Incorporating Spatial Heterogeneity in Temperature into Climate Vulnerability Assessments for Coastal Pacific Rivers

USFWS/NPLCC Funding Announcement #2

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Project Summary

Successful adaptation strategies for freshwater biota will consider how *spatial patterns* in water temperature may respond to climate change. Using remotely sensed spatially continuous maximum water temperature data for ~ 30 large rivers throughout the lower portion of the NPLCC, we will map locations of cold water patches, identify potential hydroclimatic and landscape drivers, and evaluate how detection of cold water patches depends on the spatial resolution of water temperature data. We will compare existing and future patterns of thermal heterogeneity to assess the potential influence of climate change. We will illustrate potential vulnerability of salmon to loss of thermal habitat in two case study watersheds. Products can be used to identify locations where stream temperature patterns will be most responsive to climate change and enable conservation planners to choose strategies that will promote future thermal diversity.

Need

Natural resource managers throughout the North Pacific Landscape Conservation Cooperative (NPLCC) are tasked with complex conservation decisions that address a myriad of existing stressors to rare species (e.g., habitat loss, fragmentation, nonindigenous species). Water temperature, a key driver of ecological processes in streams (Ward 1985; Webb 2008; Crozier et al. 2010), is expected to warm throughout the region as a result of climate change, further stressing stream biota. Vulnerability assessments have been a useful means for considering whether established conservation strategies will continue to be adequate when a species or ecosystem is faced with additional stressors posed by climate change. Early predictions of climate impacts to streams compared present day stream temperature at relatively coarse spatial scales with future stream temperature that is predicted to increase proportionately with increases in air temperature and to changes in mean annual discharge (van Vliet 2011; Wu et al. 2012). Recent advances in spatial statistics have produced stream temperature models capable of accurately describing stream temperature at the reach scale (~ 1 km) (Isaak et al. 2010; Peterson and Ver Hoef 2010; Isaak et al. 2013). In these models, predictions are based on relationships with environmental covariates and on statistical interpolation between temperature sensors deployed at individual sites.

Yet several challenges remain for assessing vulnerability of stream biota to climate change. First, considering *spatial patterns* of thermal habitat loss (e.g., locations and spacing of cold water patches) has not been a focus. Casting expected thermal habitat loss in terms of changes to spatial patterns relevant to stream biota could make vulnerability maps more directly useful to conservation planners. Moreover, an understanding of processes controlling spatial heterogeneity at reach scales remains elusive, especially in large rivers where modeled predictions are often based on fewer temperature sensors. Second, vulnerability analyses should assess changes in water temperature patterns at spatial scales relevant to ecological processes yet we have not previously had spatially continuous data with which to test this concept. Predictions made at too-coarse resolutions may miss thermal heterogeneity present at finer spatial scales that would enable stream biota to persist as the climate continues to warm (Torgersen et al. 1999). Finally, we don't know whether the spatial patterns we will see in the future will resemble those present today. Climate change may have stronger influence on certain controls (e.g., riparian vegetation) and less on others (e.g., geomorphology), and future patterns of stream temperature will be highly dependent on hydrologic regimes that may differ substantially from those present today.

Objectives

We propose to build on previous efforts (Isaak et al. 2010; Beechie et al. 2012; Wu et al. 2012) to assess potential impacts of climate change to stream resources by explicitly considering the role of spatial thermal heterogeneity. Our work will address three objectives for ~30 large rivers throughout the lower portion of the NPLCC. We will: (1) identify locations of cold water patches and their hydroclimatic and landscape drivers, and evaluate how detection of cold water patches depends on the spatial resolution of water temperature data; (2) construct vulnerability analyses to examine how locations of cold water patches may be affected by climate change; and (3) illustrate how climate-induced changes to thermal heterogeneity could influence vulnerability and resilience of salmon in two case study watersheds. The first two objectives address RFP Action 4.1 and the third objective addresses RFP Action 2.2.

Methods

Objective 1. We will identify the presence of cold water patches during summer afternoons when temperatures may physiologically stress stream biota (US EPA 2003) for ~6,300 km of large rivers within the NPLCC (Suppl. Fig. 1). We will relate cold water patch presence to potential hydroclimatic and landscape drivers using generalized linear mixed models. Water temperature data come from an existing dataset of remotely sensed thermal infrared (TIR) stream temperature collected during afternoons in July or August between 1994 and 2007 (Torgersen et al. 2012; R. Faux, unpublished data). Temperatures were subsampled from TIR images longitudinally along the stream midline, resulting in continuous synoptic stream temperatures for each river (Suppl. Fig. 2). We will consider potential explanatory variables from existing geospatial datasets that we believe to have mechanistic links to thermal heterogeneity (e.g., discharge, hydrologic regime, solar radiation, topography, geologic transitions, valley geomorphology, riparian vegetation, stream network properties, human influence footprint, etc.).

We will then evaluate how the resolution of water temperature data affects our ability to detect cold water patches by repeating the modeling described above, but using stream temperature data that have been coarsened to 500-m and 1-km intervals. We might also expect the influence of explanatory variables to differ at different scales. For rivers where we have both TIR data and stream temperature predictions from NorWeST (Isaak et al. 2013), we will compare patterns of spatial heterogeneity and locations of cold patches. Predictions from NorWeST, made at 1-km intervals, are expected to be available for western Washington, Oregon and California later in 2014. If our analysis finds that cold patches are easily identified at 1-km resolutions, then this would provide support for using NorWeST to evaluate spatial thermal heterogeneity in areas where we do not have TIR data. We will work with Dan Isaak and colleagues to ensure that our products are complementary throughout the NPLCC.

Objective 2. We will construct a vulnerability analysis to identify locations where cold water patches may differ as a result of climate change. To do this, we will repeat the modeling described in objective 1, but will update covariates to use future values of air temperature, discharge, and a measure of water availability based on climate scenarios. Covariates will be derived from projections recently produced by the Climate Impacts Group (University of Washington, http://cses.washington.edu/cig/) as a part of a climate change assessment over the western U.S. including the Pacific Northwest and California. These hydrologic datasets used four global climate model simulations (Echam5, Hadgem, PCM and Miroc 3.2) that were assembled for the fourth IPCC assessment for the A1B emissions scenario for two future time periods: the 2040s and 2080s. We will include a measure of water availability to represent conditions not otherwise captured by future mean annual discharge values. Namely, for snow-dominated watersheds, the impact of climate change on water temperature might be underestimated if the influence of snowmelt during summer is not explicitly considered. We will produce maps illustrating where locations and extents of cold water patches are likely to change (i.e., between current and future scenarios). Identifying where stream temperature patterns will be most responsive to climate change will help planners turn existing conservation strategies into climate adaptation strategies by highlighting where efforts should be focused to promote future thermal diversity.

Objective 3. We will demonstrate in two case study watersheds how conservation planners can adapt existing Pacific salmon conservation plans to incorporate expected changes in thermal heterogeneity as a result of climate change. We will identify at least two watersheds with active stewardship councils for which we believe our results can be used in ongoing conservation planning activities. We will meet with watershed councils to identify their needs and learn about existing projects, to outline what we can provide, and to set up a plan for working with them to ensure that our results are immediately useful for adapting their existing strategies to be more climate-ready. We will choose one watershed in Oregon and one in California. Candidate watersheds in Oregon include the Molalla/Pudding (tributaries to the Willamette River), Siletz and Umpqua (both coastal rivers). Candidate watersheds in California include the Eel, Redwood, and Mattole (all coastal drainages). Each of these rivers has an active watershed council and has identified water temperature to be a potential concern for salmon. If time allows, we will also consider the Snoqualmie watershed in Washington, where in addition to TIR data, we have 2 years of year-round water temperature from sensors distributed throughout the watershed. This river may be more susceptible to changes in snowmelt-driven hydrology than the Oregon and California rivers.

For these rivers, we will evaluate changes in thermal heterogeneity quantified at scales relevant to each life stage for selected species. For example, cold water patches may be defined as the distance over which temperature remains below a threshold that may be used as a refuge by juveniles rearing during high temperatures; or spacing between temperature troughs that would represent the distance a fish needs to travel between cold water patches during migration. We will highlight potential relationships with local landscape variables to identify opportunities for conservation of thermal habitat.

Geographic Extent

Within the NPLCC , we have remotely sensed temperature data for the following rivers: Washington: Hoh, Deschutes, Willapa, Snoqualmie, Stillaguamish, Nooksack; Oregon: Nehalem, Siletz, Yamhill, Tualatin, Molalla, Pudding, Thomas, Sandy, Siuslaw, Umpqua, Cow, Little Butte, Sprague, Rogue, Applegate; and California: Redwood, Eel, Mattole, Russian, Klamath, Scott, Shasta. See also Suppl. Fig. 1.

Timeline of Schedules, Products and Outcomes

Item	Product/Outcome	By Date
Convene collaborators	Virtual (WebEx) meeting during which we vet the general approach, identify data sources, brainstorm, and plan specific analyses	30 September 2014
Compile geospatial data	Geospatial data layers, projected, clipped	30 November 2014
Travel to meet with conservation and planning groups in 2 case study watersheds	Identify their needs; communicate what our analysis can provide; learn about watershed-specific issues; outline a plan of action	28 February 2015
Analysis of potential controls on thermal heterogeneity in rivers	Maps of cold water patches and a summary of hydroclimatic and landscape variables that were most influential in predicting thermal anomalies in ~30 rivers	31 March 2015
Assessment of thermal heterogeneity at multiple spatial scales	An understanding of the resolution of data needed to identify and predict cold water patches	31 May 2015
Vulnerability of rivers to climate effects on thermal heterogeneity	Vulnerability maps for the rivers for which we have empirical relationships	1 October 2015
Vulnerability of salmon to altered thermal heterogeneity in case study watersheds	Maps depicting existing and future spatial patterns of water temperature, cast in terms of metrics appropriate for different life stages	1 March 2016
Communicate results to the case study watersheds, the science and conservation communities, and the interested public	Outreach via presentations, publications, and by depositing data and products in the NPLCC database	Spring - Fall 2016

Disclaimer Regarding Data Sharing

There are no known restrictions on data sharing. After a thorough quality assessment, project data will be available to the public.

Literature Cited

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BUDGET

Item	Total
NOAA Personnel Fisheries Biologist	$33,854
Contractual Climate Hydrologist	$20,000
Travel Meet with watershed councils or river stewardship groups to implement the case study analyses	$1,934
Total Direct Costs	$55,788
Total Indirect Costs NOAA Support*	$19,052
Collaborators (In-Kind Contribution) Advisory consultation with cooperators and partners	($164,627)
Equipment/Supplies (In-Kind Contribution) High performance computer; ESRI ArcGIS license	($3,000)
Total Project Cost (Including In-Kind Contributions) **Amount Requested**	$242,382 **$74,840**

*A spreadsheet detailing overhead rates is available upon request

Supplemental Figures

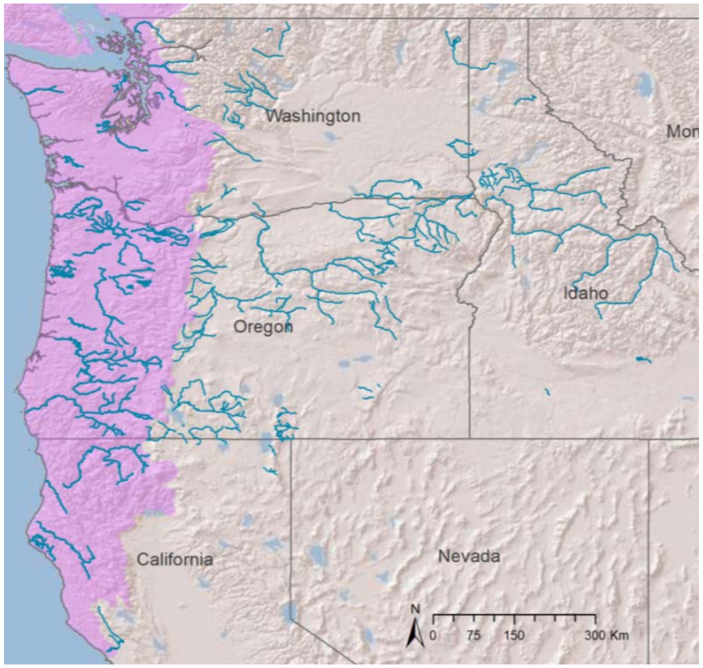

Figure 1. Rivers for which we have remotely sensed stream temperature data. The North Pacific Landscape Conservation Cooperative boundary for Washington, Oregon and California is shown in purple.

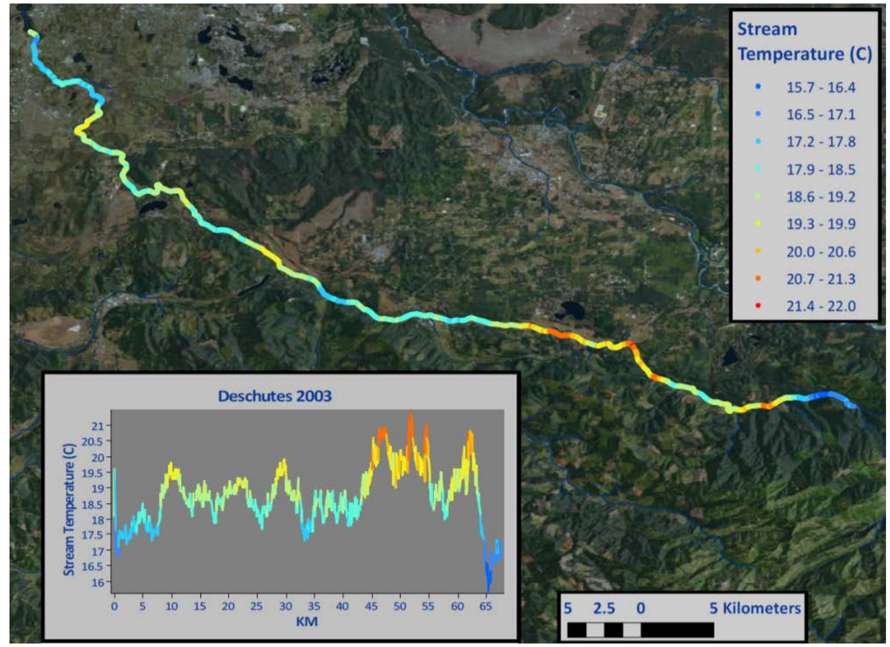

Figure 2. Stream temperatures from TIR for the Deschutes River, WA, in August 2003, illustrating thermal heterogeneity at multiple spatial scales.