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The effects of river restoration on nutrient retention and transport for aquatic food webs

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The resilience of Pacific salmon is influenced by watershed processes that supply structural components of the aquatic environment such as coarse sediment and large wood, as well as those that support the transfer of energy and nutrients through aquatic food webs (Bisson et al. 2009).

Timeline note

This project has received a no-cost extension to continue this work through the summer of 2015 to complete the proposed work. Specifically, we completed the fieldwork and analysis for Question 1 and we are writing up the thesis for publication. We started the fieldwork for Question 2 on May 20th and will be completed by September 2015. Question 2 analysis and write-up are part of Laura Livingston's thesis (May 2016 expected completion). The remaining USGS funds (~$4,000) will be spend by July 15th, 2015.

Problem and Research Objectives

Stream restoration in the United States is a multi-billion dollar industry. Federal agencies spent $1.5 billion between 1997-2001 to recover steelhead and salmon in the Columbia River Basin (US GAO 2002). More recently in 2010, $80 million was spent on Columbia basin watershed restoration to improve salmon and steelhead populations, with $30 million allocated to Washington State alone. Allocations to Washington State are high because much of the Columbia watershed lies in the state, and 61% of Washington's area is affected by ESA listings of salmon and steelhead.

NOAA listed channel structure and nutrients limitation as major factors limiting listed steelhead and salmon populations in the interior Columbia River watershed. *While the investment in engineering stream restoration projects is immense, our knowledge of how logjam structures influence hyporheic exchange and nutrient retention is lacking; in addition, we lack clear evidence of the effectiveness of salmon carcass additions to increase the biomass of listed fish.*

Our study used two restoration actions as experiments to understand the ecological influence of a logjam installation and addition of salmon carcass analogs. Specifically, (1) we used a reach scale restoration of logjams as a field-manipulative experiment to quantify their effect on transient storage, hyporheic exchange, and nutrient uptake on the Tucannon River, WA; and, (2) we are conducting a pilot study in the Methow River Basin, WA to understand how salmon carcass analogs influence invertebrate community production. We used the field experiments to resolve two questions:

- **Q1. How do log jam installation impact transient storage, hyporheic exchange, and nutrient uptake in mid-order, low nutrient streams?**
- **Q2. How do salmon carcass analogs influence invertebrate community composition and secondary production compared to non-salmon and salmon bearing streams?**

Note: Our original proposal asked similar questions for application in the Methow Basin. Unfortunately, large fires and instability in knowing when the logjams were to be installed forced us to move out of the Methow Basin for Question 1 and a year later for Question 2.

Methodology

The influence of logjam installation on shallow ground water exchange and nutrient uptake

Bonneville Power Administration (BPA) funded logjam installation in the Tucannon River in southeastern Washington in the summer of 2014. The Tucannon River in is a strongly nitrogen limited system that is currently experiencing low returns of steelhead and Chinook salmon. These logjams are intended to improve habitat for juvenile salmonids as well as add instream channel complexity and floodplain connectivity.

Our study involved evaluating how hyporheic exchange and nitrogen uptake changed after logjam installation. We applied a before after control impact, (BACI) experimental design to isolate the impacts of log jam installation on hyporheic exchange and nutrient uptake. We established two 750 m reaches: one study reach and one reference reach. Washington Department of Fish and Wildlife and Snake River Salmon Recovery Board in the study site installed engineered logjams in July 2014, while the upstream reference was not influenced by restoration activities. We measured hyporheic exchange and nutrient uptake in July, August, and September, with an additional nutrient uptake measurement taken in October. Hyporheic exchange was measured using piezometers installed 30 cm into the streambed. Nutrient uptake was measured using slug injections of ammonium, where a known mass of ammonium was injected at the upstream end of each reach and grab samples taken to measure the mass recovered downstream.

The influence of salmon carcass addition on secondary production and composition

The effect of restoration actions typically focus on monitoring fish and not on trophic production. Fish population dynamics are highly influenced by multiple factors, both within the basin and outside, which make them poor ecological indicators. This study aims to quantify the influence of salmon carcass additions on secondary production and composition, as these are the trophic basis of production for fish. The study asks 'what are the nutrient subsidy effects to lower trophic levels along both direct and indirect pathways?' We hypothesized that direct consumption is a relatively small contribution to salmon carcass effects on secondary production.

Using a controlled field manipulation, we will quantify invertebrate consumption of salmon carcasses and salmon carcass analogs. We will also compare invertebrate community composition in reaches with and without salmon carcass material. This composition data will be used to determine if salmon carcass subsidies affect invertebrate community composition and to compare relative invertebrate densities with invertebrates consumed by salmon. These manipulations will use natural salmon carcasses (spring Chinook) and salmon carcass analogs. Salmon carcass analogs are pellets of ground-up salmon that fisheries managers can use to stimulate growth of food resources for juvenile salmon.

We will conduct five controlled experiments and concomitant observational studies in the Methow River in north-central Washington in the summer of 2015. We will place salmon carcass analogs in non-salmon spawning streams during early summer and once again in early fall and measure colonization and consumption. Colonizing invertebrates will be sample and identified to species level to describe composition and abundance. We will extract gut contents from a selected number of ubiquitous taxa to quantify secondary production related to carcass addition. We will sample from control streams in both salmon spawning and non-spawning reaches. We will use stable isotopes of nitrogen (N^{15}) and carbon (C^{13}) to track enriched nutrients.

We consider the trophic transfer of nutrients to secondary production a better metric than fish population metrics for evaluating the influence of nutrient addition to restore salmon rearing ecosystems.

Principle Findings and Significance

The influence of logjam installation on shallow ground water exchange and nutrient uptake
Our results indicate that logjam installation led to increased hyporheic exchange. Immediately after log jam installation, hyporheic exchange in the study site increased 56% compared to a 31% decrease in the reference site. The study site also changed from 100% upwelling to 63% upwelling and 37% downwelling immediately after restoration, demonstrating how logjams increase the heterogeneity of hyporheic exchange. Nutrient uptake was not significantly impacted by logjam installation, which could be due to a lag time either between installation and biotic response or methodological issues.

The patchwork of upwelling and downwelling sections observed following restoration has important implications for hyporheic flow paths and the solutes they bring into the hyporheic zone. Before installation in the study site, upwelling dominated the reach which were likely from long residence time hyporheic flows that originated upstream of the reach. The patchwork of upwelling and downwelling sections after restoration makes it possible that upwelling sections are now the result of downwelling sections occurring in the same reach. This shorter residence time water is likely higher in oxygen, and the greater magnitude of flux creates better habitat for spawning fish, insects, and other hyporheic organisms.

To our knowledge, this is the largest stream where hyporheic response to large wood installation has been measured using piezometers. Expanding our knowledge of hyporheic exchange is important in streams like the Tucannon where multiple anadromous salmonids live for at least a portion of their life cycle (Chinook, steelhead, bull trout). Future work should seek to evaluate how large streams respond to wood structures over time, by monitoring both geomorphic and hyporheic flow changes after high flow events mobilize bed material. Understanding the process of how hyporheic flows establish and develop will make predicting hyporheic response to restoration actions like log placement possible in other systems.

The influence of salmon carcass addition on secondary production and composition
Marine derived material from salmon may affect secondary production through direct consumption and indirect recycling pathways (Gende et al 2002). Direct consumption represents a more efficient transfer of salmon material to secondary production than the indirect pathway. However, direct consumption of salmon carcasses may be limited to a few taxa or may be inhibited by fungal growth on carcasses (Kohler et al 2008, Garman 1992). These limits on direct consumption of salmon material suggest that direct consumption effects on secondary production may be relatively small.

Previous studies on the effects of salmon carcasses and salmon carcass analogs have shown positive effects of salmon material on invertebrate communities (Honea and Gara 2009, Kohler et al 2012, and Minakawa et al 2002). Quantifying biomass changes and tracking enriched nutrients in invertebrate communities indicate invertebrate community responses to salmon. However, these measurements do not indicate the contribution of direct consumption to salmon carcass and salmon carcass analog effects on secondary production responses. By examining invertebrate gut contents, we will provide an estimate of the contribution of direct consumption to salmon carcass effects on secondary production. While direct consumption may have a relatively small contribution to secondary production, we expect that the insect taxa directly consuming salmon carcasses will have a high dietary reliance on that material.

List of Students Supported

Joseph Parzych, MS – Environmental Science and Natural Resources May 2015
Laura Livingston MS – Environmental Science and Natural Resources May 2016 (expected)
John Jorgensen PhD -– Environmental Science and Natural Resources May 2018 (expected)

Publications, and Awards and Achievements

Parzych, JM, AK Fremier, C Hyuck Orr. Impacts of logjam installation on hyporheic exchange and nutrient uptake in a 4^{th} order Washington stream. To submit to: Freshwater Science (August 2015)
Robert Lane Fellowship, WSU School of the Environment (J. Parzych)
School of the Environment Graduate Research Stipend (2014-2015) (J. Parzych)

Invited speaker to the Regional Technical Team on restoration of hyporheic flow. Wenatchee, WA December 10 2014. (AK Fremier and JM Parzych)

Clearwater Fly Casters Scholarship (L. Livingston)
Newsroom Report, WSU Center for Environmental Research, Education, and Outreach (L. Livingston)
Boeing Environmental Award, WSU School of the Environment (L. Livingston)

Washington Department of Fish and Wildlife adopted our hyporheic monitoring protocol for monitoring logjam installation in the Tucannon in 2015. We provided the equipment and expertise for installation and study design.

References

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Kohler, A., A. Rugenski, and D. Taki. (2008) Stream food web response to a salmon carcass analog addition in two central Idaho, U.S.A. streams. Freshwater Biology 53: 446-460.

Kohler, A.E., T.N. Pearsons, J.S. Zendt, M.G. Mesa, C.L. Johnson, and P.J. Conolly. (2012) Nutrient enrichment with salmon carcass analogs in the Columbia River Basin, USA: stream food web analysis. Transactions of the American Fisheries Society 141 (3): 802-824.

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