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Research article

Can stream and riparian restoration offset climate change impacts to salmon populations?

Casey Justice*, Seth M. White, Dale A. McCullough, David S. Graves, Monica R. Blanchard

Columbia River Inter-Tribal Fish Commission, 700 NE Multnomah St., Portland, OR 97232, USA

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ABSTRACT

Understanding how stream temperature responds to restoration of riparian vegetation and channel morphology in context of future climate change is critical for prioritizing restoration actions and recovering imperiled salmon populations. We used a deterministic water temperature model to investigate potential thermal benefits of riparian reforestation and channel narrowing to Chinook Salmon populations in the Upper Grande Ronde River and Catherine Creek basins in Northeast Oregon, USA. A legacy of intensive land use practices in these basins has significantly reduced streamside vegetation and increased channel width across most of the stream network, resulting in water temperatures that far exceed the optimal range for salmon growth and survival. By combining restoration scenarios with climate change projections, we were able to evaluate whether future climate impacts could be offset by restoration actions. A combination of riparian restoration and channel narrowing was predicted to reduce peak summer water temperatures by 6.5 °C on average in the Upper Grande Ronde River and 3.0 °C in Catherine Creek in the absence of other perturbations. These results translated to increases in Chinook Salmon parr abundance of 590% and 67% respectively. Although projected climate change impacts on water temperature for the 2080s time period were substantial (i.e., median increase of 2.7 °C in the Upper Grande Ronde and 1.5 °C in Catherine Creek), we predicted that basin-wide restoration of riparian vegetation and channel width could offset these impacts, reducing peak summer water temperatures by about 3.5 °C in the Upper Grande Ronde and 1.8 °C in Catherine Creek. These results underscore the potential for riparian and stream channel restoration to mitigate climate change impacts to threatened salmon populations in the Pacific Northwest.

1. Introduction

The warming effects of climate change and land use on streams threaten to drastically reduce fish distribution and viability throughout the Pacific Northwest (Beechie et al., 2013) and across the globe (Ficke et al., 2007). Human alterations to the atmosphere and landscape and can influence water temperature by changing one or more of the primary factors that regulate stream temperature, including climatic drivers (e.g., air temperature and precipitation), discharge, stream morphology, groundwater interactions, and riparian canopy condition (Poole and Berman, 2001). Human-caused CO_2 emissions have contributed to a significant warming trend in Pacific Northwest streams during summer of approximately 0.22 °C/decade between 1980 and 2009 (Isaak et al., 2012), and August stream temperatures are projected to increase on average, +2.83 °C by the 2080s (Isaak et al., 2015). In addition to climate impacts, increases in water temperature can result from decreased streamflow, simplification of stream channels (e.g., increased width-to-depth ratio and reduced hyporheic exchange), and reduction of riparian vegetation cover (i.e., increased solar radiation reaching the stream) (Poole and Berman, 2001). These modifications are often the consequence of land use activities such as water diversions for irrigation or urban use, tree harvest in riparian zones (Beschta et al., 1987; Moore et al., 2005), poorly managed livestock grazing (Kauffman and Krueger, 1984; Belsky et al., 1999), and stream channelization associated with construction of roads, levees, and other impediments (e.g., mine tailings) (Simon and Rinaldi, 2006).

Water temperature is widely recognized as one of the most important environmental factors influencing the geographic distribution, growth, and survival of fish and other aquatic organisms (Regier et al., 1990; Armour, 1991; McCullough, 1999). Temperature

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* Corresponding author.
E-mail address: jusc@critfc.org (C. Justice).

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can directly affect physiological processes such as cardiorespiratory performance, food consumption, and osmoregulation (Whitney et al., 2016), as well as migratory behavior, resistance to disease and parasites, and inter- and intra-specific competitive interactions (Armour, 1991; Lynch et al., 2016). In addition, fish will often exhibit thermoregulatory behavior to optimize physiological performance, such as seeking out cold water refuges when ambient temperatures approach stressful levels (Breau et al., 2011; Myrick and Cech, 2004). As stream temperature regimes change in response to land management and climate change, cold-water fishes such as Chinook Salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) may be exposed to temperatures that are outside of their physiologic optimum, resulting in changes to fish communities and potential increased risk of extinction (Poole et al., 2001; Urban, 2015).

Salmon populations are an important cultural, economic and food resource for indigenous tribes and others in the Columbia River basin and throughout the Pacific Northwest. Tributary and estuarine habitat degradation, combined with other factors such as hydroelectric operations in the mainstem Snake and Columbia rivers, predation, and commercial and sport fishing contributed to the decline and subsequent listing of numerous Columbia River basin salmon populations under the Endangered Species Act (ESA) (NOAA, 2008). Recovery of these salmon populations will require a comprehensive management approach that addresses all limiting factors to salmon viability including tributary and estuarine habitat, hydropower impacts, and predation. However, recent emphasis and considerable expense has been directed at restoration of tributary habitat conditions as a means to mitigate for hydropower impacts to threatened salmon populations (BPA, 2008; NOAA, 2008). The extent to which habitat restoration can achieve this goal, particularly in the context of warming stream temperatures due to climate change, has been identified as a critical uncertainty in the Columbia River basin (ISAB/ISRP, 2016).

Given the threat that high water temperature poses on fish populations throughout the Pacific Northwest (Beechie et al., 2013) and across North America (Lynch et al., 2016), it is important to understand the extent to which stream and riparian restoration activities can mitigate future water temperature increases due to climate change (Bernhardt et al., 2005; Ficklin et al., 2014). While similar studies in the Pacific Northwest have examined the potential influence of riparian and channel restoration on water temperature (Chen et al., 1998; Sullivan and Rounds, 2004; Watanabe et al., 2005; Butcher et al., 2010), few have integrated riparian restoration with climate change projections to evaluate whether restoration actions would be sufficient to offset climate change impacts (Battin et al., 2007; Bond et al., 2015). Our research additionally draws on fish-habitat relationships developed from empirical fish and habitat data to evaluate how fish populations would respond to simulated changes in water temperature. Integrating predicted changes in habitat conditions with fish population response provides a critical link needed by natural resource managers to evaluate the potential benefits of restoration actions and to plan and adjust management decisions accordingly.

We used a water temperature simulation model to investigate potential thermal benefits of riparian reforestation and channel narrowing in context of future climate change to Chinook Salmon populations in the Upper Grande Ronde River and Catherine Creek in Northeast Oregon. Our specific objectives were 1) to simulate water temperature changes that may result from restoration actions, 2) to evaluate whether future climate change impacts could be offset by riparian and channel restoration actions, 3) to predict how simulated temperature changes would influence the abundance of Chinook Salmon summer parr, and 4) to develop a tool that can be used by restoration planners and practitioners to investigate alternative land-management strategies and prioritize restoration actions.

2. Methods

2.1. Study area

The Grande Ronde River is a major tributary of the Snake River, originating in the Blue Mountains of NE Oregon and flowing approximately 340 km north/northwest before joining the Snake River in SE Washington. The study area included select reaches of the Upper Grande Ronde Basin (UGRB), which is located upstream of the Catherine Creek confluence near the city of La Grande, and the Catherine Creek Basin (CCB), a large tributary of the Grande Ronde River (Fig. 1). The UGRB and CCB drain areas of approximately 1896 and 1051 km^2, respectively. This area is typified by cold winters with ample snow in its headwaters areas, and hot, dry summers. Basin tributaries are primarily fed by snowmelt, with peak flows occurring during the spring, and base flows occurring during the late summer. Due to the relatively lower elevation of headwater peaks in the UGRB compared with CCB, snowmelt generally occurs earlier in the UGRB, often resulting in very low summer base flows and warmer water temperatures.

Habitat for fish and other aquatic life in the Grande Ronde basin has been steadily degraded since the mid-1800s due to land use, with water temperature being arguably one of the most impaired and influential factors for ESA-listed Chinook Salmon, steelhead, and bull trout in the basin. The Environmental Protection Agency (EPA) established a set of temperature water quality standards for the Pacific Northwest region to protect threatened salmonids which include a maximum weekly maximum temperature of 16 °C for juvenile salmon/trout rearing, 18 °C for salmon/trout migration plus non-core rearing, and 20 °C for salmon/trout migration (EPA, 2003). As of 1999, approximately 92% of the Grande Ronde River upstream of the Wallowa River confluence exceeded the 18 °C temperature standard (ODEQ, 2000).

This study focused on two threatened salmon populations within the Snake River spring/summer Chinook Evolutionary Significant Unit (ESU), the Upper Grande Ronde River Spring Chinook and Catherine Creek Spring Chinook. These focal populations were chosen because of the perceived large juvenile life-stage survival gaps due to habitat impairments and because of the existence of high quality fish and habitat monitoring data.

2.2. Temperature model

We used a deterministic water temperature model, Heat Source (Boyd and Kasper, 2003), to simulate water temperature and flow dynamics in major salmon-bearing streams of the UGRB and CCB (Fig. 1). Heat Source uses stream channel geometry, hydrology, climatic conditions, and riparian vegetation cover and height to simulate stream temperature and effective shade at 100 m intervals (termed model nodes) throughout the stream network. The Heat Source model was selected because it has been applied extensively throughout Oregon (ODEQ, 2000; Crown et al., 2008; Watershed Sciences, 2008; Butcher et al., 2010) and elsewhere in the Pacific Northwest to evaluate compliance with water temperature standards, and because it's well suited to simulating the effects of riparian vegetation on stream temperature at a fine spatial resolution—a feature that is useful for restoration prioritization.

Model inputs including channel topography (i.e., stream width and gradient) and riparian vegetation (canopy height and density) were measured using light detection and ranging (LiDAR) data collected in 2009. Climatic data, including air temperature, cloud cover, relative humidity, and wind speed, were recorded by the National Weather Service at the La Grande airport and by the US