FY18 BIA Tribal Resilience Program Funding Request Proposal

SUMMARY

The Snoqualmie Indian Tribe Environmental and Natural Resources Department proposes to evaluate effects of land management scenarios and climate change scenarios on fluvial and thermal conditions and on coldwater fish populations. The Snoqualmie Watershed is a snow-influenced watershed where snowmelt cools down the summer water temperature. It is home to ESA-protected salmon and steelhead and provides traditional natural and cultural resources for the Snoqualmie People such as fishing for salmon, hunting deer and elk, and gathering berries and wild plants for food and medicine.

A warmer future climate will cause a greater fraction of winter precipitation to fall as rain, less snow accumulation, and an earlier snowmelt; these changes will decrease stores of water available later in summer (Jefferson 2011; Tohver et al. 2014). Lower summer flows may exacerbate warming in rivers where water temperatures have already increased (Kaushal et al. 2010; Orr et al. 2014; Isaak et al. 2012) and are expected to continue to warm (Mantua et al. 2010; Lee and Fullerton in prep). Coldwater fisheries managers in the Snoqualmie Tribe seek an estimate of how the availability and juxtaposition of summertime fluvial and thermal habitats will change in the future, and how this might affect anadromous and resident salmonid population viability. Water resource managers tasked with ensuring adequate water supply for irrigation and drinking water will also be challenged by low summer flows. Thus, a process is needed for predicting possible outcomes for fish so that managers can weigh the tradeoffs of potential management activities benefitting different water users.

During this project we will: (1) work with our established resource manager partners to develop **plausible management scenarios of riparian vegetation and land use;** (2) test these management scenarios using an existing **physically-based hydrology and water temperature model** and compare how well each mitigates the negative impacts of climate change on thermal and fluvial habitats needed by salmon; (3) evaluate population-level salmon responses to these scenarios using an existing **individual-based fish model**; and (4) **develop a guidance protocol for natural resource managers in other Tribes** or other jurisdictions who need to identify climate-ready management strategies to protect/restore salmon and their habitats.

We will produce and publicize (1) maps and animations of changes in fluvial and thermal habitat including predicted cold-water refuge distribution and responses by fish to climate change and management scenarios in the Snoqualmie watershed, and (2) A guidance protocol summarizing our process that other tribal fishery managers in other watersheds can follow to evaluate alternative management scenarios to develop a detailed climate adaptation plan. Products will specifically benefit the Snoqualmie Tribe by identifying near-term actions (e.g., preparing tribal members for fish harvest opportunities or needed protections in-season) and long-term actions (e.g., prioritizing conservation strategies that maximize coldwater habitat).

NARRATIVE

The people known today as Snoqualmie Tribe—the People of the Moon—have lived in the Snoqualmie Valley since time immemorial. Snoqualmie Falls is the birthplace of the Snoqualmie people and is central to their spiritual traditions. The Snoqualmie people fish for salmon, hunt deer, elk, and other game, and gather berries and plants for sustenance and medicine throughout the Snoqualmie Watershed. Water from the North, South and Middle Forks of the Snoqualmie River feeds into the salmon-bearing streams and rivers in the valley below, influencing the natural resources available to the Snoqualmie Tribe and to the Tulalip Tribes. The Snoqualmie Tribe is particularly interested in understanding natural spatiotemporal patterns of coldwater fish habitat in the Middle Fork Snoqualmie River, how human activities may have modified these patterns, how climate-induced changes may impact salmon populations, and what conservation strategies are most likely to maintain robust salmonid populations into the future. The Middle Fork is a largely forested headwater basin that provides the majority of the Snoqualmie's flow in the summer. Recently, the river has exceeded temperature criteria during the critical summer low-flow period and salmon populations have declined. A warmer climate will exacerbate these trends due to significantly reduced snowmelt that historically cooled the water (Lee and Fullerton in prep). The tribe considers it very important to understand potential climate impacts to water supply and temperature in order to consider consequences for anadromous salmon below Snoqualmie Falls as well as for resident fish above the falls.

Salmon habitat restoration in the basin presents a challenge as it is home to ESA-protected salmonids and over 14,000 acres of land in the Agricultural Production District; approximately 9,000 of those acres are actively farmed. Previous efforts to revegetate riparian areas have been challenged by farmers concerned with losing productive land, and by local organizations and policy makers tasked with preserving and increasing local agriculture. Thus, the management of riparian lands in the Snoqualmie watershed requires a collaborative, science-based approach and a transparent decision-making process. The ESA-listing of Chinook salmon (and now steelhead) in the Snoqualmie basin catalyzed several watershed planning efforts by representatives from Tribes, federal and local governments, nonprofits, and citizens. Efforts were made in 2005 in the Snohomish Salmon Conservation Plan to identify focal reaches for riparian restoration, and beginning in 2013, King County led a watershed planning process ("Fish, Farm, Flood") in collaboration with a cross-section of agricultural, salmon habitat, and flood risk reduction interests. This planning effort led to the creation of a Buffer Task Force to develop a science-based riparian buffer planting decision process for the Snoqualmie Valley.

Natural resource managers from the Snoqualmie and Tulalip tribes recently began meeting bi-monthly with multidisciplinary resource partners (county, university, and federal) about ongoing management needs and research synergies. We have identified quantitative tools and skills within the group that can help evaluate tradeoffs of the stakeholder-driven riparian management scenarios identified by the Buffer Task Force, and consider potential future fish habitat and population effects in the Middle Fork and elsewhere in the basin. Through our partnerships, we have a physically-based hydrology/temperature model that predicts fluvial and thermal habitats at a high spatiotemporal resolution (hours, meters; developed by University of Washington) and an individual-based model that predicts salmon responses to changes in fluvio-thermal habitats (developed by NOAA); both have been calibrated for and applied in the Snoqualmie watershed. These models are grounded in a substantial amount of empirical data on water temperature and fish in the watershed, and our King County, USFS, and UW research partners are collecting additional temperature data and water samples for stable isotope processing to better understand the sources of water (snow, rain, groundwater). Building on existing relationships and resources, we also propose to illustrate a process for predicting how future hydrology, water temperature, and salmon populations may respond to a suite of management scenarios and to climate change in the Snoqualmie watershed, and to demonstrate applicability of the approach in other watersheds.

The Snoqualmie Tribe envisions that these scenarios will reflect a range of best-case, worst-case and potentially realistic and/or achievable scenarios to inform future planning efforts. This coincides with the Snoqualmie Indian Tribe Environmental and Natural Resources Department's mission to protect, preserve, and enhance the Snoqualmie Tribe's traditional resources. This effort will directly benefit the Snoqualmie and Tulalip tribes that both use the Snoqualmie Watershed for traditional natural resource needs. The guidance protocol will also give benefits to tribes in other watersheds who embark on similar efforts to envision outcomes of management strategies to conserve diverse fluvial and thermal habitats needed to sustain viable fish populations alongside the needs of other water users. The modified process-based model and protocol will also be beneficial to other tribes such as the Suquamish Tribe who hope to use the same model to predict spatiotemporal patterns of water temperature in their watershed.

Assessment of Needs

1. Objectives and Methodology

Our primary objective will be to evaluate outcomes for salmon in the Snoqualmie watershed given a suite of plausible riparian vegetation and land use management scenarios. We will also develop a guidance protocol illustrating how, for any tribe/watershed, to develop, customize, and refine a set of scenarios for consideration by resource managers and their stakeholders. Our project will consist of four main steps:

1) We will solicit a suite of **plausible management scenarios of riparian vegetation and land use** from our resource management partners and the Buffer Task Force. These scenarios will represent possible scenarios under consideration by a diverse group of stakeholders (e.g., landowners, farmers, fishermen) with which our partners have an established relationship. We will evaluate these and other scenarios alongside scenarios of climate change to illustrate how management actions could affect salmon and their habitats in the future (see steps 2 & 3).

2) We will use an existing **physically-based hydrologic and water temperature model** ('DHSVM-RBM'; Sun et al. 2015) to explore the effect of the management scenarios described above on fluvial and thermal conditions at a high spatiotemporal resolution (3 h for 1-100 years; 100s of m across the watershed). We propose to modify an existing version of DHSVM-RBM in the Snoqualmie watershed to explicitly account for the potential influence of groundwater and snowmelt on fluvial and thermal habitats.

3) We will use an existing **individual-based model** (IBM; Fullerton et al. 2017) to estimate the response by salmonids to management and climate change scenarios. The IBM predicts population-level responses such as growth, survival, and phenology (accumulated across behaviors of many individuals) for one or multiple species to spatiotemporal changes in water temperature. The IBM has already been applied in the Snoqualmie; as part of this project, we propose to incorporate into the model the effects of streamflow on fish.

4) We will develop a workflow of guiding principles, hereafter **"guidance protocol,"** which can be used by practitioners who want to envision outcomes of management strategies to conserve diverse fluvial and thermal habitats needed to sustain viable fish populations alongside the needs of other water users. In addition to a generalized recipe, the guidance protocol will share practical lessons learned, and detail the aspects of models that need to be locally tailored.

These proposed components will be critical to assess a range of management decisions and outcomes in order to provide transparency in decision making in the Snoqualmie. In addition, the improved hydrology-water temperature and fish models will be tools that could be used in other watersheds for predicting more accurate responses of spatiotemporal patterns of water temperature and fish populations to management scenarios and climate change. A more in-depth description of the modeling methods can be found in Appendix A.

2. Proposed timeline: The following table provides our anticipated work schedule

Description	2018	2019		
	Q4	Q1	Q2	Q3
Project Schedule				
Developing management and climate scenarios				
Modifying DHSVM-RBM				
Calibrating DHSVM-RBM				
Projecting streamflow and water temperature with DSHVM-RBM under alternative scenarios				
Modifying IBM to include flow				
Projecting fish response under alternative scenarios				
Report Schedule				
Progress Report I				
Progress Report II				
Progress Report III				
Final Report				

3. Geographic Location

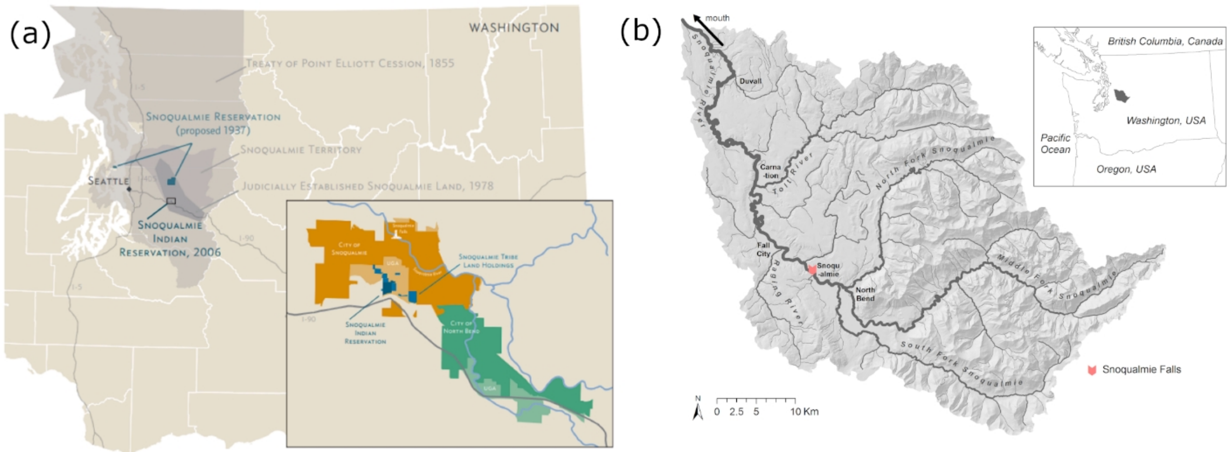

Figure 1. The location of (a) the Snoqualmie Reservation (Source: Taylor 2017) and (b) the Snoqualmie River Watershed.

The Snoqualmie Reservation (0.1 square miles/64 acres) is located in the Snoqualmie River Watershed, near where the three main forks of the river (North Middle, and South) converge (Figure 1a**)**. The reservation is positioned in a location influenced by a large upstream catchment. The watershed drains 700 mi^2 before merging with the Skykomish River to form the Snohomish River near Monroe, WA, which then enters Puget Sound shortly downstream (Figure 1b). Streamflow peaks in both late fall and spring as precipitation falls as both rain and snow (a typical hydrograph of snow-influenced watersheds).

The Snoqualmie River supports wild populations of Chinook, chum, coho and pink salmon, steelhead, rainbow trout, and cutthroat trout. Bull trout or Dolly Varden may have been present historically, but have not been observed recently. Puget Sound Chinook, Puget Sound steelhead and bull trout are listed as threatened under the Endangered Species Act (ESA). Local salmon populations have been in rapid decline, and are increasingly stressed by warm, low-flow conditions during summer, as well as by extreme events such as those observed during 2015 when a low snowpack led to record low flows and high water temperatures (Kubo et al. 2016). A warmer climate will harm these ESA-listed fish and other fauna and flora that Tribal people such as the Snoqualmie have traditionally relied on for subsistence and cultural uses. Therefore, the scope of this proposal covers every tribal member (~600 people) that continues to rely on the natural resources produced in the Snoqualmie watershed.

4. Expected Results and Products

We will engage with affected and interested tribal representatives on a regular basis to ensure their voices are heard throughout the process. Based on what we learn, we will produce a protocol intended for use by other tribes involved in prioritizing and implementing restoration projects robust to climate change. We will meet bi-monthly with our resource management partners, and will communicate findings at stakeholder meetings and scientific conferences. We will publish our research findings in a peer-reviewed journal article, and we will make the guidance protocol, data and visualization tools (e.g., maps, movies) available online. The specific new products we intend to develop during this project include:

- Maps and datasets of changes in thermal habitat including cold-water refuge distribution under different scenarios of climate change and land use and riparian management;
- Graphical and dataset summaries of predicted salmon population-level responses (individual responses available also) to climate change and management scenarios; and
- Maps of habitat conditions (i.e., temperature, flow) and fish locations at each time step made into movies for visualization.

5. Benefits of the Project

The project will better inform the Snoqualmie and Tulalip Tribes about how the warmer climate will affect the Tribes' natural and cultural resources and what kinds of management plans could be practically and effectively implemented to protect ESA-listed salmon and steelhead while also meeting the needs of other water users. Two clear outcomes of the project will include (a) specific results about the relative tradeoffs of the suite of management strategies evaluated, and (b) improved forecasting tools and a guidance protocol for application to future problems. At the conclusion of this project, apparent tradeoffs among riparian and land use management strategies will be articulated in maps and data products. In addition, Tribal resource managers will have locally-calibrated, updated models capable of more accurately predicting the spatial patterns of coldwater habitats and salmon response resulting from alternative management and climate change scenarios that could be used to assist the Tribes in preparing conservation and/or climate adaptation plans to protect their important natural and cultural resources for the benefit of their respective membership. For instance, model outputs could prepare tribal members for fish harvest opportunities or necessity for protection in-season as a near-term action, and help prioritize conservation strategies that maximize coldwater habitat as a long-term action.

Other parties outside the Snoqualmie Tribe that would benefit from this project include the Tulalip Tribes and agencies like King County, Seattle City Light, US Forest Service, US Geological Survey and NOAA Fisheries. We already have an established collaboration with these parties, and we intend to share with them the information acquired during this project. The modified process-based hydrologic and water temperature model will become available for application in any watershed. For instance, the Suquamish Tribe is interested in using the model for Chico Creek to estimate the changes in spatial patterns of water temperature and the distribution of coldwater habitats.

LITERATURE CITED

Fullerton, A. H., B. J. Burke, J. J. Lawler, C. E. Torgersen, J. L. Ebersole, and S. G. Leibowitz. 2017. Simulated juvenile salmon growth and phenology respond to altered thermal regimes and stream network shape. Ecosphere 8:e02052.

Isaak, D. J., Wollrab, S., Horan, D., and Chandler, G. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes. Climate Change, 113:499-524 DOI:10.1007/s10584-011-0326-z.

Jefferson, A.J. 2011. Seasonal versus transient snow and the elevation dependence of climate sensitivity in maritime mountainous regions. Geophysical Research Letters, 38:L16402 DOI:10.1029/2011gl048346.

Kaushal, S. S., Likens, G. E., Jaworski, N. A., Pace, M. L., Sides, A. M., Seekell, D., Belt, K. T., Secor, D.H., and Wingate, R. L. 2010. Rising stream and river temperatures in the United States. Frontiers in Ecology and the Environment, 8:461-466.

Kubo, J. 2016. Hot water and low flow: the summer of 2015 in the Snoqualmie River Watershed. King County, Water and Land Resources Division, Department of Natural Resources and Parks. Prepared for Snoqualmie Watershed Forum.

Lee, S.Y., and Fullerton, A.H. Space matters: incorporating mechanism and spatiotemporally explicit patterns into projected impacts of climate change on stream temperature to evaluate consequences for coldwater fishes. In Preparation.

Mantua, N., Tohver, I.M., and Hamlet, A.F., 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change, 102 (1-2), 187-223, DOI:10.1007/s10584-010-9845-2.

Orr, H.G., Simpson, G.L., des Clers, S., Watts, G., Hughes, M., Hannaford, J., Dunbar, M.J., Laizé, C.L.R., Wilby, R.L., Battarbee, R.W., and Evans, R. 2014. Detecting changing river temperatures in England and Wales. Hydrological Processes, 29: 752-766. DOI: 10.1002/hyp.10181.

Sun, N., Yearsley, J., Voisin, N., and Lettenmaier, D.P. 2015. A spatially distributed model for the assessment of land use impacts on stream temperature in small urban watersheds. Hydrological Processes, 29:2331-2345.

Taylor, J.B. 2017. Economic Impact of the Snoqualmie Indian Tribe. The Taylor Policy Group.

Tohver, I. M., Hamlet, A.F., and Lee, S.Y. 2014. Impacts of 21st-Century Climate Change on Hydrologic Extremes in the Pacific Northwest Region of North America. Journal of the American Water Resources Association, 50:1461-1476.

Appendix A: Methodology

Developing Management Scenarios: We will evaluate scenarios of: (1) existing landscape conditions, (2) enactment of previously developed riparian conservation strategies, (3) a set of generalized strategies for riparian buffer width management, (4) a set of specific scenarios provided to us by the Buffer Task Force, and (5) a set of riparian restoration scenarios on the Middle Fork. Throughout this process, we will work closely and iteratively with our resource manager partners to ensure that our results are closely tied to their decision-making process.

We will work directly with our King County liaison to the Buffer Task Force to learn the particulars of riparian management scenarios under consideration. We anticipate that these scenarios will involve specific, and therefore sensitive, actions potentially enacted on private properties, e.g., revegetation along the Snoqualmie mainstem, major tributaries, oxbows, and small tributaries and agricultural ditches that consider the dual agricultural and salmon recovery objectives. We have promised our partners that we will not make results from these scenarios public until we get formal permission from the Buffer Task Force. We will, however, also evaluate generic scenarios that can be published immediately, and which should provide general and useful information for application in other watersheds. These scenarios may include riparian restoration of buffers 25, 35, 75, or 150 feet wide along all streams; 15 feet on private lands and 150 feet on public lands; or a graduated approach whereby larger streams get wider buffers.

We will simultaneously evaluate management scenarios and greenhouse gas emissions scenarios to envision potential future conditions, and to see how management actions could be affected by climate change. We will use climate scenarios from the Coupled Model Intercomparison Project (CMIP5), representative concentration pathway (RCP) 8.5 (Taylor et al. 2012; van Vuuren et al. 2011), statistically downscaled to 1/16th degree resolution using the Multivariate Adaptive Constructed Analogs (MACA) method (Abatzoglou and Brown 2012).

We will iteratively share results with our partners and their stakeholders to illustrate the potential benefits and tradeoffs for fish, as well as to get feedback with which to refine scenarios. We do not intend to suggest a “best” course of action; our aim is to provide options for consideration alongside other socioeconomic and political issues that could lead to a strategy that balances the needs of user groups. We will meet bimonthly with our partners to discuss assumptions and results, and to help interpret model predictions. Our goal will be to provide flexible guidance that accommodates local knowledge and stakeholder values.

A Physically-Based Hydrology and Water Temperature Model: We will use DHSVM-RBM to explore the effect of management scenarios and climate change scenarios on future flows, water temperatures and fish. This process-based model has been used to simulate the effects of change in riparian vegetation and land use on water temperature (Sun et al. 2015; Cao et al. 2015) and the impacts of wildfire on streamflow (Surfleet et al. 2014). We previously developed and calibrated DHSVM-RBM for the Snoqualmie watershed with funding from the North Pacific Landscape Conservation Cooperative (Fullerton et al. 2017a). We propose to use this version of

DHSVM-RBM to estimate the impacts of alternative management and climate scenarios on future fluvial and thermal fish habitats.

In the Snoqualmie watershed, DHSVM-RBM was better than other models at predicting realistic spatial heterogeneity ("patchiness") in water temperature due to its greater coverage across the stream network and to its explicit simulation of streamflow. However, because the model does not currently incorporate groundwater dynamics, the spatial water temperature patterns predicted by DHSVM-RBM deviated from those observed during aerial remote sensing thermal infrared surveys at the confluence of the North, South, and Middle Forks of the river where groundwater is suspected to be influential.

We also demonstrated that DHSVM-RBM predicted larger increases in water temperature in watersheds like the Snoqualmie where snowmelt contributes to summer flow (Lee and Fullerton, in prep). Although DHSVM-RBM accounted for the reduction in future summer flow volume, it did not include melting snow (<0^{o}C) that could further cool water temperature. We therefore propose to modify the existing model to explicitly incorporate groundwater and snowmelt inputs when simulating water temperature that will be important for identifying potential coldwater habitats that could serve as refuges for fish. Contributions from upstream reaches, surface runoff, groundwater, and snowmelt can all be assigned unique temperatures that combine to determine temperatures in each stream reach. For streams and rivers that receive a substantial portion of their flow from groundwater or melting snow in the headwaters, predictions by the modified model may differ substantially from models that do not explicitly consider these inputs. We will further calibrate the DHSVM-RBM results using stable isotope analyses conducted by our partners L. McGill and A. Steel, and funded by the NW CASC. They have gathered water samples across the five main tributaries of the Snoqualmie River every two weeks since September 2017 to identify water source contributions and have established a strong ability to determine the proportion of flow coming from rain versus snow. These partners will also initiate new analyses to fine-tune estimates of groundwater input by linking air-water correlations to radon concentrations.

Individual-Based Model: We will use an existing individual-based model (IBM; Fullerton et al. 2017b) to evaluate the simultaneous effect of climate change and land management scenarios on threatened Chinook salmon and steelhead in the watershed. We will summarize behavior, growth, and survival of individuals to assess population-level responses such as phenology of hatching and outmigration, smolt body sizes, and life stage-specific survival rates. The IBM has already been applied in this watershed to evaluate how Chinook salmon responded during an anomalously warm, dry year (2015) compared to more typical years, and to consider potential additive effects of a non-native warm water predator (Largemouth Bass) present in the watershed (Hawkins et al. in prep). The current implementation does not include stream flow; fish respond only to spatiotemporally-explicit water temperatures and to other fish. We propose to develop and incorporate the fish-flow relationships necessary to evaluate how altered hydrology expected as a result of climate change and land management scenarios may impact protected salmonids. These proposed additions are denoted with underlining below.

In the model, 1000 fish eggs are deposited stochastically during the range of dates when, and at locations where, spawning has been observed over the last decade (WDFW, pers. comm.). Development of eggs is based on thermal exposure (Steel et al. 2012), and survival of eggs is influenced by peak flows capable of scouring redds (Jensen et al. 2009; Beamer and Pess 1999). After juveniles emerge (hatch and become free-swimming alevins), twice-daily movements and growth are driven by water temperature, flow, and biological interactions (competition, predation). For instance, crowded conditions and suboptimal habitat cause higher movement and lower growth. Survival is influenced by stochastic processes and direct predation events; larger fish and those that grew well in the previous time step have a better chance of surviving to the next time step. Smolting (i.e. downstream-biased movement) is governed by body size, date, and flow; fish are considered smolts when they reach the river mouth, and are removed from further simulation. The simulation ends when all fish have smolted or after one year. For each scenario, we will aggregate the results of 100 simulations each having slightly different initial conditions.

Developing a Guidance Protocol: We propose to develop recommendations that can be used by practitioners who want to compare management strategies to protect/restore diverse thermal habitats most likely to sustain viable fish populations into the future. We will present a general framework for how to use models similar to the ones we have implemented in the Snoqualmie or more general models to identify and evaluate alternative scenarios. The protocol will include examples from our Snoqualmie work, our partners' work in the Lewis River, and the work of others about what worked well and what did not work well. The protocol will describe: 1) Best practices for integrating stakeholder knowledge in scenario development; 2) Appropriate scales for identifying thermal habitats and for conducting restoration and protection management actions; 3) Lessons learned in translating model results into management and monitoring recommendations; and 4) Experience gathered from our partners in promulgating management recommendations in order to achieve desired environmental outcomes.

LITERATURE CITED

Abatzoglou, J. T. and Brown, T.J. 2012. A comparison of statistical downscaling methods suited for wildfire applications. International Journal of Climatology, 32: 772-780.

Beamer, E., and G. R. Pess. 1999. Effects of peak flows on chinook (*Oncorhynchus tshawytscha*) spawning success in two Puget Sound river basins. Pages 67-70 *in* Watershed Management to Protect Declining Species. Proceedings American Water Resources Association 1999 Annual Water Resources Conference, Seattle, WA.

Cao, Q., Sun, N., Yearsley, J., Nijssen, B., and Lettenmaier, D.P. 2016. Climate and land cover effects on the temperature of Puget Sound streams. Hydrological processes, 30:2286-2394. DOI: 10.1002/hyp.10784.

Fullerton, A.H., Lawler, J.J., Lee, S.Y., and Torgersen, C.E. 2017a. "Incorporating Spatial Heterogeneity in Temperature into Climate Vulnerability Assessments for Coastal Pacific Streams." Final Report to the North Pacific Landscape Conservation Cooperative.

Fullerton, A. H., B. J. Burke, J. J. Lawler, C. E. Torgersen, J. L. Ebersole, and S. G. Leibowitz. 2017b. Simulated juvenile salmon growth and phenology respond to altered thermal regimes and stream network shape. Ecosphere 8:e02052.

Hawkins, BL, AH Fullerton, BL Sanderson and EA Steel. Hunted in hot water: modeling Chinook Salmon (*Oncorhynchus tshawytscha*) response to a warming environment and a non-native predator. In Preparation.

Jensen, D. W., E. A. Steel, A. H. Fullerton, and G. R. Pess. 2009. Impact of Fine Sediment on Egg-To-Fry Survival of Pacific Salmon: A Meta-Analysis of Published Studies. Reviews in Fisheries Science 17:348-359.

Lee, S.Y., and Fullerton, A.H. Space matters: incorporating mechanism and spatiotemporally explicit patterns into projected impacts of climate change on stream temperature to evaluate consequences for coldwater fishes. In Preparation.

Steel, E. A., A. Tillotson, D. A. Larsen, A. H. Fullerton, K. P. Denton, and B. R. Beckman. 2012. Beyond the mean: The role of variability in predicting ecological effects of stream temperature on salmon. Ecosphere **3**:104.

Sun, N., Yearsley, J., Voisin, N., and Lettenmaier, D.P. 2015. A spatially distributed model for the assessment of land use impacts on stream temperature in small urban watersheds. Hydrological Processes, 29:2331-2345.

Surfleet, C.G., Dietterick, B., and Skaugset, A. 2014. Change detection of storm runoff and sediment yield using hydrologic models following wildfire in a coastal redweed forest, California. Can. J. For. Res. 44: 572–581 (2014) dx.doi.org/10.1139/cjfr-2013-0328.

Taylor KE, Stouffer RJ, Meehl GA (2012) An Overview of CMIP5 and the Experiment Design Bulletin of the American Meteorological Society 93:485-498 doi:10.1175/bams-d-11-00094.1

van Vuuren, D.P., Edmonds, J., Kainuma, M.L.T., Riahi, K., Thomson, A., Matsui, T., Hurtt, G., Lamarque, J.F., Meinshausen, M., Smith, S., Grainer, C., Rose, S., Hibbard, K.A., Nakicenovic, N., Krey, V., and Kram, T. 2011. Representative concentration pathways: An overview. Climatic Change, DOI:10.1007/s10584-011-0148-z.