil C (r = -0.82) and N (r = -0.88) levels. Future climate scenarios for the iPNW translate to an increase in the climate ratio. Utilizing the present day relationship between the climate ratio and soil C and N levels, a reduction in SOM levels across the iPNW under future climate scenarios is predicted. This bolsters the need for management which promotes SOM aggradation to mitigate a decline in soil health.

P3

Impact of climatic factors on cereal aphid's population density in the Pacific Northwest, USA

Seyed Ebrahim Sadeghi, University of Idaho; Davis, S. Thomas, University of Idaho; Wu, Ying, University of Idaho; Sahfii, Bahman, University of Idaho; Abatzoglou, John, University of Idaho; Eigenbrode, D. Sanford; University of Idaho*

Direct and indirect damage from aphids to crops are limiting factors for cereal crops in the Pacific North West region of United States (PNW-USA) as well as worldwide. At least ten aphid species have been known to occur in cereal crops and on perennial and annual grasses within the region. The development of sustainable integrated pest management (IPM) programs are needed to inform ecosystem management approaches across spatial large scales. This study aimed to evaluate climatic factors impact on four main cereal aphids in the PNW-USA. Aphid samples were collected by sweep net in 108 Regional approach for climatic change (REACCH) sites from May to July 2011-2014. Statistical analyses to evaluate correlation structure between climate variables and aphid densities

were conducted using SAS (9.4). Cumulative degree (CDD) and cumulative precipitation (CP) were calculated for each of the sampling sites. Significant correlations were detected among densities of aphid species and daily climatic factors (temperatures, relative humidity), CCD, and CP within each year as well as for the data pooled across all years. We found a trend of significant positive association between daily temperature and CDD with densities of individual aphid species, as well as total aphid densities. Conversely, a significant trend of negative association was observed between daily relative humidity and CP with aphid densities. The significant correlations between CDD and aphid population densities suggest that CDD can be used as a management tool for cereal aphid IPM and prediction of inter-annual aphid abundances in cereal fields of Pacific North West region of USA. It will be necessary to calculate CDD in multiple ecological zones across the seasonal phenology of each aphid species to expand our current understanding.

P4

Introducing the Eddy Covariance system to improve water use efficiency and grape quality in Washington vineyards

Sayed-Hossein Sadeghi, Washington State University; Jacoby, Peter, Washington State University, Dept. of Crop and Soil Sciences; Lamb, Brian, Washington State University, Dept. of Civil and Environmental Eng.; Chi, Jinshu, Washington State University, Dept. of Civil and Environmental Eng.; O'Keeffe, Patrick, Washington State University, Dept. of Civil and Environmental Eng.; Liu, Heping, Washington State University, Dept. of Civil and Environmental Eng.; Bartoshevich, Randy, Washington State University, Dept. of Civil and Environmental Eng.*

Grape production in Washington represents a multi-billion dollar enterprise, placing the state as the second largest grape producer in the nation. As water becomes scarcer, however, growers will face challenges in managing their limited water resources, while achieving high levels of grape quality and quantity. The problem is sharpened by projected climate change which indicates an increase in crop water stress with likely negative influences on the quality of the grapes and wines over the region in near future. To optimize effectiveness of precision irrigation, factors including plant water status, evapotranspiration (ET), and photosynthetic rate (CO2 exchange rate) must be accurately monitored during critical periods of the growing season. The Eddy Covariance (EC) method is one of the most accurate, direct and defensible approaches to achieve these objectives. This technique includes the using of a single tower equipped with micrometeorological sensors, and permits accurate assessment of the crop water stress and hypothesized rate in high temporal resolution. We installed an EC system over a commercial vineyard near Benton City, WA and report corresponding data for the very first time in the state of Washington. Using the EC method would not only ease irrigation scheduling, but also save over half the water which is currently used by growers through the erroneous estimation of ET and WUE. This could yield direct benefits worth hundreds of millions of dollars through water savings leading to the doubling of acreage in planted vineyards of wine grapes. In addition, it will have immediate impacts on reducing evaporation losses, disease and insects, as well as improving the health and longevity of the vines.

P5

Biochar effects on wheat and pea productivity

Stephen Machado, Oregon State University; Pritchett, Larry, OSU-CBARC; Ghimire, Rajan, OSU-CBARC; Bista, Prakriti, OSU-CBARC*

Biochar has the potential to increase soil organic matter (SOM) levels that have declined under the winter wheat-summer fallow cropping systems (WW-SF) predominant in the Pacific Northwest. Biochar is charcoal produced from pyrolysis (combustion at low oxygen levels) and is resistant to decomposition. Biochar increases soil water holding capacity, cation exchange capacity, nutrient retention capacity, fertilizer use efficiency, and soil microbial populations, all conditions required for sustained crop production. This study evaluated the effects of biochar derived from forest wastes. Adding biochar to soil sequesters C that would have been lost to the atmosphere as CO2 through burning or natural decomposition where it would contribute to global warming. The biochar, which contained 90% C, 0.18% N, C/N of 500, and a pH of 10.6, was applied at rates of 0, 10, 20, and 40 tons/acre in the 2012-13 crop-year to a field under winter wheat-spring pea rotation (WW-SP) before seeding winter wheat in the fall of 2012 at The Betts Farm, Athena. In the spring of 2014, spring peas were seeded after winter wheat on the same plots. In another experiment at The Pendleton Station biochar was applied at rates of 0, 5, 10, and 20 tons per acre in a WW-SP rotation in 2013. Biochar was applied to all phases of the rotation. Grain yield, ears/m2, test weight, and soil pH were determined at maturity in 2013. At the Betts farm, increasing biochar from 0 to 40 tons/acre increased grain yield from 45 to 60 bu/acre, an increase of 26 to 33%. However, applying biochar at rates above 10 tons/acre did not significantly increase yield. Biochar application did not influence ears/m2 and test weight. Applying biochar increased soil pH by a factor of 0.21. Biochar increased the following spring pea yield by 20, 25, and 15% at rates of 10, 20, and 40 tons per acre, respectively. At the Pendleton site, amending soil with biochar increased both yields of wheat and peas by 24 and 16%, respectively. These results indicated that biochar had the potential to increase grain yield of winter wheat and spring peas. The biochar used was alkaline and may have a potential to reduce the acidity that is increasingly evident in fields fertilized with N compounds and in no-till systems. This study continues

P6

Carbon exchange over wheat cropping systems: Remote sensing and direct flux measurements

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Carbon exchange over agricultural crops is an important element for understanding agricultural sustainability in the context of climate change. In this paper, we investigate a novel remote sensing method for assessing carbon exchange with direct eddy covariance flux measurements over a wheat crop in the Inland Pacific Northwest. The Spectral Reflectance Sensor (SRS, Decagon, Inc) is a new remote sensing instrument which measures the Normalized Difference Vegetation Index (NDVI) and Photochemical Reflectance Index (PRI). We address the correlation of NDVI and PRI measurements with direct flux measurements to assess whether or not the SRS is a more practical and cost-effective, yet still accurate, means of modeling seasonal and diurnal phenomena. We hypothesize that the NDVI will correlate well with fluxes and will accurately model seasonal growth. We also hypothesize that the PRI will correlate well with CO2 flux and will accurately model climate change and CO2 exchange. Using the linear regression feature in Matlab, we will compare seasonal data from NDVI, PRI, and flux measurements while using SPAD measurements as our ground control. The comparison of direct flux measurements with new remote sensing tools may lead to an improved understanding of how croplands exchange and store carbon in response to climate change. Farmers of soft-white winter wheat in the Palouse could use the SRS to accurately model the ripening rate of their crop and better understand how to optimize their yield. If our hypothesis is proven correct, it could lead to more extensive use of the SRS in both research and agricultural applications.

P7

Spatial variability in interannual relationships between winter wheat yields and climate across the inland Pacific Northwest of the United States

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Winter wheat (Triticum aestivum L.) is a major crop in the Northwestern US grown on about 62,00 square kilometers in the Columbia basin. Although wheat yields in this region have increased due to advanced agronomy techniques, potent interannual variability in yields and hypothesized to be partially attributably to interannual climate variability. Spatial heterogeneities in winter wheat yields and climate across dryland wheat growing areas within the Columbia Plateau can confound climate-yield analysis, thereby necessitating a spatially explicit analysis that examines interannual climate-yield responses across the region. Correlations between observed climate variables, including

temperature, precipitation, heat stress index, and evapotranspiration and wheat yields were examined for 27 counties covering dryland wheat farming in the Columbia Plateau from 1980 to 2013. Stepwise multiple linear regression was used to build empirical models for each county. These models can provide insight into the sensitivity of yields with climate variability and change relative to the more sophisticated process-based modeling approaches.

P8

When would irrigators invest in more water-efficient technologies as an adaptation to climate change? An analysis of the Yakima River basin in Washington State

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The Pacific Northwest is expected to experience more frequent droughts with higher magnitudes and persistence due to the climate change, with potentially large impacts on agricultural productivity and the regional economy in areas like the Yakima River Basin (YRB). A possible climate change adaptation strategy is for farmers to switch to more efficient irrigation technologies to increase water availability in the crop root zone. Because Investing in irrigation systems is considered a capital-intensive adaptation strategy, farmers' decisions will depend on how much money they project to save from reducing drought damages. The objective of this study is to explore when (and under what climate change scenarios) it makes sense economically for farmers to invest in a new irrigation system. We used VIC-CropSyst , a large-scale grid-based modeling framework that simulates hydrological processes while mechanistically capturing crop water use, growth and development. The water flows simulated by VIC-CropSyst were used to run a river system model (YAK-RW), which simulates river processes including dam operations, diversions, and return flow and calculates regional water availability for agricultural use each day (i.e., the prorationing ratio). An automated computational platform has been developed and programed to perform the economic analysis for each grid cell, crop types and future climate projections separately, determining whether implementing a new irrigation system is economically justifiable. Results of this study indicate that climate change could economically justify the investment on new irrigation systems, but the extent of farmers' response will mainly depend on the future magnitude and frequency of droughts. Other important factors affecting costs and benefits of implementing new irrigation systems are current irrigation systems, climatological characteristics within the basin, and crop type.

P9

Projected changes in cold hardiness zones and impacts on Northwest agriculture

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Cold hardiness zones, defined by average annual absolute minimum temperatures, provide a prevalent means of delineating agriculturally relevant climate zones. Projected changes in annual coldest daily minimum temperatures and mean winter minimum temperatures over the contiguous United States (CONUS) were assessed using an ensemble of statistically downscaled daily climate model output through the mid-21st century (2041-2070). Amplified warming of extreme minimum temperatures by an average of ~40% relative to mean minimum temperatures was found over the majority of CONUS and models. The mean climate velocity of annual coldest daily minimum temperatures over CONUS is 14.7km decade^{-1} and cold hardiness zones show shifts by the mid-21st century. Projected northward shifts in cold hardiness zones suggest the potential expansion of thermally suitable areas for the cultivation of less cold hardy crops. This expansion is illustrated in the Northwest with respect to high market value viniculture crops. The increase in cold hardiness zones and the differential warming between mean and extreme minimum temperature has broad implications for food security and species interactions.

P10

Quantifying the impacts of climate change and human decision-making on crop yield and water use in semi-arid environments: A modeling approach

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Agricultural sustainability will become a greater priority for farmers, stakeholders, and land managers in the near future as climate change and population growth continue in the semiarid West. Regional hydrology is expected to vary with climate change, altering the spatiotemporal water demands in domestic food production areas, such as the Lower Boise River Basin (LBRB) of southwestern Idaho. For instance, increased drought frequency and severity may increase the interannual variability in demand for water, consequently intensifying the burden of upstream reservoirs. These aspects of climate change need to be taken into consideration when applying irrigation water to crops in order to maintain the balance between irrigation and municipal supplies. It is crucial to have tools and resources that can quantify and project how growing populations and climate change will impact agricultural land and water usage, so we can address potential adaptation plans, on-farm conservation efforts, and newly implemented policies that will decrease the potential for food shortages. Here, we use a crop simulation model (CropSyst) to run point-based simulations of several farms that represent the heterogeneity of the LBRB and returns water use per unit area and crop yields. We will then couple CropSyst's outputs with an agent-based modeling framework (Envision) that creates alternative future scenarios under various climate projections. By conducting a suite of scenario analyses, we hope to identify key farm management decision variables

that, at the scale of the entire Lower Boise River, will reveal regional implications on water demand and use, as well as crop distribution and yields. Although this study is targeted toward understanding the Lower Boise, the generality of the modeling approach is potentially more broadly applicable to domestic food production systems in other semiarid environments.

P11

The effect of wildfire aerosols on crop growth in the Pacific Northwest

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In the western United States, forest fires occur each year in the summer. Climate change predictions suggest that temperatures will increase in summer and precipitation will decrease. The area burned by regional fires is expected to double by the 2040s and triple by the 2080s compared to the 1916-2006 period. Forest fires release a significant amount of smoke (aerosols) into the atmosphere. These aerosols alter the amount of solar radiation and proportion of diffused radiation received at the surface and, therefore, by crops. To investigate the impact of aerosols from wildfires on crops over the Columbia Plateau region in the Pacific Northwest, atmospheric data from the August 2012 fire season are used. Meteorological profiles are obtained from the Weather Research and Forecasting (WRF) model, while aerosol optical depths (AOD) are generated from the Community Multiscale Air Quality (CMAQ) chemical transport model. These are used as input into the Rapid Radiative Transfer Model (RRTM). RRTM calculates the direct and diffuse solar radiation in both the upward and downward directions at the surface. The solar radiation calculations across the study area are then input into a crop system model for assessing the impacts of aerosols on crop growth. These results are compared to simulations of clear-sky conditions without aerosols. The effect of aerosols on different crop types is assessed by examining how different crops utilize direct and diffuse radiation.

P12

Improving site specific nitrogen management

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With the increasing availability of variable rate technology for applying fertilizers and other agrichemicals in dryland agricultural production systems there is a growing need to better capture and understand the processes driving field scale variability in crop yield, soil water, and nitrogen use. Within the Palouse region of Washington State and northern Idaho steep topography and the redistribution of topsoil from historic erosion results in extreme variability in crop yield and soil water availability within a specific field.

Although the variable rate technology exists, many growers are reluctant to implement the technology and reduce fertilizer rates for fear of decreased crop yield. One of the greatest challenges in developing variable rate fertilizer maps is setting the potential crop yield for specific management zones within a field. With a warming climate and more extreme seasonality in precipitation the uncertainty in capturing and managing field scale spatial variability will increase. In this project we use a calibrated mechanistic cropping model, CropSyst Microbasin, to explore the processes driving variability in crop yield within a specific field located in high precipitation zone of the Palouse using long-term (100 year) statistically downscaled climate data. Spatial and temporal changes in the yield distribution simulated by CropSyst Microbasin were evaluated for three thirty-year time periods (2010-2040, 2040-2070, 2070-2100) at five points along a representative hillslope. Significant spatial variability in crop yield is simulated by the model with lower yields at summit locations and highest yields at toe slope positions. Using the yield distributions at each location we calculate the probability a particular crop yield will be produced for each time period. We evaluate the stability and variability in crop yield by slope position with time as a measure of confidence in the predictions. This potential crop yield information will provide the basis for the development of a decision support tool to assist growers in implementing variable rate nitrogen technology and provide an insight into future uncertainty added by future climate change.

P13

Historical precipitation analysis in relation to the impact of climate change on regional dairy manure storage and land application

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There is a need to understand the impact climate change has on manure management. Extreme events such as intense rainfall and heat waves are indicators of climate change: however, climate change can occur in more subtle ways such as a shift in weather patterns. Increased storm frequency and intensity is projected throughout the United States. Weather patterns in Western WA are not similar to global, national, or even statewide trends: the rainfall always seems to be unpredictable. If precipitation is increasing in frequency and intensity in Whatcom County, WA, dairies are at risk regarding manure storage: manure lagoons are designed to hold waste from the dairy cattle, average precipitation from approximately October to March, and between 7-25 centimeters of excess rainfall in case of a 25 year, 24 hour storm event while including “freeboard”, an extra 30 centimeters of room in the lagoon. Increases in average precipitation and storm event frequency are worrisome to dairies and nutrient management specialists. Precipitation data was collected for the time periods of 1950 to 2000 and 2001 to 2014 for the Clearbrook weather station in Whatcom County, three other sites in Western WA, and one Eastern, WA site. The data was processed for trends in monthly precipitation as a percent of annual rainfall and its relation to the storage period needed and available days for spring field work. In addition, the number of days it takes to reach a TSUM of 200 degrees C after January 1 of each year (which acts as an indicator of when to spread manure to fields) was calculated, one result being the days to reach a TSUM of 200 in Clearbrook, WA have significantly decreased when comparing 1950-2000 to 2001-2014. It was also determined if storm events are increasing given the historical definition of a 24 hour storm. Dairies in Western WA are required to obtain a fall soil sample for nitrate concentration after September 1 but before 12.7 centimeters (or 5 inches) of rain has accumulated. To evaluate the impact of climate change on this management practice, the 1971-2000 climate normals of various sites were compared throughout Washington and Oregon with the 1981-2000 climate normal. It was determined that the number of days to reach 12.7 centimeters of rainfall (post September 1st) has increased in Centralia, WA, Tillamook, OR, Salem, OR and Medford, OR and decreased in Clearbrook, WA affecting the timing of nutrient leaching.

P14

Climate driven future shifts in agro-ecological classes

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Land use classification studies often rely on biophysical variables hypothesized to be key drivers of land use/cover. Weak relationships, however, can occur between delineated land use classification and actual land use. In contrast, classification based on land use/cover that has emerged as a consequence of determinants may be advantageous as the actual land use can then be used for selecting important driving variables. The consequent selected variables which are drivers of current land use can therefore be used to project climate driven future geospatial shifts in land use. The National Agricultural Statistics Service (NASS) cropland data-layer of actual land use/cover was used to classify the REACCH (Regional Approaches to Climate Change) study region, in the inland Pacific Northwest, into four major agro-ecological classes (AECs): (1) annual cropping (limited annual fallow); (2) annual crop-fallow transition (e.g. 3-yr rotations with fallow every 3rd year); (3) grain-fallow, 2-yr; and (4) irrigated (Huggins et al., 2011). The main objectives of the study were to: (1) identify important climatic/bioclimatic predictors which can discriminate among current dryland AECs; and (2) use identified climatic/bioclimatic predictors with future climate scenarios to predict potential shifts in dryland AECs. To achieve the aforementioned objectives, Geographic information system software (ArcGIS) and statistical software “R” were used to process the AEC and climate data. Climatic parameters and bioclimatic variables important in Mediterranean climates were calculated for the REACCH region at a 4 by 4 km scale using 30 year (1981-2010) precipitation and temperature data. Important key predictors were identified through statistical random forest variable selection process in “R”. Identified predictors were used in conjunction with future climate change scenarios to project potential shifts in dryland AECs in REACCH region.

Climate Change Adaptation and Communication

P15

Planning for climate impacts to wastewater and storm water infrastructure – lessons learned from local government engineers

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Rising sea levels threaten to damage infrastructure built in low-lying areas by increasing the risk of coastal flooding, storm surge inundation, coastal erosion, shoreline retreat, and wetland loss. These impacts pose a threat to wastewater and stormwater infrastructure in Western Washington. In addition, increased flood risk statewide as a result of climate change poses a threat to inland wastewater and stormwater infrastructure located adjacent to impacted rivers statewide. This summer (2015), Washington Department of Ecology staff will interview wastewater and stormwater engineers with experience in preparing for the increased risk of flooding, sea level rise and storm surge inundation. Staff will identify engineers with expertise in this area from local governments such as King County, the City of Olympia, and others. The final project report will summarize lessons learned from the interviews in key area and review the key steps such as gathering applicable data, inspecting facilities, mapping relevant infrastructure using GIS, completing a vulnerability assessment, describing risk to wastewater and stormwater facilities, discussing results with decision makers, integrating priorities into capital planning, and connecting engineers to valuable tools and resources. The interviews will be summarized in a report and inform upcoming agency guidance on Ecology's Orange Book (Criteria for Sewage Works Design) and the Water Quality Program's grant and loan program.

P16

Vulnerability Assessments in the Great Basin Region: incorporating science into decision-making

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Interactions between science and decision-making are often complex, as a result, including science in policy-making can be a challenging endeavor. Vulnerability assessments (VAs) are a tool that can potentially improve such interactions by using systematic science to assess the resilience, sensitivity, and adaptive capacity of a species, ecosystem or resource in response to climate change. The intent of the VA is to produce results that are useful to the decision-making process for resource managers. The Great Basin region contains a collection of stakeholders with diverse interests and their use of VAs differs according to their resources, legislative mandate, expertise and values. Barriers to successful VA implementation may include lack of resources and lack of knowledge on how to integrate the results of VAs into policy, and pre-existing processes and institutions. Additionally, when it comes to the VA itself, there is lack of consistency in the design, style, depth and conduction of data collection that produces varying results. This can lead to potential conflict among stakeholders with overlapping jurisdictions, whose assessments promote different reactionary policy proposals. The project presented here is developing a better understanding of the selection and use of vulnerability assessments, whilst also identifying the barriers that are prohibiting VAs from being used to their full potential to improve the integration of science into decision-making. Here, we present the work completed thus far, including the identification of key stakeholders within the Great Basin region and our engagement with them through an on-line survey, designed to assess their use of VAs. As climate change continues to affect natural resources, the use of VAs have the potential to protect and preserve natural resources in the long term by equipping managers with the necessary knowledge to make better decisions.

P17

Evaluation of Participation from a Free Online Course on Animal Agriculture in a Changing Climate

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A national online course was designed specifically for Extension educators, technical service providers and other agricul¬ture professionals seeking to understand the relationship between animal agriculture and climate change, and intended to prepare professionals to engage their stakeholders. The Animal Agriculture in a Changing Climate (AACC) online course is self-paced and consists of eight lessons: climate trends, climate science, impacts on animal production, adaptation, contribution of and mitigation of greenhouse gases, policy, market opportunities, regulation and communication of science during controversy. The self-paced course requires approximately 12 to 15 hours to complete in a 4-6 week time period. After completing the course les¬sons and assessments, the students have the background necessary to inform farmers and ranchers on issues relating to animal agriculture and climate change and are awarded a certificate of completion that can be used as validation for continuing education. During the first year of the course, September 2013- September 2014, 205 students (14% from the Western Region) registered for the course with a 32% completion rate. Affiliations of students consisted of 42% extension educators, 19% other, 16% university (non-extension), 9% private sector, 5% NRCS, 4% non-profit, 3% regulator and 2% producer. Two online surveys were administered to follow up with those that registered for the online course at least 3-6 months after they completed the course: one for participants who completed the course and one for those who registered or began the course and did not complete it, including extension directors. The main challenge faced by those registering for the course (whether they completed the course or not), was time, both the amount of time required to take the course as well as the timeframe in which it needed to be completed. Both evaluations indicated that knowledge of animal agriculture and climate change is important to for the general agriculture industry, while some Extension directors and program leaders do not believe that their Extension staff are currently competent in this area. Overall feedback between those who completed the AACC online course and those who did not are similar, with few significant differences. Those who completed the course found the information to be valuable, and those who did not complete the course do intend to do so in the future.

P18

Climate change and public health

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Climate change is one of the greatest environmental and public health challenges for our generation, and directly affects the quality of life in our communities. Addressing climate change is a critical public health challenge facing state and local health departments. The Washington State Department of Health is building capacity to support state and local policy and planning to adapt to changes in the climate and mitigate effects of climate change where possible.

P19

Forest and climate change graduate certificate at Oregon State University - Online

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Forests worldwide have begun to be impacted by global climate change, and over the coming century they will be profoundly altered by it. Adaptation of managed forests to climate change may require both silvicultural and genetics-based options. Since forests have the capacity to both emit and sequester carbon dioxide, a leading greenhouse gas contributing to climate change, there is tremendous interest in managing forests for mitigation of climate change. These considerations suggest that a good understanding of the relationship of forests to climate change will be a critical requirement for sustainable management of forest resources. To meet this need, Oregon State University has initiated (Fall 2015) a set of new on-line courses associated with a Graduate Certificate in Forests and Climate Change. The courses are designed to provide a thorough grounding in assessing the impacts of climate change on forests, evaluating proposed adaption strategies, and development of management practices to enhance forest carbon sequestration for the mitigation of climate change. Disciplinary knowledge in ecology, genetics, forest measurement, forest modeling, economics, business and policy is covered. The full curriculum consists of 19 credit hours of course work, including an independent project. The Graduate Certificate in Forests and Climate is appropriate for a wide range of student backgrounds, especially mid-career, company, industry or agency employees who want more training and experience in natural resources management and climate change. Students should have a Bachelor's Degree in Arts, Humanities or Science, and preferably will have at least two years' experience working in natural resources related fields. Offering the FCC Certificate entirely online through OSU Extended Campus enhances the opportunity to interact with students across the country and around the world.

P20

Engaging Students in Climate Science with Place-Based Data and Models

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Over the last 5 years, University of Washington faculty and graduate students have collaborated with high school science teachers in Washington and Idaho to design and implement data and inquiry-based climate change instructional modules. These modules include student instructions, essential climate change background information and regional data, and were designed to accompany ATMS 211; an undergraduate climate change course taught in the high school for UW credit. The modules have also been taught in Advanced Placement Chemistry and Environmental Science and undergraduate Earth Science and Climate courses. The modules allow students to explore data graphically using Excel, and guide them to make statistical inferences while examining future trends in global and local climate phenomenon. These instructional strategies engage students in global and local climate change concepts, making these labs important and valuable teaching resources for addressing core ideas of the Next Generation Science Standards. Specific topics within climate change can be used to explain how to use empirical evidence to differentiate between cause and correlation, and how stability and change can be quantified and modeled over time. For instance, one module goes deeply into this topic, as students compare regional and global temperature change and variability using weather station data. Three other modules include published data and/or models to examine (1) the correlation between ocean acidification and larval production in the Whiskey Creek Hatchery in Oregon, (2) the statistical relationship between precipitation in Everett WA, snowpack at Mt. Rainier with El Niño, and (3) energy balance to understand current and future mountain snow melt in the Cascades. These labs provide truly authentic learning experiences, and high school students report that using data in these modules helps them better understand what scientists do, and that by examining local impacts with data, they are more interested and engaged in learning about Earth's climate systems and change. Assessments of student learning outcomes demonstrate increased mastery of basic climate principles and content retention when local data are used in instruction. Forty high school teachers and twenty graduate students have participated in professional development workshops on our climate science instructional modules. Initially funded by a NASA Global Climate Change Education Grant, annual workshops are now hosted by the University of Washington Program on Climate Change, and provide opportunities for teachers to understand the climate concepts presented in the labs and for scientists to learn how to communicate the science and data in the classroom. We encourage you to contact us if you'd like to see your data brought to life in the classroom through similarly engaging modules.

Hydrology and Water Resources: Impacts and Adaptation

P21

The impacts of Columbia River Treaty scenarios on agriculture, hydropower production and flood risk in a future climate

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Over 200 international water agreements were signed during the last 60 years on river basins that share boundaries between two or more countries. The Columbia River Treaty (CRT) is one such ground-breaking and significant treaty between the U.S. and Canada, ratified in 1964. The Columbia River basin (CRB) comprises parts of seven north-western states of the United States (U.S.) and a portion of British Columbia, Canada. For proper operation of dams in the upper Columbia River for flood control and hydropower benefits the CRT is now a functional agreement between these two countries. Starting from 2024, U.S. or Canada can terminate or bring changes in the Treaty provisions with a 10 year advance notice leading to potential changes in reservoir operations and water resource availability. In addition, climate change also has a great influence on Columbia River hydrology and water resources. All these changes are predicted to affect the different water uses of the Columbia River. Modeling the impacts on agriculture by simulating alternative treaty scenarios where storages are operated for flood risk and flow augmentation may bring valuable information to the agricultural sector in the CRB. The uniqueness of the study lies on the impact assessment on this sector too. Hence, the objective of this study is to assess the impact of possible changes in the CRT on agriculture while the treaty scenarios are developed prioritizing flood control and hydropower production under projected climate change scenarios. A reservoir operation modeling tool, known as the Columbia River Simulation Model (ColSim), is utilized for simulating reservoir operations. This model has been applied extensively in climate change impact analysis in water resources management sectors in the Columbia River Basin region. Streamflow inputs to ColSim are obtained from a coupled land surface hydrology and cropping systems model known as VIC-CropSyst implemented on 1/16th

degree resolution. VIC-CropSyst routs unregulated stream-flow at a daily time-step. This coupled model is also applied to estimate agricultural demand and this demand is compared to the legally-available water supply under different treaty and climate change scenarios for impact assessment. This study will be a helpful tool for the resource managers to deal with future uncertainties in water availability, especially during the summer due to changes in the treaty.

P22

Modeling future water availability in the Boise River Basin, Idaho

Amy Steimke, Boise State University; Flores, Alejandro, Boise State University; Han, Bangshuai, Boise State University; Leonard, Andrea, Boise State University*

Many communities in the semi-arid western U.S. rely on capturing and storing spring snowmelt which is then slowly released throughout the hot, dry summer. If the timing and magnitude of water delivery shifts, current practices of reservoir operations may be inadequate to provide flood control and late-season irrigation demand. There exists a greater need for improved modeling of water resources under a range of climate projections and management scenarios to ensure resiliency in our water supplies. Because land use and land cover play a critical role in how water moves through a system, we will explore how changes in vegetation and forest management may affect water supplies. Here, we will couple statistically-downscaled climate projections with the agent-based modeling framework, Envision, to build a hydrologic model of the Boise River Basin, ID using the Flow plug-in. This spatially-explicit framework treats the managed landscape as a dynamically coupled human and natural system where management activities and biophysical processes can be simulated on the landscape. We will examine outputs of timing and magnitude of water delivery under the various modeled scenarios. The results from this study will allow us to quantify and identify potential causal relationships between management activities and regional hydrology in the context of a changing climate.

P23

Review of WA State 2014-15 Drought: How does it compare to previous droughts?

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Drought has impacted WA State, with the Governor making the first drought declaration in the state since 2005 in April 2015. A brief review of the conditions that led to the declaration will be presented, including a timeline of when key decisions were being made on the state drought committee level. Fall forecasts were of considerable concern early, but the lack of snowpack became the most monitored and concerning as the winter progressed. Conditions will be compared to those of WA droughts or “almost-droughts” in previous years – 2001, 2005, and 2013-14 – emphasizing how water year 2015 was different. For example, even though water year 2015 is most similar to the

2005 drought, there are differences: namely, the winter temperatures in 2015 were even warmer than those in 2005, the nature of the winter weather differed, and 2015 did not have the benefit of a wet spring.

P24

A multivariate drought assessment of the Yakima River Basin under observed and future climate

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In lieu with the recent and anticipated more server and frequently droughts incidences in Yakima River Basin (YRB), a reliable and comprehensive drought assessment is deemed necessary to avoid major crop production loss and better manage the water right issues in the region during low precipitation and/or snow accumulation years. In this study, we have conducted frequency analysis of hydrological droughts and quantified associated uncertainty in the YRB under both historical and changing climate. Streamflow drought index (SDI) was employed to identify mutually correlated drought characteristics (e.g., severity, duration and peak). The historical and future characteristics of drought were estimated by applying tri-variate copulas probability distribution, which effectively describe the joint distribution and dependence of drought severity, duration, and peak. The associated prediction uncertainty, related to parameters of the joint probability and climate projections, were evaluated using the Bayesian approach with bootstrap resampling. For the climate change scenarios, two future representative pathways (RCP4.5 and RCP8.5) from University of Idaho's Multivariate Adaptive Constructed Analogs (MACA) database were considered. The results from the study are expected to provide useful information towards drought risk management in YRB under anticipated climate changes.

P25

An Analysis of Historic and Projected Climate Scenarios in the Western United States using Hydrologic Landscape Classification

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Identifying areas of similar hydrology within the United States and its regions (Hydrologic landscapes - HLs) is an active area of research. HLs have been used to make spatially distributed assessments of variability in streamflow and climatic response in Oregon, Alaska, and the Pacific Northwest. They are currently being applied across the Western U.S. to assess historic and projected climatic impacts. The HL classification process analyzes the primary drivers (climate, seasonality, aquifer permeability, terrain, and soil permeability) that are associated with large scale hydrologic processes (storage, conveyance, and flow of water into or out of the watershed). Hypotheses regarding the dominant hydrologic pathways derived from the HL classification system are tested to corroborate or falsify these assumptions. Changes in climate are more likely to affect certain hydrogeologic parameters than others. For instance, changes in climate may result in changes in the magnitude, timing, or type of precipitation (snow vs. rain). Air temperature and the seasonality of dominant hydrologic processes may also be impacted. However, the effect of these changes on streamflow will depend on soil and aquifer permeability. In this analysis, we summarize (1) the HL classification methodology and (2) how historic (1900-present) PRISM climate data and climate projections are being used to assess how changes in climate affect hydrologic processes and their associated impacts (e.g. water resource availability, ecological impacts, etc.) in the Western U.S.

P26

Water Year 2015: The Oregon Cascade Mountain Snowpack Deficit

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The winter of 2015 produced the lowest snowpack on record for the Oregon Cascade Mountains, as measured by Natural Resources Conservation Service (NRCS) snow monitoring sites with at least 30 years of record. The Oregon Cascades are characterized by a maritime snowpack that normally has to 4 to 5 meters of snow depth, and as much as 2 meters of snow water equivalent (SWE) at the peak of the snow season. During the 2015 winter, the Oregon Cascades seasonal snowpack peaked 70 to 90% below normal; a deficit of up to 1 meter of SWE at some monitoring sites. The majority of the lower elevations had snow on the ground for only a few weeks, while the higher elevation snowpack melted months earlier than normal, setting records for the earliest melt-out dates. Unseasonably warm winter temperatures and below normal precipitation during January through May caused the record low snowpack. Many of the winter storms were atmospheric river events, which brought short durations of intense rainfall, often followed by extended periods of mild, dry weather. Heavy rain during February melted the limited snowpack at the low and mid-elevations. Many of these areas remained snow-free for the rest of the winter. The lack of winter snowpack has resulted in major impacts on summer surface water supplies affecting agriculture, fisheries, recreation, and reservoir storage. Earlier drying of mountain soils has created early season fire threats in the Cascade region. This spring, many rivers and streams have set records for the lowest streamflow observed. Many water users that depend on streamflow and reservoir storage have already experienced shortages and have implemented conservation measures much earlier than normal. The specific impacts on Oregon's water resources resulting from the 2015 snowpack deficit are still unfolding. However, history has shown that the effects from a well-below normal snowpack persist into future water years.

P27

Integration of MODIS Snow, Cloud and Land Area Coverage Data with SNOTEL to Generate Inter-Annual Snow Depletion Curves and Maps

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The behavior of inter-annual trends in mountain snow cover would represent extremely useful information for drought and climate change assessment; however, individual data sources exhibit specific limitations for characterizing this behavior. For example, SNOTEL data provide time series point values of Snow Water Equivalent (SWE), but lack spatial content apart from that contained in a sparse network of point values. Satellite observations in the visible spectrum can provide snow covered area, but not SWE at present, and are limited by cloud cover which often obscures visibility of the ground, especially during the winter and spring in mountainous areas. Cloud cover, therefore, often limits both temporal and spatial coverage of satellite remote sensing of snow. Among the platforms providing the best combination of temporal and spatial coverage to overcome the cloud obscuration problem by providing frequent overflights, the Aqua and Terra satellites carrying the MODIS instrument package provide 500 m, daily resolution observations of snow cover. These were only launched in 1999 and the early 2000's, thus limiting the historical period over which these data are available. A hybrid method incorporating SNOTEL and MODIS data has been developed which accomplishes cloud removal, and enables determination of the time series of watershed spatial snow cover when either SNOTEL or MODIS data are available. This allows one to generate spatial snow cover information for watersheds with SNOTEL stations for periods both before and after the launch of the Aqua and Terra satellites, extending the spatial information about snow cover over the period of record of the SNOTEL stations present in a watershed. This method is used to quantify the spatial time series of snow over the ~9000 km^2 Upper Snake River watershed and to evaluate inter-annual trends in the timing, rate, and duration of melt over the 30+ year period beginning in the early 1980's to the present, and shows promise for generating snow cover depletion maps for drought and climate change scenarios.

P28

Integrating climate change and urban growth in an agent-based modeling framework to project future water availability in semi-arid Idaho

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The Treasure Valley area, located in Southwest Idaho, is a rapidly developing socio-ecological system (SES) with urban growth displacing agricultural production, and the associated conversion of land driving changes in water resources. Climate change exerts additional uncertainty about water sustainability because the area is located in a semi-arid region where both water supply and demand are highly sensitive to climate-induced outcomes such as the timing, magnitude and spatial distribution of water supply. We are developing a simulation-based scenario analysis and visualization tool to foster improved understanding of this changing SES, better communicate with stakeholders, and support

decision-makers' planning over the next few decades. In this study, we developed an integrated model using the Envision multi-agent framework to evaluate future water availability in the Treasure Valley area. This modeling tool captures elements of both urban growth, land use change, and future climate variations. Future scenarios are composed from statistically downscaled climate change scenarios under different atmospheric CO2 emissions coupled with local urban growth projections. Current model results demonstrate the potential value of this platform for integrating changes in climate change, urban growth pattern, land use to explore their coupled impacts on future water resources.

Northwest Climate: Dynamics, Variability, and Change

P29

Physical parameter sensitivity in a superensemble regional modeling experiment

Sihan Li, Oregon State University; Rupp, David, Oregon Climate Change Research Institute; Mote, Phil, Oregon Climate Change Research Institute*

The sensitivities of regional temperature and precipitation to choices of physical parameter values in a regional climate model are investigated. Different parameter values are implemented in the 25km resolution regional climate model HadRM3P for the western US, using weather@home, a crowd-sourced computing platform, to generate a 'superensemble' of simulations. We explore the parameter space to find parameter combinations for which the model performs well compared with observations and discuss connections between parameter combinations and relevant physical processes. We also explore the potential for deducing an "optimal regional model" (i.e., a combination of parameters that minimizes some cost function), and assess the implications for climate response to changes in greenhouse gases.

P30

High resolution superensemble regional modeling for the western US

Sihan Li, Oregon State University; Rupp, David, Oregon Climate Change Research Institute; Mote, Phil, Oregon Climate Change Research Institute*

Western United States climate was simulated for the recent past (1985-2014) and future (2030-2059) using a coupled regional/global model (HadRM3P/HadAM3P) at 25-km resolution in the regional domain. A superensemble of simulations (~10K) was generated using weather@home, a crowd-sourced computing platform. The very large number of simulations permits the identification of robust spatial patterns of anthropogenically forced change, where present, from amidst the "noise" of natural variability, in means and extremes in temperature, precipitation, and snow water equivalent. We compare projected climate changes from weather@home with those from ten regional/global coupled model pairings from the North American Regional Climate Change Assessment Program (50-km regional resolution). We also investigate different mechanisms contributing to future projected changes in daily precipitation.

P31

Modeling the hydro-climate of southwest Idaho over a range of historical conditions

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Observational weather and climate data in the semiarid West, in general, and mountainous regions therein, particularly, are sparse, temporally discontinuous, and often poorly representative of the domain of interest. We explore the utility of a coupled land-atmosphere modeling system forced with reanalysis data for generating high-resolution gridded climate datasets for historical periods. Specifically we use the Weather Research and Forecasting (WRF) model to dynamically downscale the North American Regional Reanalysis (NARR) to 1km horizontal resolution over a region of southern Idaho including the Dry Creek and Reynolds Creek Experimental Watersheds, as well as the Snake River Birds of Prey National Conservation Area for select water years representing a range of climatological conditions (e.g. wet, dry, warm, cool, average). We then evaluate modeled precipitation and near surface temperature by comparing these results to precipitation gauge and weather station observations from monitoring networks within the experimental watersheds and from Snow Telemetry (SNOTEL) stations throughout the domain. We are simultaneously working on cyberinfrastructure (e.g., scripts, web-hosting, and data exploration tools) to distribute and disseminate these data to stakeholders.

P32

Development of high resolution (250m) historical daily gridded air temperature data with distribute sensor networks for the US Northern Rocky Mountains

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Gridded temperature datasets are typically produced at spatial resolutions that cannot fully resolve fine-scale variation in surface air temperature in regions of complex topography. These data limitations have become increasingly important as scientists and managers attempt to understand and plan for potential climate change impacts. Here we describe the development of a high resolution (250 meter) daily historical (1979-2012) temperature dataset for the US Northern Rocky Mountains using reanalysis and observations from both long-term weather stations and a dense network of low-cost temperature sensors. Empirically based models for daily minimum and maximum temperature incorporate lapse rates from regional reanalysis data, modeled daily solar insolation and soil moisture, along with time invariant canopy cover and topographic factors. Daily model predictions demonstrate excellent agreement with independent observations, with mean absolute errors of less than 1.4 °C for both minimum and maximum temperature. The form of the models may provide a means for downscaling future temperature scenarios that account for potential fine-scale topographically-mediated changes in near-surface temperature. Topographically resolved temperature data may prove useful in a range of applications related to hydrology, fire regimes and fire behavior, and habitat suitability modeling.

P33

Contrasting multiple downscaled climate datasets used for ecological applications in the Pacific Northwest

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Climate change is already impacting forest ecosystems in the Pacific Northwest region. To assess these impacts and forest responses, gridded data from global climate models (GCM) outputs are used to drive ecosystem model simulations. However, the spatial resolutions of outputs from currently available GCMs are too coarse to be used in many impact assessments at regional or landscape scales. Therefore, climatologists have downscaled GCM projections based on different methods (e.g., statistical and dynamical models). These downscaled climate data are being used as inputs to impact models, such as forest dynamics, crop growth, and hydrological models. However, without comparing differences and quantifying the uncertainties among the downscaled driving datasets, it is difficult for ecosystem modelers and resources managers to select the most appropriate dataset for their specific interests. Our study is aimed at evaluating the performance of different downscaled datasets in representing local and regional climates. We are also investigating the uncertainties among different data sources, especially for projected future periods. We analyzed and contrasted five recently developed downscaled dataset: NEX-DCP30, WorldClim, MACAv2-METDATA, MACAv2-LIVNEH, and ClimateNA. We evaluate the biases in each downscaled dataset by comparing it with observation-based gridded datasets, such as PRISM (Parameter-elevation Relationships on Independent Slopes Model) for the historical period. In this work, we aim to provide recommendations for scientists and natural resource managers to enhance science-based climate change adaptive management across the Pacific Northwest.

P34

Scenarios, variability and climate models: Understanding the range of possibilities for future Northwest climate

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Climate change projections always consist of a range -- sometimes a wide range -- among different models and scenarios. Differences among projections are a result of three factors: (1) choice of greenhouse gas scenario, (2) differences between global Earth System Models, and (3) natural variations in climate. Greenhouse gas scenarios -- "what if" scenarios of future greenhouse gas emissions -- are the largest source of uncertainty by the end of the century. The remaining uncertainty is a combination of our uncertainty about our ability to properly model the climate, and the inherent unpredictability of the Earth system itself. The former, model uncertainty, is reflected in the variation between models in the Coupled Model Intercomparison Project Phase 5 (CMIP5). The latter, internal variability, is assumed to remain relatively constant and is reflected in the decadal excursions from the long-term trend. To gain insight into the range of possibility for future climate, we quantify the relative contribution of each of these sources of uncertainty to the overall variability of fundamental climate variables like temperature and precipitation in model projections, building on previous work (Hawkins and Sutton 2009). We use 21 CMIP5 models for which all four Representative Concentration Pathway (RCP) scenarios are available to perform this exercise for the Northwest. For temperature, we find that model uncertainty dominates until ~60 years into the current century, when the uncertainty due to greenhouse gas scenarios begins to contribute the larger fraction. Internal variability is important as well, contributing a substantial fraction of the overall uncertainty, especially in the first half of the century. This suggests that improvements in model capability, especially those that pertain to projections of decadal variability, could reduce the uncertainty, with a greater impact on the overall uncertainty for short lead times (near-term projections, prior to mid-century). The range projected for the end of the century is far more uncertain in the absolute sense because of scenario uncertainty. For precipitation, on the other hand, model uncertainty and internal variability are far more important than the scenario for all lead times. This is both important to planning -- since different sources of uncertainty dominate depending on the future time period of interest -- and for impacts assessment, since scenarios should be chosen that span the range of possibilities among projections to lead to more robust risk assessments.

P35

Holocene glacial fluctuations and paleoclimate for the North Cascades from Lyman Lake, WA

Harold Wershow, Western Washington University; Clark, Douglas, Western Washington University*

The glaciers of the North Cascades are a critical water supply for fisheries, agriculture, industry and people. The region depends upon the sustained flow of glacial melt water during the otherwise dry Cascadian summers. The recent histories of alpine glaciers provide insight into how and why glacial water supplies change over time. Alpine glaciers are sensitive indicators of climate change; they advance and retreat (fluctuate) rapidly in response to variations in temperature and precipitation. As such, glacial fluctuation histories reflect past changes in climate, and they help constrain forecasts of future changes in glacial extent. My goal is to develop the first high-resolution, continuous history of Holocene fluctuations and climate for a representative glacier in the North Cascades. Sediment cores collected in August of 2014 from Lyman Lake's protected lower basin preserve a detailed sedimentation record that reveals local glacial history. Lyman Lake is fed by meltwater from Lyman Glacier, a small (0.20 km2) alpine glacier that aligns with regional glacial fluctuations. Analyses (visual stratigraphy, magnetic susceptibility, loss on ignition, grain size) of the sediment cores highlight three patterns of activity; background sedimentation, peak glacial sedimentation, and regional volcanism. Ongoing analyses are sorting these three signals and calibrating the magnitude of the glacial sedimentation signal to glacier size, allowing reconstructions of former glacier extents. The sediment cores have been dated via radiocarbon (14C) and tephrochronology, and the near-surface sediments have been dated with 210Pb analysis. Completion of age-depth modeling will result in a history of glacial fluctuations over ~8000 years with approximately century-level time precision. The goal of this project is to connect past glacial fluctuations to the climatic perturbations that drove them. Equilibrium-line altitudes (ELAs), which mark the elevation of the transition between a glacier's accumulation and ablation zones, are controlled by climate parameters such as summer temperature and winter precipitation. Crucially, ELAs can be inferred from a glacier's extent, allowing paleo-ELAs to be reconstructed from a glacier's fluctuation history. Because the Lyman Glacier's fluctuations and climate over the 20th-century are well-documented, the glacier's ELAs can be correlated to climatic conditions. Using the Lyman Glacier's ELA:climate relationship, I will reconstruct a paleo-climate history for the duration of sedimentation record (~8000 years).

P36

Updated and Forward Looking Rainfall and Runoff Intensity-Duration-Frequency Curves for Washington State

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The observed and anticipated increasing trends in extreme storm magnitude and frequency as well as the associated flooding risk in the Pacific Northwest highlighted the need for revising and updating the local intensity-duration-frequency (IDF) curves, which are commonly used for designing critical water infrastructure. In Washington State, much of the drainage system installed in the last several decades uses IDF curves that are outdated by as much as half a century, making the system inadequate and vulnerable for flooding as seen more frequently in recent years. In this study, we have developed new and forward looking rainfall and runoff IDF curves for each county in Washington State using recently observed and projected precipitation data. Regional frequency analysis coupled with Bayesian uncertainty quantification and model averaging methods were used to developed and update the rainfall IDF curves, which were then used in watershed and snow models to develop the runoff IDF curves that explicitly account for effects of snow and drainage characteristic into the IDF curves and related designs. The resulted rainfall and runoff IDF curves provide more reliable, forward looking, and spatially resolved characteristics of storm events that can assist local decision makers and engineers to thoroughly review and/or update the current design standards for urban and rural storm water management infrastructure in order to reduce the potential ramifications of increasing severe storms and resulting floods on existing and planned storm drainage and flood management systems in the state.

Wildfire, Wildlife, and Terrestrial and Aquatic Ecosystems: Impacts and Adaptation

P37

CMIP5 climate models predict rapid and deep soil warming

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Despite the widespread importance of soil temperature to estimating future agricultural production, health of natural ecosystems, and for characterizing carbon-cycle and surface energy-exchange feedbacks on climate change, it has received little attention in comparison to land-surface, air, and ocean temperatures. Here we investigate soil warming predictions for 14 models participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5), focusing on: 1) the magnitude of soil warming relative to near-surface air, 2) the impacts of warming at 1 m depth relative to shallow soil, and 3) evaluation of model performance, based on comparisons of model predictions for the recent past to observations. The model ensemble showed consensus that soil warming will track with air warming, with snow and soil ice acting as buffers that reduce the magnitude of warming experienced in the soil. Where snow does not occur, soil and air warming are predicted to occur at the same rate, whereas the presence of snow reduces soil warming relative to air warming, by a constant proportion through time. Soil warming is slowest in the boreal region, in contrast to air warming rates, which increase monotonically with latitude. The models also showed consensus in predicting that warming at the soil surface propagates downwards through soil rapidly, resulting in negligible differences in warming at 1 m depth in comparison to 1 cm depth. Many of the models faithfully represented global patterns in soil thermal dynamics observed from meteorological stations, but the greatest complexities and uncertainties are in representations of snow and permafrost.

P38

Radial growth and wood anatomy of limber pine in a natural simulation of global change effects on Grate Basin ecosystems

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Future climate change is expected to increase both frequency and severity of drought episodes, with drastic changes in the composition and distribution of plant species. Possible consequences for forest landscape range from extended die-off phenomena to the upward migration of forest ecosystems. Detailed analysis of tree growth measured along climatic gradients can serve as “natural simulation models” to capture the complex interactions between biotic and abiotic components determining the ecosystem’s response to changing climatic conditions. Wood properties depend on mechanical and physiological trade-offs between structural development and resistance to drought, thus providing insights on intra-annual hydraulic adjustments to water availability. The Nevada Climate-ecohydrological Assessment Network (NevCAN) consists of two transects of monitoring stations equipped with standard meteorological instruments, soil moisture probes, and tree sensors. We used repeated cellular measurements and dendrometer records to monitor cambial activity, wood anatomy, and radial growth of limber pine (Pinus flexilis E.James) during two consecutive water years (2013-2014) at two NevCAN sites (Montane and Subalpine) located on the western side of the Snake Range (Nevada) and characterized by naturally contrasted environmental conditions. Mean annual temperature is on average 3.7° cooler at the subalpine site, which receives on average 170 mm yr-1 of precipitation more than the montane site. The growing season for Pinus flexilis lasted 75 days at the montane site, while at the subalpine site tree-ring formation was completed in 89-107 days. Reduced or no stem increment was recorded at the drier montane site by dendrometers, while at the higher elevation stem increment was consistent with xylogenesis patterns derived from cellular measurements. A strong inverse correlation between minimum air temperature and cell production rate was found at the montane site. Anatomical features of woody tracheids, expressed by means of tracheidograms, showed smaller cells and narrower lumens under water-limited conditions, as an adaptation to drought stress. In the arid and semi-arid regions of the

western US predictions of future species performance are highly dependent on local conditions. We observed how increasing warmer and drier conditions would lead to a shorter growing season, a lower amount of tree growth, and an overall lessening of forest productivity. By shifting elevation to simulate climatic changes and their realized ecosystem feedbacks, it was possible to express tree responses to climate change as wood anatomical adaptations for maintaining hydraulic safety.

P39

Linking climate impacts with avian cavity nester viability: Modeling long term habitat suitability across multiple ecological scales

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The effects of climate induced ecosystem disturbances on avian forest species is complex and varies based on life history phenology. Avian cavity nesters are particularly sensitive to habitat change because of the complex interactions between life history requirements and habitat conditions resulting from disturbance events and post disturbance management practices, e.g. fire and salvage logging. As climate change affects habitat suitability and forest management practices evolve, the long term viability of cavity nester populations is not well understood. The management of these populations subjected to climate impacts will require projections of future habitat use. Forest landscape models (FLM) such as LANDIS-II that predict ecosystem responses to stochastic processes such as fire provide long term projections of forest ecosystem production. Using LANDIS-II along with multiscale ecological modeling and habitat suitability models, we are developing models to predict Black-backed Woodpecker, Lewis's Woodpecker and Flammulated Owl habitat suitability based on occupancy within the next century in Idaho and Oregon. Occupancy within these species is affected by multiscale landscape processes, some at scales finer than the FLM results. The FLM model results will be downscaled using general additive models to link the results across different landscape scales and predict local habitat patterns over broad spatial scales. The management and disturbance parameters within the FLM models will be varied to determine the sensitivity of cavity nester occupancy to future climate scenarios. Initial results from the FLM models, multiscale ecological modeling, and habitat suitability predictions will be presented along with statistical issues with uncertainty analysis and data transferability across multiscale models.

P40

Biogeochemical impacts of drought on Idaho forest ecosystems: can we resolve species level differences with high resolution measurements?

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Widespread increases in the frequency and intensity of drought are predicted as a function of climate change, potentially inflicting severe effects on Idaho forest ecosystems. Building a robust understanding of regional climate-forest feedbacks therefore embodies an essential research topic. The primary goal of this project is to evaluate and quantify the biogeochemical impacts of drought on Idaho forest ecosystems, with particular attention to species specific patterns of drought response. This objective will be accomplished through the use of in-situ, high-temporal resolution measurements of forest productivity and water status in new long-term ecosystem monitoring plots at the University of Idaho Experimental Forest. Data will be integrated from individual tree to ecosystem, yielding novel insights into forest ecosystem drought response at the time-steps relevant to mechanistic processes. Project results will facilitate the evaluation of ecosystem model sensitivity to drought and species-level drought stress coefficients will be developed to enhance prediction certainty. Ultimately, this project will advance knowledge of Idaho forest ecosystems in order to meet the needs of the research and management community, simultaneously elevating regional representation by incorporating results into an international research network. Preliminary results from the precision automated dendrometers installed in forest plots suggest that low soil moisture in spring 2015 prohibited cell expansion and stem growth prior to rain events in late May and early June; following virtually no growth earlier in the season, precipitation led to immediate, large stem increment and appeared to initiate subsequent steady growth. Such observations suggest that low early-growing season soil moisture strongly limited Net Primary Productivity and that large delays between tissue formation and tissue expansion occurred.

P41

Toward modeling Pacific Northwest tree species using CARAIB dynamic vegetation model

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While uncertainties remain regarding projected temperature and precipitation changes, climate warming is already affecting Pacific Northwest (PNW) ecosystems, notably forest species composition. In this research, we use the process-based dynamic vegetation model CARAIB DVM (Dury et al., iForest - Biogeosciences and Forestry, 4:82-99, 2011) to simulate current distribution of common tree species in PNW ecosystems. This DVM includes the influence of soil water content, atmospheric CO2 concentration and disturbances like fires, all essential to consider for reliably predicting present and future plant species distributions. Classically, dynamic vegetation models represent vegetation at the scale of plant functional types (PFTs). However, since they have a narrower bioclimatic spectrum, individual species are probably more vulnerable to climate change than PFTs. Here, we first perform simulations with the CARAIB global vegetation classification based on 26 Plant Functional Types (3 herbaceous, 8 shrubby and 15 arboreal PFTs). Then, we apply the vegetation model at the species level in order to analyse the response of a selected set of plant species to current climate. Representing the European vegetation at the scale of individual species has been successfully performed with CARAIB. The simulated individual species are differentiated by their proper climatic requirements and tolerances. Concerning physiological and structural parameters, species share the traits of the respective PFT, but we progressively improve their characterization by the use of global or local trait databases (e.g., TRY database). The model is driven with climatic observation data over the period 1951-2012 across the PNW region at different spatial resolutions. We test the model's ability to reproduce the present spatial and temporal variations of carbon stocks and fluxes as well as the observed species and biome distributions over the PNW. We then assess model predictions using a variety of available datasets, including eddy covariance and satellite observations.

P42

Forest carnivore distribution and occurrence in the Idaho panhandle

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The Multi-species Baseline Initiative (MBI) is a collaborative of organizations which conducted a comprehensive inventory for 20 Species of Greatest Conservation Need across the Idaho Panhandle and adjacent mountain ranges. From 2010-2014, MBI partners established 497 winter bait stations to collect photographs and DNA from forest carnivore species in the Purcell, Selkirk, Saint Joe, and West Cabinet Mountains. The bait station setup includes a large piece of meat and gunbrushes to collect hair (DNA) samples attached to the bait tree and a remote camera attached an adjacent tree. During the winters of 2010-2014, three wolverines, two lynx, and 39 individual fishers were detected at bait stations in addition to numerous marten, bobcat, squirrels, and other species. Species showed differences in distribution according to elevation across the study area. Bait stations are an effective means of detecting rare and elusive carnivores in addition to providing a means of monitoring more common species that will provide a baseline of information for future use as our climate changes.

P43

Continuous monitoring of winter canopy skin temperatures of an old-growth coniferous forest

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Recent global warming has dramatically changed the severity and length of chilling during winters. In forests, canopy surface temperature represents the thermal status of trees' leaves and trunks which respond to changing environmental conditions such as climate and hydrology. Measuring canopy temperatures is also useful for examining changes in forest eco-physiology as a result of extreme climatic events in winters. We installed a thermal infrared camera on the 60-m level of the flux tower in the old-growth mixed Douglas-fir and western hemlock stand of the Wind River Experimental Forest located in Carson, WA in October 2014. Thermographic images were collected every 2 minutes from 10 spots using a pan/tilt motion system (every 20 minutes per each spot), which allow measuring canopy temperatures from a large canopy area throughout the winter time by March 2015. The main objectives of this study are exploring temporal and spatial variations of forest canopy temperatures during winter time, and investigating how the variation of canopy thermal status is affected by winter climate and correlated to energy, water, and carbon fluxes. Over the six months of our study period, canopy temperatures averaged 5.4°C and spanned from –12.3 to 31.2°C. Chilling below 0°C was mostly found in November and January. There were small differences in the temporal temperature variation by measuring spot, revealing that similar thermal response occurred in the same forest stand. Overall, canopy temperatures were closely correlated to air temperatures, radiation, and relative humidity ($p < 0.01$) but less strongly correlated to precipitation and wind ($p > 0.05$), and they were less correlated with energy, water, and carbon fluxes ($p > 0.05$). Chilling of the canopy was mostly related to the lowest air temperatures, although canopy temperatures were higher than air temperatures. Therefore, physiology of trees in winter as driven by canopy temperatures is predominantly affected by air cooling during this time.

P44

Many species, many threats: A composite risk assessment of climate impacts for salmonids in the Skagit River, WA

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The life cycles of salmonid species span freshwater, estuarine, and marine environments, exposing these economically, ecologically, and culturally important species to a wide variety of climate change threats. The diverse life histories of salmonids make them differentially vulnerable to climate change based on their use of different habitat types and the variability in climate change threats across these habitat types; however, previous studies have focused mainly on assessing the vulnerability of particular life stages for a few species. Hence, we lack a broad perspective of how multiple climate threats are expected to impact the entire salmonid community. This lack of knowledge hampers our ability to prioritize various adaptation strategies for salmonid conservation that target different threats. In order to conduct a more extensive vulnerability study of salmonids, we performed a life cycle-based risk assessment of climate change threats for nine species of salmonids (species within Oncorhynchus, Salvelinus, and Prosopium genera) inhabiting the Skagit River watershed. This system is inhabited by all nine species, which are subject to an array of climate impacts including changing flow regimes, rising temperatures, sea level rise in estuaries, and decreasing dissolved oxygen levels in nearshore waters. Our risk assessment integrated projections of impacts from various climate threats with expert-based assessments of species-specific sensitivity and

exposure. We found that projections (multiple global climate models under moderate emission scenarios) of both changes in magnitude and frequency of three flow-related impacts (flooding, low flows, and suspended sediment pulses) were more severe than most other threats for which we could obtain projections. Combining projections with expert-based sensitivity and exposure scores revealed that these three threats exhibited the highest risk across all species. Of the nine species, the four most vulnerable were Chinook and coho salmon, steelhead, and bull trout, most of which are listed as threatened under the Endangered Species Act. Adaptation strategies that addressed river flow-related impacts had the greatest potential benefits, based on their feasibility of implementation, ability to reduce stressor magnitude and species-specific exposure, and ability to ameliorate current population status and habitat conditions.

P45

Coastal invertebrates and fishes: Evaluating risk from climate change – incorporating climate scenarios into the web-based Coastal Biodiversity Risk Analysis Tool (CBRAT)

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The Coastal Biodiversity Risk Analysis Tool (CBRAT) is a public website that functions as an ecoinformatics platform to synthesize biogeographical distributions, abundances, life history attributes, and environmental tolerances for near-coastal invertebrates and fishes on a broad ecoregional scale. The twelve ecoregions being examined range from the Beaufort Sea down through the Gulf of California. The initial phase of CBRAT focused on developing a conceptual framework to predict risk (high, moderate or low) based on abundance, distribution, environmental and other biotic and natural history traits. The second phase of the research uses the functionality provided by CBRAT but shifts the focus towards evaluating climate drivers (ocean acidification, sea surface temperatures and sea level rise) into the algorithm for predicting overall species vulnerability. We summarized predicted mean sea-level rise values from the literature for 2100 and, using extent of SLR and potential for landward migration, assigned a qualitative risk value for each ecoregion. In a proof-of-concept analysis for determining species' risk to ocean acidification, we used projected aragonite saturation values for 2100 for each of IPCC's Reference Concentration Pathways (RCPs) scenarios. From the literature, low, moderate, and high aragonite saturation thresholds for decapods (first taxon attempted) were estimated to be 1.5, 1.2, and 0.9 ΩAr respectively. To determine an organism's relative vulnerability to an increase in sea surface temperature (SST), we are developing thermal cutpoints based on current mean SST data and projected increases in SST for each ecoregion. Using 28 years of remote sensing data, relative risk to temperature increases for each species will be determined based on maximum temperature tolerances in the southernmost ecoregion while lower temperature ranges in the northernmost ecoregion are used to predict the likelihood for northward migration with an increase in SST. Although still in the analysis stage, our ultimate objective is to combine climate impact

rules with trait-based species information to project patterns of impacts on coastal invertebrates and fishes and to inform the development of practical adaptation strategies.

P46

From the Andes to the PNW: How temperature associated with climate change influence insect diversity and population dynamics

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Diversity loss is a phenomenon that can result in the disruption of food webs in a variety of ecosystems. Even though there are millions of insect species and many more to be discovered, insect population decline is notable, especially at higher elevations. Estimates of population parameters are lacking for many insect species in the Andes of South America and in the Pacific Northwest (PNW), thus the long term goal of our study is to determine how population of insects, mainly of the genus Premnotrypes in South America and Circuliffer in the PNW, varied over time and space at different altitudes under different regimes. Premnotrypes, the Andean weevil, is the most serious pest of potato at high altitudes (above 2,800 m). As temperatures climbed in the last several years, so Premnotrypes spp. distribution. Therefore, potato transects were planted by local farmers ('papa Arawinas') in Paru, Paru, Pisac Peru at altitudes ranging from 4,050 to 4450 m. Plots followed local commercial practices. At least three different species of Premnotrypes were identified however an initial statistical analysis does not show differences in proportion of species numbers along the study gradient; insect damage was also quantified at the various altitudes and will be further analyzed. Circuliffer was also affected by minor altitude gradients creating "hot" areas of distribution within the region. Results of our study raise concerns for the population status of Andean weevil and other arthropods collected and provide insights into the population dynamics of various insect groups.

P47

Identifying tipping points in the phonological responses of coast Douglas-fir to climate change

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The timing of annual growth initiation in plants has large impacts on species distributions and ecosystem function, and is sensitive to climate. These phenological traits are important because starting growth too early in the spring exposes vulnerable young tissues to frost damage, while starting too late results in plants missing periods that are amenable to growth (periods with warm temperatures and abundant soil moisture).

Under climatic warming, plants will need to initiate growth earlier to track suitable growing conditions. We modeled the timing of height and diameter growth initiation (budburst and cambial activation, respectively) in coast Douglas-fir (Pseudotsuga menziesii var. menziesii), a foundation species of great importance to the ecosystems and economies of the Northwest, to determine whether changes in phenology are likely track ongoing changes in climate. We assessed the response of growth initiation to a wide range of climatic conditions by combining data from 1) an observational field study spanning much of the tree's geographic range, thus covering much of the climatic conditions the tree currently experiences, and 2) experiments in which we manipulated the temperatures plants were exposed to, in order to simulate warmer conditions that are not currently experienced in the tree's native range but will become prevalent with climate change. For the high latitude/elevation portions of the species' range, the models predicted that growth initiation will occur earlier in the year with climate change and allow trees to experience a greater proportion of climatically suitable growing conditions while actively growing without being exposed to greater frost risk, thus representing an adaptive phenological response to climate change. However, towards the lower latitude/elevation edges of the range, the models forecasted that phenological responses will cross a tipping point where growth initiation occurs later in the year and trees experience a smaller proportion of suitable growing conditions while actively growing, representing a maladaptive response to climate change that could reduce growth and potentially result in range contractions. These results can be useful for managers because they identify mechanisms for how climate change could threaten the performance of this important species and geographic areas where it will likely be most vulnerable to this threat.

P48

Deriving spatiotemporally distributed net ecosystem exchange estimates combining eddy flux and remote sensing data

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Net Ecosystem Exchange (NEE) is a key ecological indicator of the direction and magnitude of exchange in carbon dioxide between the land and atmosphere. Generally there are two different approaches for estimating NEE: field-based measurement via eddy flux towers and deriving estimates from multispectral remote sensing data. Here we combine the advantages of the two methods using a machine leaning approach to develop a spatiotemporally distributed estimate of NEE in a semiarid ecosystem. The study site is the Reynolds Creek Experimental Watersheds (RCEW) in southwest Idaho, USA. Remote sensing data are in the form of 4-day composite estimates of the absorbed fraction of Photosynthetically Active Radiation (fPAR) derived from the MODerate-resolution Imaging Spectroradiometer (MODIS) at 1 km spatial resolution (MCD15A3 product). Additional remote sensing data available at RCEW include Leaf Area Index (LAI) from MODIS, topography and vegetation height derived from a 2007 Lidar flight, as well as other ancillary data such as vegetation type and soils. There are a total of five eddy flux towers within RCEW that provide estimates of NEE at temporal resolutions as fine as 30 minutes. We develop a Random Forest (RF) model to derive spatiotemporal estimates of NEE for RCEW using data from one eddy flux tower and use the model simulations to validate the rest of four eddy flux tower station data. Input predictors to the random forest scheme include fPAR, LAI, topography, vegetation height, soils, etc. in the vicinity of the eddy flux towers. The RF model has the advantage that we can explore the relative importance of different predictor variables to better explore the relationship between NEE and different parameters. The RF model can also be used to obtain measures of uncertainty in the predicted NEE by analyzing the spread of the ensemble of outputs. Improved estimates of NEE, as well as improved understanding of the observable predictors of NEE, can assist land managers to identify areas and times in which the landscape serves as a net source or sink of carbon.

Working Across Boundaries

P49

Prioritizing areas to protect under a changing climate: An intertemporal ecological and economic framework for quantifying outcomes of alternative conservation mechanisms on landscapes with natural and working lands

Isabel Guerrero Ochoa, Oregon State University

The main objective of this research is to determine the optimal use of regulatory (Protected Areas) and voluntary (Payment for Ecosystem Services and Adoption of Conservation Practices) types of conservation tools across a stylized landscape with natural and working lands. Both land uses have ecological/biological value, but only working lands have economic returns. From the social planner's perspective, biological and economic goals are desirable for a landscape. However, climate change adds uncertainty to the ecological/biological value and impacts the use of regulatory and voluntary conservation tools across a landscape when their temporal characteristics are taken into account. At the same time, temporal characteristics of the conservation tools affect the way uncertainty will be dealt with. The study has two components, the theoretical analysis and the empirical investigation. The theoretical analysis will inform the empirical application, and the latter tests theoretical results. The empirical application will be carried out in a Pacific North West (PNW) landscape; potentially the Columbia Plateau Basin. The problem of the study will be set up as an optimization problem. The social planner will choose conservation mechanisms to apply to natural or working lands in order to maximize a biological score subject to an economic score for the landscape. When adding uncertainty from climate change and the temporal characteristics of the conservation tools, the problem becomes a dynamic optimization problem. This study will contribute to the broader goal of decrease biodiversity loss and ecosystem degradation across a landscape when climate change takes place. Two main research questions will be explored in this study: Will the optimal combination of conservation tools efficiently improve the biological score for the landscape? Will short term conservation tools perform better than long term conservation tools under uncertainty? This study will be adding to the literature of landscape planning under climate change. Specifically, it aims to contribute to better understand the role working lands play in conservation policies. Furthermore, the results from this study will give insights to policy makers on where, when and which conservation tool to use to efficiently enhance biodiversity conservation and ecosystem services provision in a stylized landscape and particularly in a PNW landscape facing a changing climate. By understanding the tradeoffs between conservation tools and outcomes, this research aims to be transferable to other PNW ecosystems. This study is part of the dissertation for a PhD in Applied Economics. It is expected to be completed by June 2016.

P50

Valuing the effects of climate change on forestry: a Ricardian approach

Cassie Finer, Oregon State University

Forest productivity, which is strongly driven by local climate characteristics, is expected to shift under changing global climate patterns. Recent work in the Pacific Northwest has shown highly heterogeneous climate change effects on productivity, with projected higher productivity for many high elevation forests and projected lower productivity for many low elevation forests (Latta et al. 2010). Privately owned land – and hence, much of the current market supply of timber – is disproportionately found on lower elevation forests. These anticipated shifts in forest productivity have implications for timber mangers, conservation managers, and policy makers. The Ricardian method, first outlined in the 1994 article by Mendelsohn, Nordhaus, and Shaw (1994) (MNS) and applied to agriculture, offers one approach to valuing these welfare changes. The basic hypothesis of the Ricardian approach is that land values capitalize the effects of climate on production. Using current land values and climate data one can estimate the relationship between forestland value and climate characteristics. This relationship is then used to estimate the economic impact under various future climate change scenarios. While common in agriculture, the lack of large-scale databases on forestland values has to this point precluded application of the Ricardian method to forestry. This research conducts the first application of the Ricardian method to value the effects of climate change on forestry, using Oregon as a case study. We construct a unique dataset using Oregon's real market value property data for forestlands, available from each individual county's land information office. Real market values are an estimate of a parcel's market transaction price, as opposed to an assessed value for tax purposes. We compile and link a statewide panel dataset of real market values with PRISM climate data and timber stand characteristics from the U.S. Forest Service's Forest Inventory Analysis Program. Hedonic price functions for timberland are estimated by regressing parcel-level real-market values on climate, site productivity, species-specific stumpage prices, and other parcel specific spatial attributes. Once the functional link between climate and forest real market values is estimated, we follow the methods of prior agricultural applications and feed projected climate change scenarios from recent IPCC reports through the hedonic price function to analyze both the overall effect and the spatial pattern of climate change on Oregon forests. Past literature on the effects of climate change on forest productivity suggests that climate change will have substantial spatial variation on the real market value of private Oregon forests.

P51

The effect of water quality on lakefront property values in the wildland-urban interface of the American West: Evidence from Coeur d'Alene, Idaho

Haifeng Liao, University of Idaho

Since 2007, China has overtaken the U.S. as the world's biggest CO2 emitter. In order to achieve a more sustainable development under global climate change due to carbon emission, the Chinese government promised to reduce 40%-45% below the level of the year 2005 in its carbon intensity by 2020. The realization of this goal, however, raises an important concern about the potential trade-off between underdevelopment in the lagging regions and reducing CO2 emission at the national level. Drawing upon the Environmental Kuznets curve (EKC) framework and regional development theories, this paper will explore the economic geography of inequality-emission nexus in China using finer scale data. By taking into account regional structural characteristics and the context of economic transition, we will quantify the impact of regional income disparities on CO2 emissions, and the findings will shed further light on the inequality- and emission-reduction policies in China.

Tools Café

TC1

So you have data, now what?

Dominique Bachelet, Conservation Biology Institute; Brown, Melanie, CBI; Gough, Mike, CBI; Sheehan, Tim, CBI; Ferschweiler, Ken, CBI*

Pacific Northwest ecosystems contribute to the economic, social, and ecological stability of the region by providing sustainable timber production, high carbon sequestration potential, unique wildlife habitat, and high water quality. Climate change may jeopardize these ecosystem services through increased temperatures and reduced snowpack, exacerbating the influence of disturbance such as fire and pest/pathogen outbreaks. Furthermore heat waves and declines in water availability in the rest of the country will likely cause human population migrations to the Northwest which means increased demand for services but also amplified need for effective carbon sequestration measures that could partially mitigate human-caused disturbances. The combination of projected climate change and land use adds uncertainty to the long-term effectiveness of current management strategies. Managers need reliable information to adjust their strategies as population density increases. However they are currently overwhelmed by the diversity of available information and the multiplicity of sources. Our goal is to centralize and package effectively the usable information for land managers and for the general public in order to increase awareness and promote preparation for the challenges ahead. We are designing conservation planning atlases in Data Basin for a number of landscape conservation cooperatives to address this need. We are adding some user-friendly tools to specifically serve the available climate projections and land use data in a meaningful way. By working closely with a group of managers, our goal is to understand how consideration of these projections figures into the decision-making process and refine the ways we can deliver relevant metrics. We have been holding interviews to gather information and critical feedback on existing climate-related web pages and tools, providing us with benchmarks for improvement. Through an iterative process we hope to continue this collaboration and address the variety of issues managers continually have to face to maintain healthy ecosystems.

TC2

Visualizing and accessing data from the Integrated Scenarios of the Future Northwest Environment project

Katherine Hegewisch, University of Idaho; John T. Abatzoglou, University of Idaho, Edward Bechinski, University of Idaho, Erich Seamon, University of Idaho,Paul Gessler, University of Idaho, Sanford Eigenbrode, University of Idaho*

Wheat and other small grain production in the Northwestern US encompass 4 million acres and contribute approximately $2 billion annually to the economy. Inter-annual variability in climate directly impacts crop yield in parts of the NW through energy and moisture constraints. These crops are also subject to indirect yield reductions caused by insect pests, weeds and pathogens that if managed appropriately can be minimized. The Regional Approaches to Climate Change in Pacific Northwest Agriculture (REACCH) project has developed a set of mobile decision support tools that can assist farmers with timely decisions regarding crop planting, fertilizing, spraying and harvesting to maximize theoretical yield. We highlight a set of tools that use a 4-km gridded real-time weather monitoring dataset to aid decision-making on when to plant or treat crops. Historical datasets and seasonal climate forecasts for the next 6-months are also incorporated for contextualizing conditions of the current growing season and providing outlooks tailored to specific locations, respectively. Finally, phenological models for several pests, weeds and pathogens have been incorporated into the decision support tool enabling multi-species comparisons. By placing weather monitoring and forecast tools on a mobile app accessible to farmers, we aim to improve decision-making for managing key pests and weeds, as well as to improve grower understanding of organism biology and responses to climate drivers.

TC3

An agricultural producer learning tool for the Columbia River Basin

Kirti Rajagopalan[*] and Chad Kruger[*], Washington State University; Potter, Nicholas, CSANR, WSU; Walden, Von, Dept. of Civil Engineering, WSU; Yorgey, Georgine, CSANR, WSU

A primary factor affecting risk management for agricultural producers is weather and its variability. At key decision points throughout the year, producers use the information available to them to make the best possible decisions in spite of uncertainties. Decision support tools can help producers make better informed short-term decisions about their operations, such as what to plant, when to plant and how to manage crops under variable weather conditions. Such tools can be adapted to be used as "learning tools". Learning tools can help producers evaluate past operational decisions, or explore the possible future impacts of long-term strategic decisions before they are actually made. For example, drawing on historical and future climate projections, a producer might explore what the future climate normal and extremes might be, look at historical analogs for a specific scenario, or explore adaptation strategies. Based on existing data, tools, and methods that are useful for agricultural producer decision making, a prototype learning tool has been assembled for the Columbia River Basin in the Pacific Northwest US. The primary goals are: (1) Visualize historical climate and crop yield data in a format that is relevant for producers. (2) Provide access to short-term and seasonal weather forecasts that can be viewed in the context of historical data. (3) Provide a learning tool that gives producers the flexibility to evaluate "what if" scenarios with respect to operational decisions made in the recent past. (4) Provide a learning tool for producers to visualize what future climate projections look like, identify historical analogs and evaluate adaptation alternatives.

Although the current prototype focuses on weather and climate-based visualizations, the framework can be expanded to include other aspects that impact producer decisions. There is also potential to integrate what we learn through on-going regional earth system modeling partnerships in the Columbia River basin to enrich the toolkit and help producers make informed decisions that prepare them to adapt to a changing climate.

TC4

Climate registry for the assessment of vulnerability (CRAVe): A tool to track climate change vulnerability assessments

Jessica Hitt, EcoAdapt[*]; O'Malley, Robin, USGS; Thompson, Laura, USGS

CRAVe – CAKE, a joint project administered by NCCWSC and EcoAdapt, will provide users with a searchable, centralized public registry of climate change vulnerability assessments. The CRAVe-CAKE database was developed in partnership with the Interagency Land Management Adaptation Group (ILMAG) aims to make information about ongoing and completed vulnerability assessments more readily accessible and available, so that resources devoted to such assessments can be most efficiently used. The database will be hosted by both CAKE and the USGS.

TC5

Conveying climate change at the local level with SimSalmon, a virtual underwater Alaska

John Anderson, University of Idaho; Solomon, Mark, University of Idaho; Srivastava, Anurag, University of Idaho*

Conveying climate change vulnerability of local watersheds is advanced through the use of data-driven, interactive virtual worlds. The Managing Idaho Landscapes for Ecosystem Services (MILES) project has developed a virtual environment as a decision support tool for Fernan Lake (Idaho) stakeholders to: (1) assist in the prediction of climate and management induced system shifts in order to mitigate or prevent declining ecosystem services prior to conflict, (2) better communicate ecosystem complexity to disparate communities of interest, and (3) help identify social heterarchies competing for ecosystem service provisions. Fernan Lake is challenged by recurrent toxic blue-green algae blooms of increasing historical incidence and duration. The risk of fire vulnerability due to intensified heat, and drought forecast by downscaled climate models, and consequent increased loading of nutrient precursors to the lake, exacerbates this condition. Management activities focused at minimizing phosphorus loading to Fernan Lake will benefit from a better understanding of phosphorus sources and sinks in this watershed and how they will respond to a changing climate. The Virtual Fernan environment employs a regression relationship between fire occurrence and the Keetch-Byram Drought Index (KBDI) correlated with the total soil water (TSW) predicted from the Water Erosion Prediction Project (WEPP) model for historical climate conditions as its baseline condition. Future scenarios in Virtual Fernan are developed using WEPP-predicted TSW as an indicator of the likelihood of future fire occurrence and resultant algae blooms using the Coupled Model Intercomparison Project Phase 5 for the four Representative Concentration Pathways scenarios. Users of Virtual Fernan explore the effects of user-selected climate change induced wildfire regimes and management scenarios on the incidence of blue-green algae blooms in Fernan Lake. Social data and models are incorporated in the Virtual Fernan decision support tool, advancing the understanding of social ecological system response to climate change. Ongoing research using a novel application of network analysis and the Virtual Fernan prototype is testing how sensitive managed ecosystems are to human decision-making relative to climate change and continued urban growth, and the associated ecological and social tradeoffs.

TC6

An indigenous approach to adapting to climate change: An interactive 3-D Landscape

Rodney Frey[*] and Brian Cleveley[*], University of Idaho; Campbell, Leanne, Coeur d'Alene Tribe; Cleveley, Brian, University of Idaho

The Indigenous peoples of the Americas have proven successful, since time immemorial, in adapting to numerous environmental changes threatening their ways of life. In the example of the Schitsu'umsh (Coeur d'Alene) of Idaho, they have engaged the physical changes in their world by relying upon their traditional knowledge and practices, called hnkhwelkhwlnet "our ways of life in the world." The Schitsu'umsh offer invaluable insights and lessons that can contribute to better policies and practices addressing climate change. Acknowledging the unequivocal relationship between the content, the "what" of hnkhwelkhwlnet, and the means of accessing and disseminating that content, the "how," if Indigenous ways of knowing and engaging the world are to be understood and appreciated, consideration must also be given to the manner of approaching, presenting and teaching it, the "how" of understanding hnkhwelkhwlnet. For the Schitsu'umsh, the act of re-telling the oral traditions, 'me'y'mi'y'm (the "how") has been and continues to be essential to disseminating their hnkhwelkhwlnet from generation to generation. It is a form of education based upon attentive listening, stmi'sm, and active participation, 'itsh'u'lm. We will demonstrate that an interactive 3-D Landscape (based virtual world technology) as means of accessing and disseminating hnkhwelkhwlnet closely aligns with the structure and dynamics of 'me'y'mi'y'm, and is thus more effective means of communicating Indigenous knowledge and practice to the scientific community. We will discuss the nature and key attributes of hnkhwelkhwlnet, and how it is similar and distinct from other forms of Traditional Ecological Knowledge. And we will focus on one particular attribute of hnkhwelkhwlnet that offers specific insights for climate change, what is called snukwnkhwtskhwts'mi'ls ł stsee'nidmsh – "empathic adaptability."

TC7

Data Visualizations of the Combined Effects of Projected Sea Level Rise, Storm Surge, and Peak River Flows on Water Levels in the Skagit Floodplain

Jonathan Kemp, Environmental Science Associates[*]; Mike Leech, Environmental Science Associates; Alan Hamlet, University of Notre Dame; Larry Wasserman, Swinomish Tribe; Carol MacIlroy, Carol MacIlroy Consulting

There is a strong scientific consensus that human behavior is altering greenhouse gas concentrations and the global climate system. Projected changes in climate in the Pacific Northwest (PNW) and the Skagit River basin include reduced snowpack, changes in seasonal streamflow timing, more intense and frequent hydrologic extremes (floods and low flows) and sea level rise (SLR). To effectively manage and adapt to these changes, communities will need a more complete understanding of the combined effects of SLR, storm surge and changes in river flooding on near-coastal environments. Recent polling conducted by the Skagit Climate Science Consortium and the Yale Center on Climate

Change Communications found that 62% of people living in Skagit County feel that climate change will personally impact them through worse flooding. 30% of people in Skagit County would like more information to help protect them and their property against climate impacts. This project examines several techniques for visualizing the combined effects of projected future climate change on flooding in the Skagit floodplain and estuary based on the results of modeled scientific data with the intent of providing scientifically derived, easy-to-access tools to better understand future flood risks. To achieve this we used a combination of open source and proprietary software and tools to generate a set of 3D visualizations and an interactive web map depicting historic conditions, current conditions, and 2040 and 2080 projected scenarios. Output data was converted to Google Earth format for generating 3D fly-through animation and static image scenes. We also created visual simulations depicting flooding of historic landmarks in the lower Skagit basin. For the interactive map, we developed a set of tools to allow users to toggle between modeling scenarios to visualize the lateral extent of SLR and flooding while also being able to zoom in and out at various spatial scales. The results of this project will be deployed to the Skagit Climate Science Consortium's website and made available through presentations and interactions with the public in a variety of settings. Additionally, people will be able to share these tools with others via social media (Twitter, Facebook, etc.). This project was funded by the Swinomish Indian Tribal Community through funds from the US EPA National Estuaries Project (NEP) and in partnership with the Skagit Climate Science Consortium.

TC8

Climate Engine: Cloud computing for visualization and analysis of climate and remote sensing

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The changing climate in the 21st century will have many adverse effects on society through increased temperatures, reduced water availability, agricultural production, and increased wildfire risk. The advent of gridded and compatible datasets that cover observed and projected climate provide the potential to improve planning for climate sensitive resources. However, the sheer size and complexity of these datasets limits their ability to be used by a wide range of stakeholders. We have developed a web application called Climate Engine that utilizes Google Earth Engine's massively parallel cloud computing platform to overcome data barriers and enable users to interactively visualize different climate metrics at multiple time scales and in near real time. We provide examples of the use of this application for monitoring agricultural resources and future decision-making.

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