Monitoring Recovery Trends in Key Spring Chinook Habitat Variables and Validation of Population Viability Indicators: Annual Report 2012

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Executive Summary

Background and Objectives

The Columbia River Inter-Tribal Fish Commission (CRITFC) is conducting a fish habitat monitoring program in the Upper Grande Ronde River and Catherine Creek basins designed to evaluate the effectiveness of aggregate restoration actions in improving freshwater habitat conditions and viability of salmonids listed under the Endangered Species Act. A critical uncertainty for fisheries managers in the Columbia Basin is whether habitat restoration actions will yield a net improvement in basin-wide habitat quality. Bonneville Power Administration (BPA) funds our project and has an interest in determining whether expected improvements in fish production can be brought about by improvements in the quality and quantity of salmon habitat.

The primary objectives of this project are to:

1) Assess current status and trends in fish habitat characteristics considered to be key limiting factors (particularly water temperature, pool habitats, streamflow, and fine sediment) to viability of spring Chinook salmon populations.
2) Evaluate effectiveness of aggregate stream restoration actions aimed at improving key limiting habitat factors.
3) Develop a life cycle model to link biotic responses of spring Chinook populations to projected changes in stream habitat conditions.

Life Cycle Model as an Organizing Concept

One of the central components of this project is a spring Chinook life cycle model which provides a means to integrate habitat monitoring efforts with recovery planning. The life cycle model is a tool to simulate fish population trends in relation to projected habitat conditions, and to examine the relative benefits of habitat improvements on fish population recovery potential. The fundamental basis of the model is that intrinsic watershed factors (such as geology, climate, or valley morphology) interact with human actions (such as forest harvest, cattle grazing, or stream restoration) to affect processes that drive known limiting factors (e.g., flow, temperature, pool area, etc.), and therefore fish survival via both density-dependent and density-independent processes. This conceptual model, illustrated in Figure 1, represents the general structure of our research program.

The life history model is comprised of several interacting subcomponents that are built independently, each of which provides critical information about the interaction between landscape characteristics, instream habitat conditions, and fish response. Individual subcomponents of the life cycle model, and of our research program, include modeling stream temperature from local riparian and geomorphic conditions, a sediment delivery model, linking fine sediment and water temperature to fish survival, mapping potential natural vegetation, estimating food base and growth potential for salmonids from macroinvertebrate drift data and habitat characteristics, and evaluating the vulnerability of sites to low stream flows (Table 1). Though these components are described here as providing inputs to the life cycle model, each model is a valid research project in its own right that is likely to yield interesting scientific insights and practical applications for conservation.

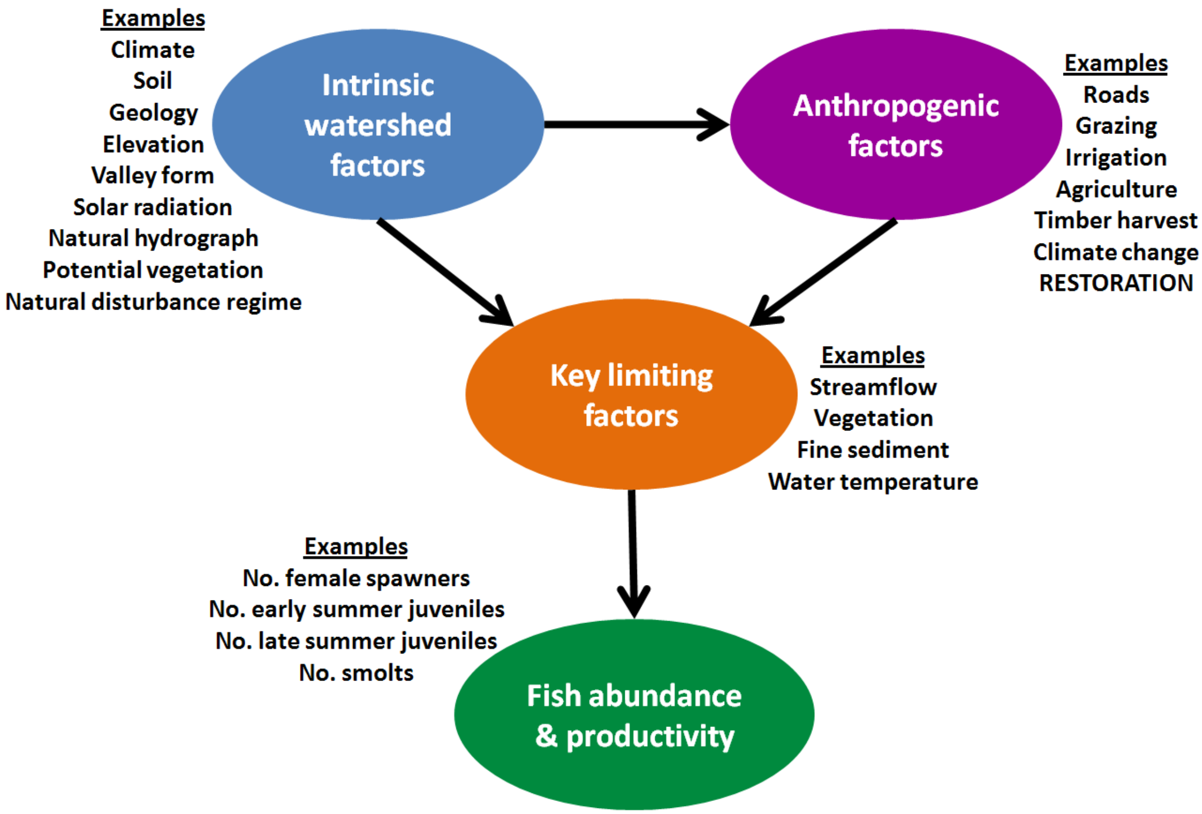

Figure 1. Conceptual framework for relating fish abundance and productivity to watershed characteristics and limiting factors. Direction of arrows indicates direction of influence.

Table 1. Individual habitat model components.

Habitat model	Data sources	Model output
Heat Source Temperature Model	LiDAR, FLIR, stream temperature & flow, stream channel morphology, riparian condition	Spatially-explicit predictions of water temperature under various land use & restoration scenarios
Sediment Delivery Model	Hillslope and channel gradient, road density, grazing intensity	Identification of at-risk areas in the watershed where sediment is likely to have detrimental effects on fish
Fine Sediment-Fish Survival	Literature effects of fines, field tests of incubation survival	Functional relationship between fine sediment values measured in the field and theoretical fish survival
Water Temperature-Fish Survival	Literature effects of water temperature on survival and growth	Functional relationship between stream temperature measured in the field and theoretical fish growth and survival
Natural Potential Riparian Vegetation	Historical vegetation maps, geology & soil maps, aerial photos, valley morphology, climate data	Map of current & historical vegetation as a reference condition to compare against alternative riparian management scenarios
Macroinvertebrate Drift	Drift samples, riparian condition, upstream land use, stream substrate, water temperature	Spatially-explicit predictions of energetic resources available to fish
Low Flows	USGS flow data, watershed area, geology, mean annual precipitation, drainage basin morphology	Spatially-explicit predictions of stream reaches vulnerable to detrimental low flows

Progress and key findings from 2012

We continued several monitoring activities established from previous years, compiled new data on watershed-scale anthropogenic factors, and made headway on several analyses of fish-habitat relationships that feed into our individual model components. This work is summarized below in terms of progress and key findings to date.

Stream habitat conditions

Progress

- ✓ Continued collection of stream habitat condition data using the Columbia Habitat Monitoring Program (CHaMP) methodology at 25 sites in 2012 and totaling 40 sites in the spring Chinook sample frame to date. These data contribute to a growing body of information across the Columbia basin that can be used to understand fish-habitat relationships.
- ✓ Continued QA/QC of 2011-12 CHaMP data and assistance with revisions to CHaMP protocol.
- ✓ Preliminary analysis of key habitat metrics in relation to stream channel size and basin identity.

Key findings

- ➢ The distributions of several key habitat factors important for salmon—pools (Figure 5), large woody debris (Figure 6), and pool tail fine sediments (Figure 7)—were dependent on basin identity and channel size, indicating that future analyses that establish fish-habitat relationships will need to account for at least these components of background environmental variability.

Habitat relationships for fish and benthic macroinvertebrates

<u>Progress</u>

- ✓ Continued surveys and metric generation for stream biota (fish and benthic macroinvertebrates) paired with 55 CHaMP habitat monitoring sites in 2012, in coordination with Oregon Department of Fish & Wildlife (ODFW).
- ✓ In collaboration with ODFW, development of a scaling factor for fish counts from snorkel surveys and electrofishing to actual population size, based on a mark-recapture study.
- ✓ Compilation of existing databases listing ecological and life history traits of stream invertebrates.
- ✓ New and updated statistical analyses associating fish and benthic macroinvertebrates to watershed and site-level characteristics.

<u>Key findings</u>

- ➢ Summertime rearing densities of spring Chinook salmon were highly variable but showed trends of a year and basin effect; fish densities scaled to habitat types (pools, riffles, and glides) in a predictable fashion (Table 15).
- ➢ When bivariate relationships were explored (Table 16), salmonids were found to be most strongly associated with mean annual flow at the watershed scale and thalweg profile at the site level. Benthic invertebrates were most strongly associated with longitude (possibly a basin effect) at the watershed scale and large wood at the site level.
- ➢ We confirmed previous findings that juvenile Chinook densities are affected directly by large wood, but also indirectly through the role large wood plays in pool formation. When benthic macroinvertebrates were added to this model, they demonstrated a more tightly coupled response to site-level characteristics (i.e., large wood) than did fish (Figure 26).

Stream temperature analyses

<u>Progress</u>

- ✓ Continued monitoring of stream temperature at 45 sites.
- ✓ Analysis of peak temperatures in relation to physiological tolerances of fish.
- ✓ Expansion of Heat Source model to include a broader temporal window.

<u>Key findings</u>

- ➢ Based on Heat Source modeling of water temperature from 2010, a total of 76% of the habitat that was historically available to Chinook salmon currently exceeds the upper incipient lethal temperature of 21 °C maximum weekly maximum temperature in the Upper Grande Ronde basin, compared with 24% in Catherine Creek.

- ➢ Heat Source model simulations also indicated that restoration of potential natural vegetation could reduce water temperatures in the entire mainstem Grande Ronde River to below 15°C, representing a recovery of the river to thermal conditions that are conducive to salmonid production (Figure 25).
- ➢ The frequency of occurrence of summertime thermal regimes that are able to kill 50% of a spring Chinook juvenile rearing population is high in many years in the Upper Grande Ronde mainstem above Fly Creek and increases in a downstream direction. This is associated with the patterns of distribution of hourly water temperatures from 25°C to 29°C.

Subsurface sediment

<u>Progress</u>

- ✓ Continued collection and processing of subsurface sediment core samples.
- ✓ Analyzed the relationship between depth fines and surface fines to assess the validity of using rapid and less expensive surface fines methods to predict the quantity of fines at depth, which are more relevant to salmonid egg survival.

<u>Key findings</u>

- ➢ Most survey sites had fine sediment concentrations below what might be considered a critical threshold level for survival of incubating eggs (Figure 17). Median egg-to-fry survival rates, as predicted by a literature-based model, were 90.8 and 87.2% for Catherine Creek and the Upper Grande Ronde River basins, respectively (Figure 18).
- ➢ We demonstrated significant correlations between surface fine sediments (measured by the CHaMP protocol) and subsurface fine sediments (measured with the CRITFC protocol). These results lend support to the ability to conduct rapid analyses of surface fine sediment conditions as a means of identifying important trends in subsurface fines.

Riparian vegetation mapping

<u>Progress</u>

- ✓ Riparian ecology experts hired as subcontractors began assembling a natural resource database that will be essential in mapping current and potential natural vegetation communities.
- ✓ Riparian contractors collaborated in development of procedures for mapping vegetation in streamside zones for both study watersheds.

Hydrological analysis and streamflow monitoring

<u>Progress</u>

- ✓ Hydrologic neighborhood analysis linking watershed characteristics with low-flow metrics conducted, using long-term data records from 41 USGS gage sites.
- ✓ Continued collection and summarization of streamflow data at two CRITFC-operated gages on North Fork Catherine and Sheep Creeks.

<u>Key findings</u>

- ➢ Preliminary analysis revealed that watershed characteristics derived from a geographic information system (GIS)—elevation, precipitation, and stream density—were strongly correlated with low-flow metrics—variability, groundwater influence, and timing of low flow. This relationship demonstrates that low-flow metrics can be predicted at ungaged sites using GIS data (p. 60).

Watershed conditions

<u>Progress</u>

- ✓ Development of procedures for using Basin Tools and batch processing of StreamStats for watershed analysis.
- ✓ GIS mapping of new roads and consolidation and refinement of two existing GIS road layers for use in calculating road density by proximity to study sites.
- ✓ A method for mapping historical riparian vegetation and stream complexity using GIS and Government Land Office (GLO) surveys from the late 19th century was developed (Figure 14).

<u>Key findings</u>

- ➢ There are numerous unmapped roads in the Upper Grande Ronde River watershed that will significantly increase the estimated road densities from what has previously been mapped (e.g., Figure 13). Existing road layers are mapped with poor spatial precision.

Evaluation of solar radiation input methodologies

<u>Progress</u>

- ✓ Solar radiation measurements were reported on only a single site. Analysis will be continued on other, more complex sites to explore the universality of our conclusions.

<u>Key findings</u>

- ➢ The Solmetric SunEye device provides a reliable method for measuring direct beam solar radiation and consequently, trends in solar access measured at a consistent point will reveal improvements in riparian canopy cover.
- ➢ The SunEye device and Heat Source program analysis indicate that very similar levels of solar access (%) at the water surface are calculated by these two very different methods, providing support for continued use of each method for detecting trends.

Evaluation of air temperature methodologies

<u>Progress</u>

- ✓ Air temperature monitoring was evaluated at only a single site. Variations in adiabatic lapse rate or correlation with the La Grande climate station data or other Upper Grande Ronde annual sites may exist and will be explored. The results of this analysis will be used to yield more precise water temperature estimates from the Heat Source model.

Draft life cycle model

Progress

- ✓ Implemented spatial structure into life cycle model.
- ✓ Integrating prediction of ocean survival with TRT Matrix model.
- ✓ Developed framework for resource optimization component to allocate habitat actions spatially for optimal production.

Key findings

- ➢ Preliminary sensitivity analysis indicates that production gains from cumulative habitat improvements can be non-linear in nature, and can lead to spatially and temporally variable habitat improvement strategies.

Coordination with regional agencies, tribes, and landowners

Progress (p. 72)

- ✓ Continued active participation in design and implementation of CHaMP.
- ✓ Participation on FCRPS Adaptive Management Implementation (AMIP) steering committee.
- ✓ Participation on FCRPS Expert Panel and Implementation Prioritization Strategy for the upper Grande and Catherine Creek basins.
- ✓ Participation with Pacific Northwest Aquatic Monitoring Partnership (PNAMP) macroinvertebrate committee, including co-organizing a symposium at Oregon Chapter of the American Fisheries Society.
- ✓ Participation in data sharing and fish-habitat modeling with the Integrated Status and Effectiveness Monitoring Program (ISEMP).
- ✓ Hosted a tribal habitat workshop for the four CRITFC member tribes, with the goals of developing a strong tribal voice on habitat conservation, share lessons learned from past and current fish habitat monitoring, understanding regional monitoring needs, and considering opportunities to coordinate future fish habitat monitoring efforts.
- ✓ Continued communication with landowners for access to private property; development of methods for summarizing site-specific results for individual landowners.

Review and refine monitoring protocols and statistical designs

Progress (p. 74)

- ✓ Provided detailed reviews and reviews and feedback on field collection and analysis methods for CHaMP.
- ✓ Assisted with training of field crews and logistics at “CHaMP Camp,” an annual training program for field crews across the Pacific Northwest.
- ✓ Refinements to temporal and spatial design for sampling at Chinook sites in our project area.

Develop and manage fish habitat condition database

Progress (p. 74)

- ✓ Continued acquisition, QA/QC, and summarization of several fish and macroinvertebrate metrics, site-level habitat conditions, and watershed conditions (Table 5).

Response to RM&E Questions from BPA

As discussed in the main body of this report, we feel it is too early in the development of our research program to definitively answer the RM&E questions posed by Bonneville Power Administration. However, this is not to say that our work has not significantly contributed to developing material that will be highly valuable in answering those questions in the near future. Below, we report progress on how we are actively addressing the three questions:

- *What are the tributary habitat limiting factors (ecological impairments) or threats preventing the achievement of desired tributary habitat performance objectives?*

  Several of our individual project components seek to address this question (Table 1). Most notably, a life cycle model (Appendix A) where scenarios of management actions can be evaluated in terms of the population-level response by fish, will become the most useful means to address this question fully. The life cycle modeling approach is ideally suited to address questions of "limiting factors" via its ability to identify important environmental bottlenecks to population growth. For example, based on preliminary analysis we strongly suspect that water temperature is limiting production of particular life stages of spring Chinook salmon in many locations throughout the basin (Table 6), but incorporating this and other potential limiting factors into a life cycle model will provide evidence on the extent to which a given factor actually limits fish production at the population level. Further progress in making our life cycle model fully functional awaits completion of a system to classify stream segments, calculating average values for all key limiting factors, and finalizing adoption of survival functions for these limiting factors. In the interim, progress reported here indicates a growing body of information on fish/habitat relationships (e.g., effects of fine sediments during incubation, effects of water temperature during summer rearing) derived from model components (Table 1).

  One area in which our project is unique is in linking intrinsic watershed factors and anthropogenic activities to site-level limiting factors and biological response (Figure 1). These relationships among watershed, land use, and response of aquatic biota are likely to be very complex, and we are developing statistical tools to deal with this complexity (p. 32).

- *Are tributary actions achieving the expected biological and environmental improvements in habitat?*

  In collaboration with ODFW, which has adopted CRITFC procedures for snorkeling and benthic macroinvertebrate sampling, we are amassing a large database of stream biota records that can be coupled with CHaMP habitat data and watershed characteristics (Table 5). Our habitat data collection using CHaMP protocol paired with biotic surveys began in 2011, so we have only two years of data at this point Rates of habitat improvement in watersheds undergoing restoration are typically slow (decadal timeframes). Aquatic biota respond relatively rapidly to habitat improvements that do occur, but also exhibit considerable annual variations not attributable to changing habitat conditions that must be understood in order to recognize those changes that reflect improved habitat. While estimating upward or downward trends in fish abundance or macroinvertebrate indices will require more seasons of data collection, it will be possible to

estimate the effects of habitat restoration using a space-for-time approach. This method involves using existing habitat status and level of past and current management effect (i.e., degree of restoration or land use impact) throughout the watershed (and potentially outside the watershed) and evaluating the response of fish or macroinvertebrates to infer what effects habitat restoration could have in comparable geomorphic settings. Furthermore, we have gained access to ODFW records of fish abundance and survival at the population level that will help us validate parameters in our life cycle model and, eventually, evaluate fish population trends over time.

- *How has regional coordination supported communication or the development and adoption of standard requirements for metrics, sample designs, data collection protocols, data dictionary, meta-data, and data access… how does regional coordination support prioritization of habitat restoration?*

  In the interest of contributing to efforts leading to science-based decision making for prioritizing tributary habitat restoration, we have devoted significant time and resources to coordination with several regional programs. We are deeply ingrained in the CHaMP program, including development of field-collection and data analysis methods, metric review, and QA/QA of raw data (p. 74). Our adoption of the CHaMP protocol and dedication to its continued development stem from our interest in using standardized sample design, data collection, metric calculation, and data access. We are also coordinating with several other agencies including the Adaptive Management Implementation Plan (AMIP), BiOp expert panel for the upper Grande Ronde and Catherine Creek, Pacific Northwest Aquatic Monitoring Partnership (PNAMP), Integrated Status and Effectiveness Monitoring Program (ISEMP), and CRITFC member tribes—Yakama, Nez Perce, Umatilla, and Warm Springs (p. 72). All of these coordination efforts serve the purpose of broadening the scope of data collection and inference to include other watersheds and fish populations in the Columbia basin.

Introduction

The Columbia River Inter-Tribal Fish Commission is conducting a fish habitat monitoring program in the Upper Grande Ronde River and Catherine Creek basins designed to evaluate the effectiveness of aggregate restoration actions in improving freshwater habitat conditions and viability of ESA-listed salmon populations (McCullough and Sharma 2009). A critical uncertainty for fisheries managers in the Columbia Basin involves determining whether habitat restoration actions will yield a net improvement in basin-wide habitat quality. Bonneville Power Administration funds our project and has an interest in determining whether expected improvements in fish production can be brought about by improvements in the quality and quantity of salmon habitat.

Habitat restoration is being conducted by agencies such as the US Forest Service (Upper Grande Ronde mine tailings restoration, where channel damage was done by historic dredge mining of the streambed), the Umatilla Tribe (e.g., McCoy Creek Meadows restoration, where natural river meanders are being restored to a channelized stream), the Oregon Department of Fish and Wildlife, and the Grande Ronde Model Watershed (e.g., riparian fencing, riparian planting, improvement of irrigation diversions). The US Bureau of Reclamation is also conducting studies of water use and availability in Catherine Creek watershed and may implement projects based on the findings.

There have been many studies conducted in recent years examining the current condition of fish habitat in all the subbasins of the Columbia River. Some of the most common impediments to survival of salmon tend to be high water temperatures, increased concentrations of fine sediment in spawning gravel, loss of riparian vegetation, channelization, loss of large woody debris in the channel, loss of large pools for adult fish to hold in prior to spawning, and summertime depletion of streamflows in the channel. Added to these concerns caused by human influence is climate change, which can lead progressively to changes in the timing of runoff from snowmelt, increased summer air temperatures, and change in the seasonal distribution of precipitation.

We are attempting to monitor all habitat factors that have been identified by previous studies as the key limiting factors. Our monitoring plan includes measurement of: water temperature, streambed substrate composition and fine sediment concentrations, streamflow, water chemistry, riparian condition, stream channel morphology (including spawning habitat and large pool distribution), large woody debris, benthic macroinvertebrates (diversity and density, which indicate long-term water quality), drifting macroinvertebrates (indicating fish food availability), and fish snorkeling (indicating relative abundance of salmonids and qualitative indices of abundance of non-salmonids). Habitat surveys are conducted in 25 sites per year distributed throughout the currently used spring Chinook spawning and rearing habitat in the Upper Grande Ronde and Catherine Creek basins following methods developed by the Columbia Habitat Monitoring Program (CHaMP; www.champmonitoring.org).

As a means to integrate habitat monitoring efforts with recovery planning, CRITFC is developing a life cycle model. The current prototype population is Catherine Creek spring/summer Chinook, but the model's utility will extend to other salmonid populations and life history types. The fundamental basis of the model is that habitat conditions are drivers that affect known limiting factors (e.g., flow, temperature, pool area, etc.), and therefore survival via both density dependent and independent processes. Habitat/survival relationships are built into several fresh water and marine life stages such that both age structure and spatial structure can be predicted in relation to changes in environmental conditions. Thus, the current and future habitat conditions can act as predictors of relative change in survival at different life history stages, and therefore affect recovery potential. Furthermore, the spatial availability and quality of spawning and rearing habitat, and the allocation of resources to improve

habitat can have an indirect but quantifiable effect on the potential production of a population. Climate change will be integrated into population predictions as an exogenous factor that affects some of the key limiting factors. The life cycle model is being designed as a tool to simulate population trends in relation to projected habitat conditions, and to examine the relative benefits of habitat improvements on population recovery potential.

The primary objectives of this project are to: 1) Assess current status and trends in fish habitat characteristics considered to be key limiting factors (particularly water temperature, pool habitats, streamflow, and fine sediment) to viability of spring Chinook salmon populations; 2) Evaluate effectiveness of aggregate stream restoration actions aimed at improving key limiting habitat factors; 3) Develop a life cycle model to link biotic responses of spring Chinook populations to projected changes in stream habitat conditions.

Methods: Protocols, Study Designs, and Study Area

Tributary Habitat RM&E

Monitor and evaluate tributary habitat conditions that may be limiting achievement of biological performance objectives.

What are the tributary habitat limiting factors (ecological impairments) or threats preventing the achievement of desired tributary habitat performance objectives?

<u>Study Area</u>

This study was conducted in the Grande Ronde River and its tributaries, which originates in the Blue Mountains of NE Oregon and flows 334 km to its confluence with Snake River near the town of Rogersburg, Washington (Figure 2). Focal watersheds include the Upper Grande Ronde River above the town of La Grande, Catherine Creek, and to a lesser extent, the Minam River, which drain areas of approximately 1,896, 1,051, and 618 km² respectively.

The topography of the upper portion of the subbasin (i.e., upstream of the Wallowa River confluence) is characterized by rugged mountains in the headwater areas and a broad, low gradient valley between the Blue and Wallowa Mountains. Peaks in the Wallowa Mountains reach a maximum elevation of 2,999 m (9,838 ft), and provide the source of many of the Grande Ronde's tributaries including Catherine Creek and the Wallowa River. The Blue Mountains reach elevations of 2,347 m (7,700 ft), and are the source of the Grande Ronde River, Wenaha River, and other tributaries. Due to the lower elevation of the Blue Mountains, snow melt generally occurs earlier in these tributaries, often resulting in very low flows during summer.

Surface geology of the Grande Ronde Subbasin is dominated by rocks of the Columbia River Basalt group, with some older granitic intrusives and older volcanics with associated sedimentary deposits present in the headwater areas of the Upper Grande Ronde and Catherine Creek. The climate is characterized by cold, moist winters and warm, dry summers with mean daily air temperatures near La Grande averaging -0.42 °C (31 °F) in January and 21 °C (70 °F) in July. Average annual precipitation ranges from 36 cm (14 in) in the valleys to 152 cm (60 in) in the mountains, with most of the precipitation in the mountains falling as winter snow.

The vegetation community at lower elevations is dominated by grasslands consisting of Idaho fescue-bluebunch wheatgrass (*Festuca idahoensis-Agropyron spicatum*) and bluebunch wheatgrass-Sandberg's bluegrass (*Agropyron spicatum-Poa sandbergii*) (Nowak 2004). As elevation increases, the grasslands transition to shrub/scrub plants, and eventually to coniferous forests in the mountains. Forest species consist of low elevation Ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*) associations grading into Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), subalpine fir (*Abies lasiocarpa*), and mountain hemlock (*Tsuga mertensiana*) associations at higher elevations. Riparian vegetation is dominated by black cottonwood (*Populus trichocarpa*) and willow (*Salix spp*), black hawthorn (*Crataegus douglasii*), mountain alder (*Alnus incana*), and mountain maple (*Acer glabrum*).

Approximately 49% of the land in the Grande Ronde basin is publically owned, of which about 97% is managed by the US Forest Service. The remaining public land is managed by the Bureau of Land Management and the States of Oregon and Washington. With the exception of the Eagle Cap and Wenaha-Tucannon Wilderness Areas, the National Forests are managed for multiple use including timber production, livestock grazing, and recreation. Private property comprises 51% of the land in the basin and is located primarily in lower elevation valleys and along rivers. A large proportion of the private property is used for agriculture including crop production, livestock grazing, and forestry. Only 0.1 % of the land in the Grande Ronde Basin is currently owned by the tribes, although the tribes retain fishing and hunting access rights at all usual and accustomed locations as afforded under the treaties of 1855 and 1863.

Spring Chinook populations in these basins were listed as threatened under the Endangered Species Act in 1992. Population declines over the past century were due in part to severely degraded habitat conditions resulting from intensive anthropogenic disturbances including timber harvest, cattle grazing, levee and road construction, and stream diversions for irrigation. Specifically, stream temperature, streamflow, fine sediment, habitat diversity, and quantity of key habitats such as large pools, have been identified as key limiting factors for recovery of Chinook populations in these basins (Nowak 2004).

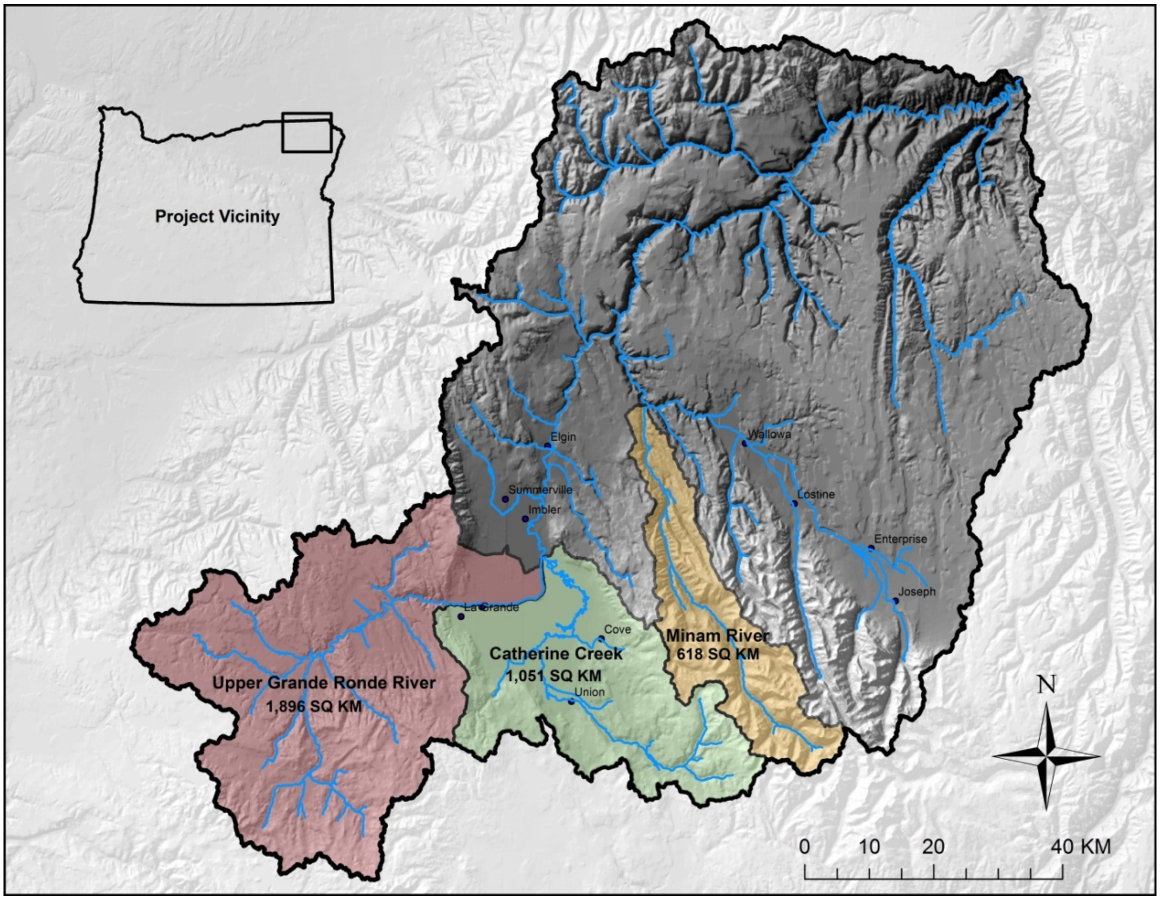

Figure 2. Study area in the Grande Ronde River basin, NE Oregon. Focal watersheds include the Upper Grande Ronde River, Catherine Creek, and Minam River.

Work Element C 157: Collect water temperature, sediment, streamflow and habitat condition data

Habitat condition—We used methods described in the Columbia Habitat Monitoring Program (CHaMP) protocol to collect stream habitat data at 25 sites within current spawning and rearing areas for spring Chinook salmon in the Upper Grande Ronde and Catherine Creek basins during the summer of 2012 (CHaMP 2012; http://www.monitoringmethods.org/Protocol/Details/416). CHaMP is designed as a Columbia River basin-wide habitat status and trends monitoring program built around a single protocol with a programmatic approach to data collection and management (RM&E Workgroup 2010). CHaMP will result in the collection and analysis of systematic habitat status and trends information that will be used to assess basin-wide habitat conditions. When coupled with biological response indicators, this status and trends information will be used to evaluate habitat management strategies.

The CHaMP program will be integrated with ongoing Pacific Northwest Aquatic Monitoring Program (PNAMP) recovery planning efforts and will be part of the collaborative process across Columbia Basin fish management agencies and tribes and other state and federal agencies that are monitoring anadromous salmonids and/or their habitat. The implementation of CHaMP will characterize stream responses to watershed restoration and/or management actions in at least one population within each steelhead and spring Chinook Major Population Group (MPG) which have, or will have, “fish-in” and “fish-out” monitoring. CHaMP was designed to deliver trends in habitat indicators and requires that monitoring occur for three cycles of a sampling panel, at least 9 years.

Survey sites were randomly selected using the Generalized Random Tessellation Stratified (GRTS) survey design (Stevens and Olsen 2004), and were distributed with equal probability across all wadable portions of the stream network that were classified as current spawning and rearing areas for spring Chinook salmon (Figure 3). The fish use classification was modified from fish distribution maps produced by ODFW StreamNet (StreamNet 2009), the Grande Ronde Subbasin plan (Nowak 2004), and the NOAA's Interior Columbia Basin Technical Recovery Team (ICTRT), and is described in more detail in McCullough et al. (2012).

We used a 3-year rotating panel design with the intention of achieving a good balance between power to describe current status (i.e., accurate description of spatial variation across the entire sampling extent) and power to detect trends over time. This temporal design includes 5 annual sites and 10 rotating panel sites in each basin. Annual sites are surveyed every year and rotating panel sites are surveyed every 3 years. A total of 30 sites are surveyed each year, with a total sample size of 70 unique sites after 3 years. Note that 5 of the 30 sites within our target sample frame are surveyed by ODFW each year.

A large suite of stream habitat variables are measured at each site, generating over 100 metrics describing the condition of the stream. Most of the variables measured were chosen because they are directly related to salmonid fish growth and/or survival or because they provide critical information used to describe ecological processes in the stream or broader landscape that may be indirectly related to fish productivity. Some of the key habitat variables that we measure include general channel topography (gradient, bankfull width, sinuosity), channel unit type and dimensions (i.e., pools, riffles, cascades), large woody debris frequency and volume, fish cover (overhanging and aquatic vegetation, woody debris, undercut banks), stream temperature, discharge, substrate size composition and fine sediment, riparian structure and cover, and solar input. Detailed descriptions of the full suite of habitat variables and the methods used to collect the data can be found in CHaMP protocol (CHaMP 2012).

Some of the key habitat metrics developed from the CHaMP data were summarized with boxplots to display basin-wide average values and to examine the general distribution of the data. These data were also used to analyze the relationship between fish density and habitat conditions. No attempt was made at this point to evaluate trends in habitat conditions over time due to the limited number of years for which data was available. The full suite of habitat metrics as well as other summary plots of the data is available on the CHaMP website (www.champmonitoring.org).

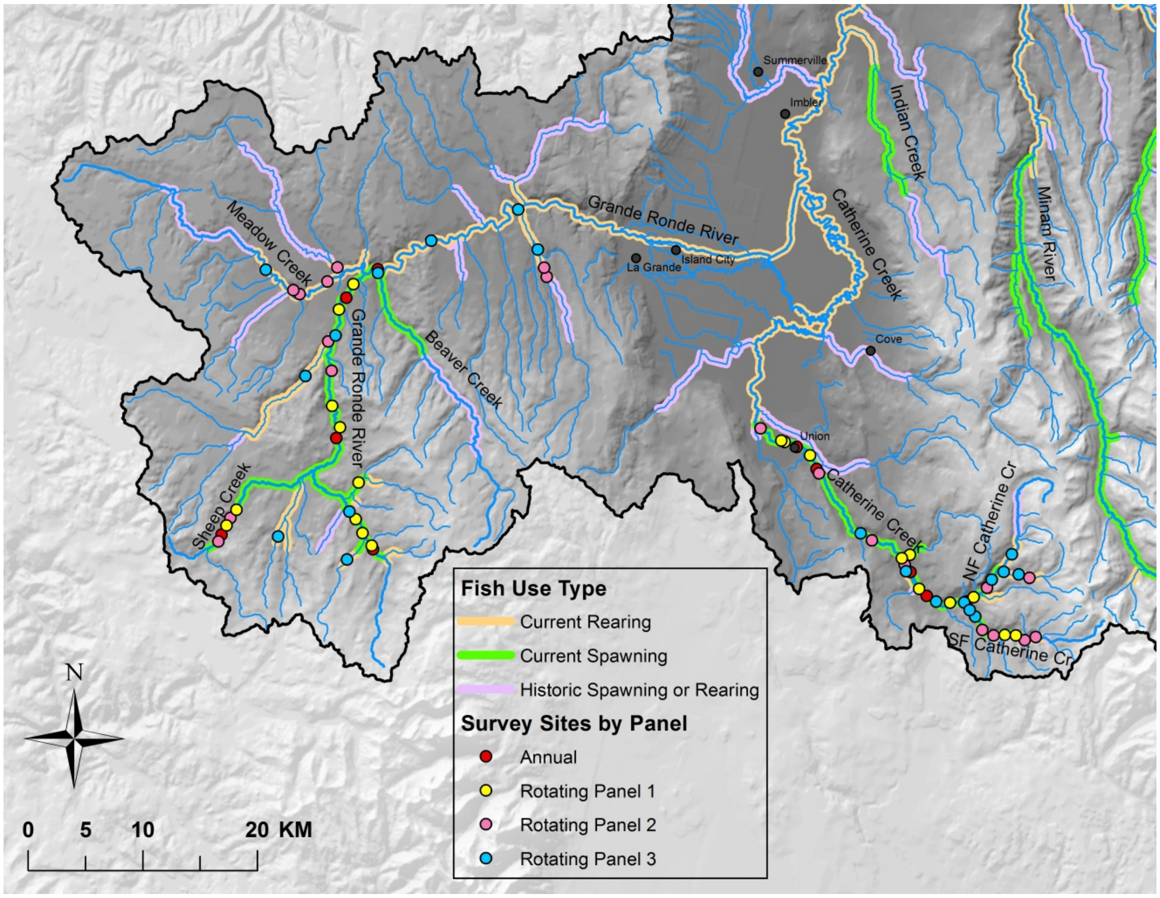

Figure 3. Sampling design showing the distribution of habitat survey sites in the Upper Grande Ronde River and Catherine Creek basins.

Table 2. Rotating panel design for CHaMP survey sites in the Upper Grande Ronde River and Catherine Creek basins. Note that 5 of the 30 sites in our survey design are surveyed by ODFW each year.

	Year								
Panel	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Grande Ronde Chinook									
Annual Panel	5	5	5	5	5	5	5	5	5
Rotating Panel 1	10			10			10		
Rotating Panel 2		10			10			10	
Rotating Panel 3			10			10			10
Catherine Creek Chinook									
Annual Panel	5	5	5	5	5	5	5	5	5
Rotating Panel 1	10			10			10		
Rotating Panel 2		10			10			10	
Rotating Panel 3			10			10			10
Total Annual Samples	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**
Total Unique Samples	**70**								

Stream temperature—A detailed analysis of current stream temperature conditions throughout the entire Chinook distribution area within the Upper Grande Ronde River and Catherine Creek was conducted using the Heat Source Model (see Work Element J 162 below). In addition, we summarized stream temperature data collected using Hobo water temperature loggers (U22 and TidBit loggers) at 45 monitoring locations in the Grande Ronde River and Catherine Creek basins in order to understand general temporal and spatial patterns in stream temperatures across the two watersheds and to identify areas exceeding critical thermal requirements for rearing salmonids. We calculated six different temperature metrics including average daily temperature during summer (*Avg*; July 1 – September 15), the lowest daily temperature recorded during summer (*Min*), the highest daily temperature recorded during summer (*Max*), the maximum weekly average temperature (*MWAT;* e.g., maximum 7-day running average of the daily average temperature), the maximum weekly maximum temperature (*MWMT;* e.g., maximum 7-day running average of the daily max temperature), and the number of days that the daily maximum temperature exceeded thresholds of 16, 18, 20, and 24°C. We also highlighted locations where the MWMT exceeded the temperature standard of 17.8°C as defined by the Oregon Department of Environmental Quality (ODEQ) in their total maximum daily load (TMDL) evaluation of the Upper Grande Ronde Basin (ODEQ 2000).

Stream temperature data was also analyzed to assess potential lethal impacts to rearing spring Chinook. Stream temperature data from the mainstem Grande Ronde River above Fly Creek (N45.20875° lat, W118.397° long) from 1999-2009 was used to calculate the potential lethal thermal loads that would be accumulated by rearing juvenile Chinook salmon. This site was selected because downstream of this, the thermal loads were so great that 100% fish kill during the summer was a near certainty over the course of the summer. In the upstream reaches of the mainstem that are the prime spawning areas, summer rearing could not be shown to produce direct thermally induced mortality. The mainstem Grande Ronde above Fly Creek appeared to have daily maxima above critical levels that could cause mortality if maintained for a significant period.

The time required to accumulate a lethal dose was computed using the formula:

log(time) = a + b (temperature)

Coefficients used in this formula were reported in Brett 1952 (as cited by EPA 1973) and Armour (1991) (Table 3). These coefficients apply to spring Chinook acclimated to temperatures of 5, 10, 15, 20, and 24°C and then subjected to higher exposure temperatures. Log(time), and thereby time (in minutes), required to result in 50% kill of the population was computed for the temperature observed at each time interval (either 30- or 60-min intervals) during each day assuming that the temperature during each interval was maintained at a constant temperature. The fraction of a median lethal dose was calculated as the time interval (either 30 or 60 minutes) divided by the number of minutes required for 50% mortality. The total daily thermal dose was calculated by summing the half-hourly or hourly fractional doses accumulated during the day. If 100% of a median lethal dose was accumulated during a day, one would assume that this exposure history would kill 50% of the population. In addition, it has been observed in various studies that multiple consecutive days of exposure to thermally stressful conditions where a full median lethal dose was accumulated within a 2-day period is still sufficient to cause mortality of a portion of the population. It was assumed that median lethal doses that were accumulated in either 2, 3, or 4 days were sufficient to predict potential mortality for 50% of the population.

Accumulated thermal doses in 2, 3, or 4 days of exposure to the hourly temperatures experienced in the Upper Grande Ronde mainstem above Fly Creek mouth were explored using a and b coefficients derived from Brett (1952) for spring Chinook (Table 3), with the assumption that fish are able to acclimate to a temperature that is (1) equal to the average hourly temperature for the previous 24-hour period, (2) the

mean of the previous 72 hour period and then as (3) the midpoint of the maximum and mean daily temperatures for the previous 72 hours. These analyses were done using *a* and *b* coefficients specific for acclimation temperatures of 5, 10, 15, 20, and 24°C. Acclimation temperatures that were equal to these threshold values ±2.5°C were assigned to the mid-point (i.e., acclimation temperatures of 10± <2.5°C were taken as acclimated to 10°C). Acclimation temperatures were computed for every hourly step

Table 3. Coefficients for thermal exposure after acclimation to various temperatures for calculating median lethal dose. See file: UGR above Fly Creek-2009-USFS data_dm.xlsx, tab UGR-abv Fly-2007

Acclimation (° C)	a	b	Lethal threshold
5	9.3155	-0.3107	21.5
10	16.4595	-0.5575	24.3
15	16.4454	-0.5364	25.0
20	22.9065	-0.7611	25.1
24	18.994	-0.5992	25.1

Tables of thermal response coefficients from EPA (1973) also provide means to calculate the thermal dose required to kill 90% of the population. Data from Snyder and Blahm (1970) and Blahm and McConnell (1970) presented in EPA (1973) each have coefficients for 90% mortality. By compositing these data and average the coefficients for acclimation temperatures of 10, 11, 13, 18, and 20°C (Table 4), it was possible to compute the incidence of conditions where 2, 3, and 4 days of exposure produced the required thermal load. Data from the UGR above Fly Creek were evaluated for July and August, 2007 to assess the accumulated thermal dose to kill 90% of the population. Acclimation was assumed to be in relation to the previous 3-day period's average temperature.

Table 4. Composite coefficients for 90% mortality with acclimation temperature, derived from studies by Snyder and Blahm (1970) and Blahm and McConnell (1970) presented in EPA (1973).

Acclimation (° C)	*a*	*b*	Lethal threshold
10	16.1402	-0.5488	24.5
11	19.2211	-0.6679	23.8
13	12.7368	-0.4040	23.0
18	14.2456	-0.4434	23.5
20	20.9294	-0.7024	24.8

Watershed Condition— In addition to in-stream physical habitat conditions, water temperature, and streamflow, CRITFC is collecting several types of data that relate to landscape or watershed-scale features known to affect local conditions for fish (Table 5). Watershed conditions include intrinsic factors such as geology, climate, cumulative drainage area, and natural potential vegetation that act as high-level controls on local processes. Watershed conditions also include anthropogenic factors such as levels of forest harvest, intensity of cattle grazing, or road density.

Roads in particular are expected to have a detrimental effect on fish habitat quality because they are the source of much of the fine sediment delivery to the stream. This can be measured in terms of road density in (1) the riparian zone for the entire stream network upstream of a study site, (2) the riparian zone upstream of the study site by a fixed distance (e.g., 1 km, as an immediately effective environment), (3) the lateral watershed contributing to the upstream portion of the river segment in which the study site is located, and (4) the entire upstream watershed, including its embedded riparian zone.

CRITFC has assembled, as part of its GIS geodatabase, road layers for the study watersheds. The USFS office in Baker City sent us their forest roads GIS layer. This file shows the location of forest roads, including many main transport roads as well as secondary roads. This file has extensive data by road segment on road characteristics, such as road surface type. We also obtained the TIGER road layer (US Census Bureau), which is a statewide road mapping system that focuses on main transportation routes, including roads through national forest land and private land. We included the two road layers in our geodatabase. We then superimposed these two road layers on the NAIP imagery at 1:6000 scale and digitized roads that were visible on the imagery but were not mapped with either the USFS or TIGER roads maps.

Table 5. Components of habitat data, fish surveys, and benthic macroinvertebrate sampling acquired or modified in 2012.

Data type	Data source	Example metrics	Progress in CY2012
Water temperature	Heat Source model	Spatially-explicit prediction of maximum weekly maximum water temperature	Broadened window of model input to include relevant summer period; generated new GIS layers of predicted values
Fish habitat surveys	ODFW Aquatic Inventories	Valley type, % eroded bank, pool frequency, etc.	QA/QC of three decades of data and combined into single geodatabase
Fish habitat surveys	CHaMP	Bankfull width, thalweg profile, water chemistry, etc.	All CHaMP data housed at www.CHaMPMonitoring.org
Stream flow	USGS gauged sites	Low-flow frequency, flow excedence values	Designation of 41 important gauges for hydrologic analysis (USGS cooperative agreement)
Road density	TIGER, Wallowa-Whitman NF	Density of roads along riparian buffer or upstream watershed area, frequency of road crossings	Began comparison of two GIS road layers, mapping new roads from aerial photos
Historic stream & riparian conditions	Government Land Office (GLO) surveys	Distribution of vegetation by species and type along riparian areas	Worked out methods for mapping GLO data into GIS; preliminary analysis on changing stream widths
Watershed characteristics & land use	USGS StreamStats	Soil permeability, cumulative precipitation, land cover (% forest, % impervious surface)	Worked out methods for batch processing in StreamStats, computed metrics for CHaMP sites
Basin characteristics	BasinTools software	Basin slope, relief, azimuth, rotundity, elongation factor, main channel sinuosity, etc.	Worked with software developers to get program working on USGS streamflow gage sites, for hydrologic analysis
Fish density and on-site human disturbance	CRITFC & ODFW field collections	Density by species, size class, and habitat type, on-site human disturbance (road crossing, cattle grazing, etc.)	Adjustments to on-line data entry and reporting program
Benthic macroinvertebrates	CRITFC & ODFW field collections	Biomass, proportion of functional feeding groups, water quality indices	Continuation of annual database of reach-scale metrics

Work Element E 157: Collect benthic macroinvertebrate samples and process

We collected benthic macroinvertebrate samples at all 25 CHaMP sites using the sampling protocol developed by the Pacific Northwest Aquatic Monitoring Partnership (PNAMP 2007; https://www.monitoringmethods.org/Protocol/Details/44). The sampling protocol was designed to generate data sufficient to characterize the benthic macroinvertebrate assemblage and evaluate impacts from human caused disturbances.

In short, we used a Hess sampler to collect 8-square foot subsamples of the benthos at randomly selected locations within riffle habitats at each site. The subsamples were combined to produce a single composite sample for each site. Benthic macroinvertebrate samples were preserved in 95% ethanol, and shipped to ABR, Inc. for processing and analysis. Invertebrate taxa were identified using the standard levels of resolution for Northwest benthic macroinvertebrate samples, as established by the Northwest Biological Assessment Workgroup. These standards generally include identification of all major taxonomic groups to genus/species.

ABR computed the following macroinvertebrate community indices from our 2011 and 2012 data: Easter Oregon (Grande Ronde) IBI, Predator (WCCP Model), ODEQ temperature and fine sediment stressor models, functional feeding group composition, Hilsenhoff metrics, tolerant/intolerant species, taxa densities, and biomass per m^2. The IBI metrics include components for mayfly, stonefly, caddisfly richness, sensitive taxa, sediment tolerant taxa, % dominant to develop a score. The functional feeding composition accounts for classification of taxa by functional groups, such as collector-filterer, collector-gatherer, macrophyte herbivore, omnivore, parasite, piercing herbivore, predator, scraper, shredder, and unknown. Benthic insect densities are calculated as indiv/m^2, whole sample dry mass. The Predator Model uses a RIVPACS approach to develop observed vs expected taxa relationships for evaluating site macroinvertebrate composition vs. a reference condition. Stressor indicator taxa are used to evaluate to what extent the community is adapted to various stressors. For example, if a particular stream site is high in surface fine sediments, it becomes more likely that the community would have a greater density, biomass, or number of taxa adapted to high sediment conditions. Water temperature is another stressor that can favor taxa that are more or less tolerant to warmwater or coldwater conditions.

Work Element F 157: Collect McNeil sediment core samples and process

We collected sediment core samples using a modified McNeil sampler at 9 of the 25 CHaMP sites in 2012 to quantify the amount of fine sediment present in Chinook salmon spawning gravels. Core sampling was conducted only at sites with suitable spawning habitat for Chinook salmon. In addition, some sites were not sampled due to the presence of spawning salmon and/or freshly-built redds. All sediment samples were returned to the lab where they were dried, sieved, and weighed to determine particle size distribution and fine sediment composition. Detailed sampling and processing methods are described in Justice et al. (2012(a)) (https://www.monitoringmethods.org/Protocol/Details/723).

For each site, we quantified the proportion of sediment particles in the streambed subsurface that was smaller than 2 mm and 6.3 mm, respectively, in accordance with commonly cited studies examining the effects of fine sediment on egg-to-fry survival of salmonid fishes (Tappel and Bjornn 1983, Chapman and McLeod 1987). Prior to calculating the fraction of fine sediment in each sample, we truncated the data by removing all sediment particles greater than 63mm from the sample to ensure that estimates of percentage fines were not disproportionately affected by the presence of a few anomalously large cobbles as recommended by Church et al. (1987).

We compiled all McNeil samples collected between 2010 through 2012 to assess average fine sediment levels for the Upper Grande Ronde and Catherine Creek basins and potential implications for survival of

Chinook salmon eggs. For sites that were surveyed more than once between 2010 and 2012, the data were limited to the most recent sample year to eliminate the possibility for pseudo-replication. Summary statistics were calculated for percent fines within each basin. No attempt was made to evaluate trends in fine sediment conditions over time due to the limited number of years for which data were available.

We examined the potential effect of observed levels of fine sediment on Chinook egg-to-fry survival using predictive formulas developed from laboratory studies. We used a relationship developed by Irving and Bjornn (1984) based on data from Tappel and Bjornn (1983) to estimate survival to emergence S_e as a function of the proportion of sediment particles finer than 6.35 mm p_f (Equation 1).

Equation 1:

$$S_e = \frac{96.0}{1+e^{-8.1+0.2(p_f*100)}}.$$

We also evaluated the relationship between fine sediment levels measured from the McNeil samples and several other measures of surface fine sediment collected as part of the CHaMP protocol. The objective of this comparison was to determine if visual estimation methods may serve as a useful surrogate for more intensive subsurface sediment sampling methods. We computed standard Pearson correlation coefficients to evaluate pairwise relationships among a set of 9 different fine sediment metrics including: 1) McNeil fines < 2 mm (*mnfines2*), 2) McNeil fines < 6.35 mm (*mnfines6*), 3) pool tail fines < 2 mm (*ptfines2*), 4) pool tail fines < 6 mm (ptfines6), 5) pebble count fines < 2 mm in riffles (*pebble2)*, 6) pebble count fines < 6 mm in riffles (*pebble6*), 7) ocular fines < 2 mm in all habitat types (*ocfinesall2*), 8) ocular fines < 2 mm in scour pools (*ocfinespools2*), and 9) cobble embeddedness in riffles (*embed*). Relationships with correlation coefficients > 0.50 were subsequently analyzed using linear regression to compute R^2 and P-Values. Measures of embeddedness, pool tail fines, and ocular fines were not available for sites surveyed in 2010 due to changes in the monitoring protocol in 2011. As a result, comparisons involving these metrics were based on a sample size of 30 instead of 34.

Work Element P 157: Current and potential riparian vegetation mapping of Catherine Creek

We are working with riparian plant ecologists to classify and map the potential natural riparian vegetation throughout the streamside zone in Catherine Creek and the Upper Grande Ronde River basins. Detailed methods for this work are described in http://www.monitoringmethods.org/Protocol/Details/805. This project includes four objectives including: 1) Classify and map existing and potential natural vegetation (PNV) upstream of Ladd Creek on Catherine Creek and La Grande on the Upper Grande Ronde River; 2) Attribute PNV polygons based on vegetation height and density with estimates of canopy height and density to use in computing the solar radiation input parameter in the water temperature model; 3) Classify and attribute PNV polygons based on estimates of natural levels of streambank stabilization of dominant plant species; and 4) In the area downstream of La Grande and Ladd Creek, map existing vegetation and identify broad groups of native plant species that may have typified these areas before human settlement.

In the area upstream of La Grande and Ladd Creek, the mapping will follow an Integrated Terrain Unit (ITU) approach (Jorgenson et al 2003) modified for northeastern Oregon. Integrated Terrain Unit Mapping is the process of adjusting terrain unit boundaries so that there is increased coincidence between the boundaries and occurrences of interdependent terrain variables such as hydrography, geology, physiography, soils and vegetation units. The riparian plant ecologists will use currently available classification systems and other pertinent literature to tailor the ITU classification system to northeastern Oregon.

In the area downstream of La Grande and Ladd Creek, we will map existing vegetation and geomorphic surfaces at a scale of 1:24,000 – 1:48,000. Field surveys of current native vegetation as well as historic

photos or historic accounts of the riparian vegetation will be used to draw inferences regarding broad groups of native species that may have typified this area before human settlement

The ITU components will be displayed on maps individually to produce distinct geomorphology, surface form, and existing vegetation maps, as well as aggregated to display PNV, physiography, existing and PNV vegetation height and density, canopy structure and complexity, streambank stability, canopy type (broadleaf vs. needleleaf), ecotype (local-scale ecosystem), and Plant Association Groups (Powell et al. 2007). This multi- parameter, aggregative technique makes the ITU approach a powerful mapping tool for completing the study objectives.

Work Element Q 157: Current and potential riparian vegetation mapping of Upper Grande Ronde

See Work Element P 157 above.

Work Element I 162 C: Hydrological analysis

A primary objective of this work is to develop the capacity for CRITFC personnel to conduct characterizations of low-flow regime as needed for specific ungaged stream reaches of interest. With that in mind, the USGS is developing detailed analytical protocols for each step of the analysis, and plans to demonstrate their application for selected streams and reaches to be determined in collaboration with CRITFC. Work began on this project in April 2012. Analytical methods follow previously-published methods for calculating flow metrics (Grehys 1996a, Grehys 1996b, Smakhtin 2001), incorporating climate and landscape-scale characteristics into streamflow predictions (Mayer & Naman 2011), and using the hydrological neighborhood approach (Ribeiro-Correa et al. 1995, Kelly & Jett 2006).

Overview of Analysis

1. Identify appropriate gage stations and acquire streamflow data.
2. Calculate baseflow index (BFI) and derive low-metrics from theoretical frequency distribution for annual 7-day low flow.
3. Identify significant watershed attributes that are associated with low-flow metrics.
4. Conduct canonical correlation analysis (CCA) to quantify multivariate relationship between flow and watershed features.
5. Utilize CCA results to score target ungaged sites along watershed dimension to identify gaged streams that comprise suitable hydrologic neighborhood for target sites.
6. Utilize data from neighborhood sites to generate theoretical regional frequency curves for target sites and derive low-flow metrics.

Once the best and final set of watershed metrics are identified, watersheds for the target ungaged stream reaches will be characterized in the same way. Scores will be calculated for the ungaged sites along the watershed dimension so that the appropriate group (or "neighborhood") of gaged sites can be identified for each target site. Data from these sites will be combined to generate the set of low-flow metrics for the ungaged site.

Work Element I 162 F: Develop draft life cycle model

As part of recovery planning, CRITFC is developing a life cycle model that not only reconstructs population trends consistent with changes in freshwater habitat conditions, but also serves as tool for finding optimal solutions for increasing fish productivity using a range of different policy scenarios. The model consists of three modeling components: 1) a population model, 2) a habitat model, and 3) a

policy optimization model. The approach also embeds functional relationships at an additional level of complexity, i.e., the prediction of changes in habitat conditions as a direct result of management actions. For example, if the population model predicts productivity at the fry-to-parr stage to be sensitive to water temperature change, and if water temperature is affected by shade from tree canopy closure, then changes to riparian forest cover would indirectly predict productivity. Therefore, changes to riparian forest cover would impact population recovery. The model seeks to quantify the relative recovery potential from measurable management actions. One example would be riparian planting. Other examples of recovery actions include changes to streamflow conditions, which could be achieved by purchasing water removal rights and decommissioning barriers. The key element of the CRITFC model is the ability to quantify the degree to which population recovery improves with investment in critical habitat improvements. The model will be used to quantify the relative benefit of alternative management actions, both in magnitude and spatial distribution.

The model CRITFC is developing currently focuses on the Catherine Creek population of the Grande Ronde River basin. It predicts abundances of spawners, eggs, emerging fry, juveniles rearing in different reaches of the river, parr that migrate downstream in fall to overwinter, later migrating parr, smolts, fish in the ocean, and returning adults. Fish return to spawn after a number of years rearing in the ocean, which is determined probabilistically such that the age distribution of returning adults is consistent with the observed age distribution. Throughout the life history, survival from one stage to the next is predicted with a Beverton-Holt (BH) survival function. A more detailed description of the model is provided in Appendix A.

Work Element J 162: Heat Source Model Expansion

As part of a previous contract with The Columbia River Inter-Tribal Fish Commission (CRITFC), Watershed Sciences (WSI) completed stream temperature modeling of 17 streams in the Upper Grande Ronde River basin. Heat Source models were set up and calibrated for a 3-week time period spanning August 6–27, 2010 in order to assess critical summertime conditions. CRITFC subsequently contracted with WSI in 2012 to expand these 3-week models to cover the months of July, August, and September of 2010. A detailed summary of the remote sensing and ground level data and a description of the expanded stream temperature modeling results are provided in Watershed Sciences (2012b).

The goal of the project was to use previously collected high-resolution LiDAR, streamflow, and FLIR data to develop the Heat Source stream temperature model (Boyd and Kasper 2003). Stream temperature was simulated for the Grande Ronde River, Catherine Creek, and several of their tributaries for a period between July 10 and September 20, 2010. The simulation period is representative of low-flow and high stream temperature conditions when salmonid habitat is at its most critical condition. Approximately 398 stream kilometers were simulated above the confluence of Catherine Creek and the Grande Ronde River combined. The streams of interest are either historic or current salmonid habitat.

Model output includes stream temperature at points spaced every 100 meters along the stream network for every hour of the day during the simulation period (Jul 10 - Sep 20). From these data, we calculated the maximum weekly maximum temperature (MWMT; the maximum of the 7-day running average of the daily maximum temperature), and produced a map showing the distribution of MWMT throughout the Chinook distribution area. In addition, we examined model output for various restoration scenarios representing projected changes in riparian vegetation cover, streamflow, or climatic conditions.

Monitor and evaluate the status and trends of juvenile fish productivity in tributaries relative to habitat quality improvement targets.

Are tributary actions achieving the expected biological and environmental improvements in habitat?

Work Element D 157: Snorkel sample to estimate fish densities by reach

We conducted snorkel surveys at all 25 sites where CHaMP habitat data were collected in 2012 to quantify juvenile Chinook salmon and steelhead abundance and size as well as fish assemblage structure and to assess potential fish/habitat relationships. The Columbia River Inter-Tribal Fish Commission (CRITFC), Oregon Department of Fish & Wildlife (ODFW), and Confederated Tribes of the Umatilla Indian Reservation (CTUIR) have recognized the need to use a common snorkel survey so that information collected by individual entities can help managers determine whether aggregate habitat restoration actions will yield a net improvement in basin-wide habitat quality for ESA-listed fish species (NOAA 2007). To this end, we developed a snorkeling protocol drawing heavily from the protocols of Thurow (1994) and O'Neal (2007), intended for use among all agencies responsible for data collection in the Upper Grande Ronde, Catherine Creek, Minam River, and potentially other nearby basins. Details about the snorkel survey methodology can be found in White et al. (2012); https://www.monitoringmethods.org/Protocol/Details/499).

We participated in a coordinated effort with ODFW during the summer of 2012 to develop a correction factor for fish counts using mark-recapture estimates of fish abundance. The correction factor was used to expand snorkel and electrofishing counts to account for unobserved fish during snorkel surveys, thus providing an unbiased estimate of true abundance for each survey site. Details of this effort are described in Horn and Sedell (unpublished technical report, 2013).

Several analyses are underway to help describe relationships among fish distributions, habitat characteristics (site and landscape-scale), and benthic macroinvertebrates. As a first order comparison of fish densities by Tier I habitat unit type (CHaMP 2012), we calculated these values by year and basin. Next, in order to discover novel relationships in our data, we computed the maximal information coefficient (MIC) values for best-fit relationships among fish metrics, habitat, and macroinvertebrates. MIC values are similar to Pearson correlation coefficients in that they are a method for rapidly finding strong relationships, but have the advantage of incorporating non-linear relationships (Reshef et al. 2011). This method has the advantage of iteratively searching for novel relationships in very large datasets such as ours (e.g., Table 5), where many thousands of combinations are possible. Structural equation modeling (SEM) is a statistical approach to hypothesis testing that accounts for direct and indirect relationships among variables (Grace 2006). SEM evolved from path analysis with several notable improvements including analysis of covariance among variables (versus analysis of correlations), incorporation of hierarchical modeling approaches, and the use of latent variables. SEM is an appropriate tool for fish-habitat modeling when the interrelationships among factors influencing fish abundance or fish performance (growth, survival, etc.) are of interest. In addition to testing hypotheses about interrelationships between fish and their habitat, SEM can also be used to predict fish habitat conditions in unsampled areas. These predictions based on observed relationships can then be incorporated into simulation analyses such as life cycle modeling.

Results

Tributary Habitat RM&E

Monitor and evaluate tributary habitat conditions that may be limiting achievement of biological performance objectives.

What are the tributary habitat limiting factors (ecological impairments) or threats preventing the achievement of desired tributary habitat performance objectives?

<u>Work Element C 157: Collect water temperature, sediment, streamflow and habitat condition data</u>

Habitat Condition Data—CHaMP program staff are currently in the process of completing quality control (QC) of all stream habitat data collected in 2011 and 2012. Although tremendous progress has been made in identifying and repairing data errors and in refining CHaMP analysis tools to streamline production of habitat metrics, this process has not yet been completed. As a result, we have limited our analyses of CHaMP data to a general summary of the data and a preliminary analysis of fish habitat relationships (see Work Element D 157). As additional years of CHaMP data are collected and QC procedures are completed, more thorough analyses of the data will be completed, including, but not limited to, assessment of trends in habitat conditions over time, incorporation of habitat data into a life cycle model, and refinement of fish habitat relationships via structural equation modeling.

One of the most powerful tools implemented by the CHaMP program is the use of surveying equipment (e.g., Total Station) to develop a detailed and spatially-referenced topographic map of the stream channel. These topographic maps can be used to evaluate changes in channel topography over time with a very high degree of accuracy. An example of a topographic map we generated for a site on McCoy Creek in 2012 is provided in Figure 4. Raw topographic data consist of points and lines collected at key locations within the stream channel such as the channel thalweg (i.e., channel location with the highest streamflow), edge of water, bankfull elevation, channel unit boundaries (e.g., perimeter of pools or riffles), etc. (Figure 4a). Raw survey data are edited using Survey Pro software and then converted to a triangular irregular network (TIN) using custom tools in ArcGIS (Figure 4b). The TIN, which provides a rough 3-dimensional representation of the stream channel, is edited further in GIS to remove any additional surveying errors, and is then converted to a digital elevation model (DEM) (Figure 4c). The DEM essentially represents a detailed grid of channel elevations with a 10 X 10-cm grid cell resolution. Information about the water surface elevation and channel unit boundaries can be overlaid with the DEM to evaluate water depth and channel unit boundaries (Figure 4d). Channel topographic data are then analyzed by CHaMP using the River Bathymetric Toolkit (RBT) to produce a suite of habitat metrics of potential importance to fish.

Boxplot summaries of some of the key habitat metrics generated from the CHaMP data are presented in Figure 5-6. The percentage of total stream surface area classified as pools (i.e., percent pools) across all sites ranged from 0 to 86 % (median = 22%). Percent pools was highest on average in small sites (bankfull width < 8 m) within the Upper Grande Ronde River basin (median = 35.6%), and was lowest in large sites (bankfull width > 8 m) within the Catherine Creek basin (median = 16.2%, Figure 5). The amount of pool habitat was most variable in small sites in the Upper Grande Ronde basin, and least variable in small sites in the Catherine Creek basin. In general, the quantity of pool habitats was similar for Catherine Creek sites and large Upper Grande Ronde River sites, but was generally higher and more variable for small Upper Grande Ronde River sites.

The volume of large woody debris (LWD) per 100 m ranged from 0 to 209 m^3 (median = 3.4 m^3) across all sites. LWD volume was highest in small sites in the Catherine Creek basin (median = 10.5 m^3) and lowest in large sites in the Upper Grande Ronde River basin (median = 1.7 m^3, Figure 6). Similar to percent pools, LWD volume was most variable in small Upper Grande Ronde River sites. As expected, small sites, which were located further upstream in the watershed, had higher volumes of LWD compared with larger sites.

The percentage of surface fine sediment < 6 mm in pool tails (i.e., pool tail fines) ranged from 1 to 66% (median = 11%) across all sites. Pool tail fines were highest in small sites in the Catherine Creek basin (median = 19%) and lowest in large sites in the Upper Grande Ronde River basin (median = 6%). Similar to percentage pools and LWD volume, pool tail fines were most variable in small sites in the Upper Grande Ronde River basin.

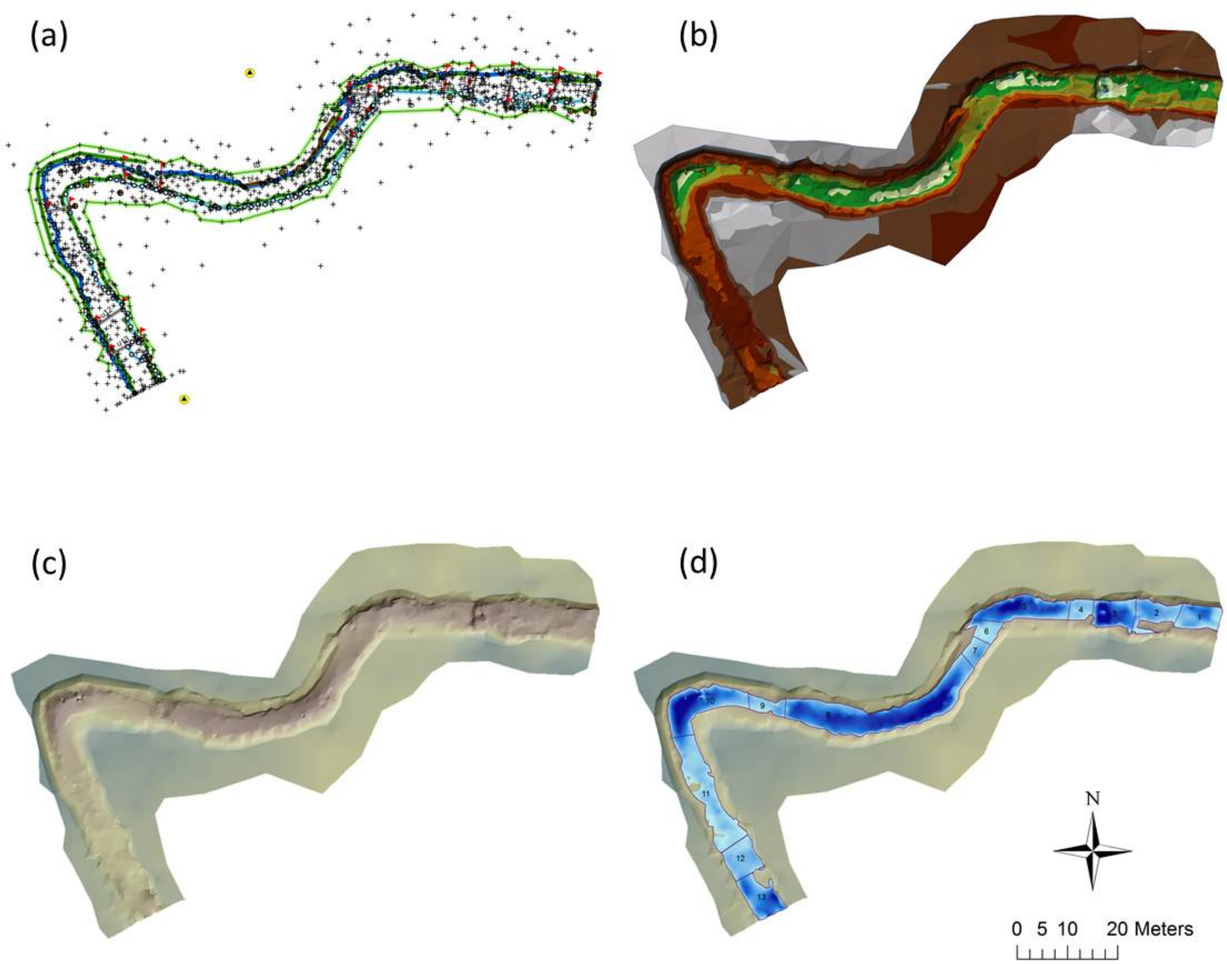

Figure 4. Example of stream channel topographic data collected using the CHaMP protocol at site CBW05583-015162 in McCoy Creek during summer 2012. The figure shows a) raw topographic point and line features, b) the triangular irregular network (TIN) generated from the raw topo data, c) the digital elevation model (DEM) generated from the TIN, and d) the DEM with water depth and channel unit boundaries.

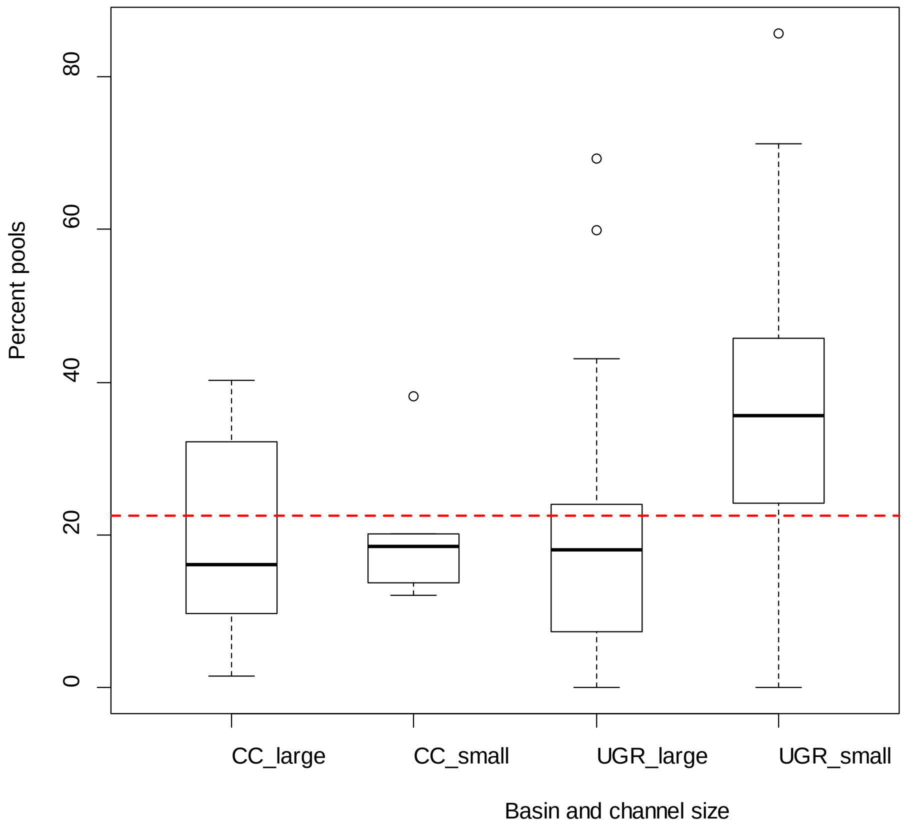

Figure 5. Distribution of percent pools (i.e., percentage of total stream surface area classified as pools) by basin (UGR = Upper Grande Ronde, CC = Catherine Creek) and channel size (large = > 8 m bankfull width, small = < 8 m bankfull width) from 86 unique sites surveyed using the CHaMP protocol during summer, 2011 to 2012. The median for all 86 sites is denoted by the red dashed line.

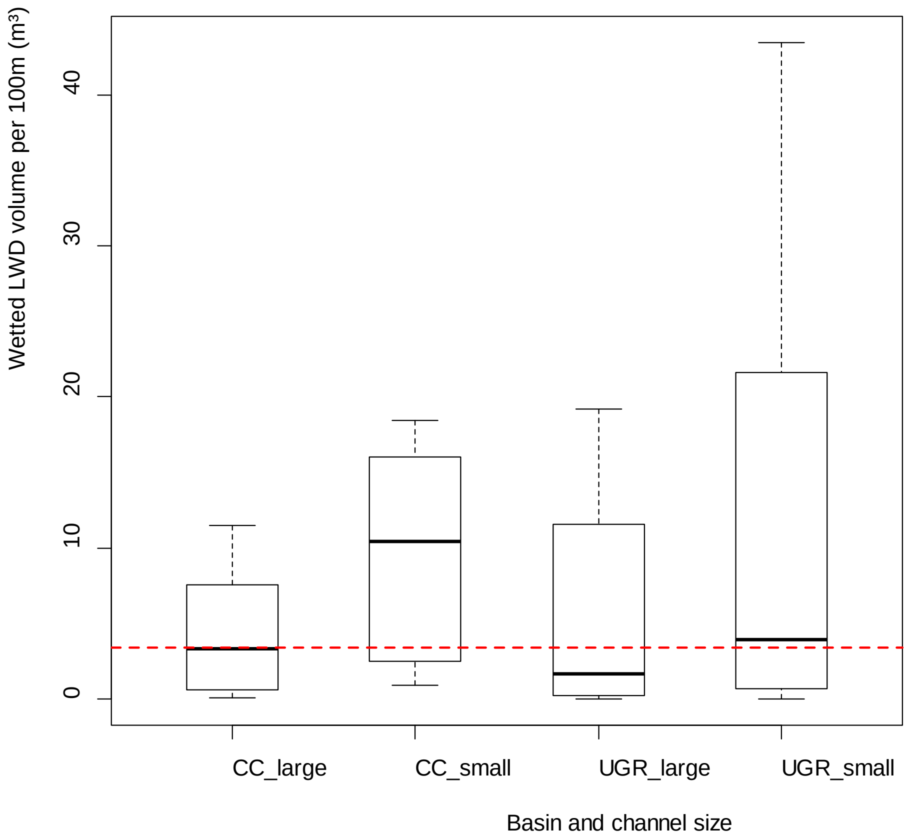

Figure 6. Distribution of large woody debris (LWD) volume (m^3) per 100 m stream length by basin (UGR = Upper Grande Ronde, CC = Catherine Creek) and channel size (large = > 8 m bankfull width, small = < 8 m bankfull width) from 86 unique sites surveyed using the CHaMP protocol during summer, 2011 to 2012. The median for all 86 sites is denoted by the red dashed line.

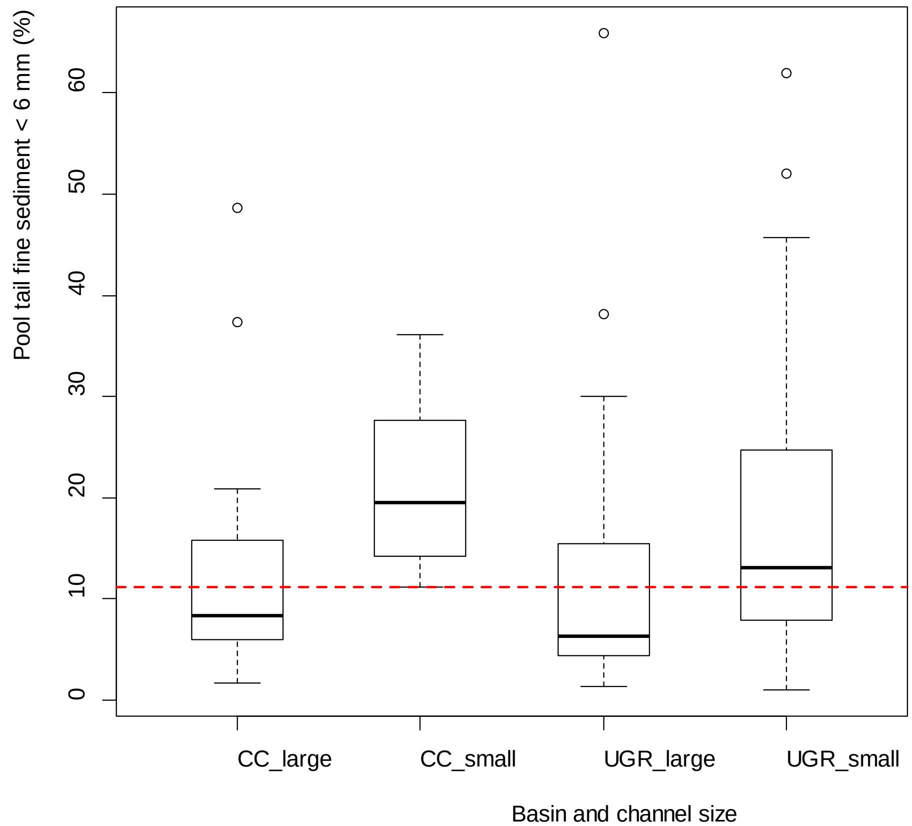

Figure 7. Distribution of percent fine sediment < 6 mm in pool tails by basin (UGR = Upper Grande Ronde, CC = Catherine Creek) and channel size (large = > 8 m bankfull width, small = < 8 m bankfull width) from 86 unique sites surveyed using the CHaMP protocol during summer, 2011 to 2012. The median for all 86 sites is denoted by the red dashed line.

Stream Temperature—Among the 45 temperature monitoring sites (with the exception of one Grande Ronde site), peak stream temperatures were found either in the period July 8-13 or August 6-8 in 2012 (Figure 8). Average summer stream temperatures (mean from July 1 – Sept. 15) ranged from 9.3°C to 16.7°C (mean = 12.6°C) in the Catherine Creek basin and from 11.7°C to 20.1°C (mean = 15.4°C) in the Grande Ronde River basin (Table 6).

Catherine Creek sites had cooler temperatures than Grande Ronde River sites on average and reaches closer to the stream source were generally cooler than those further downstream in the basin. Ten Catherine Creek sites and two Grande Ronde River sites met the 17.8°C MWMT water temperature standard defined by ODEQ for Chinook salmon rearing habitat in the Upper Grande Ronde sub-basin. MWMT ranged from 12.3°C to 22.3°C (mean = 17.7°C) in the Catherine Creek basin and from 16.7°C to 28.7°C (mean = 23.1°C) in the Grande Ronde River basin.

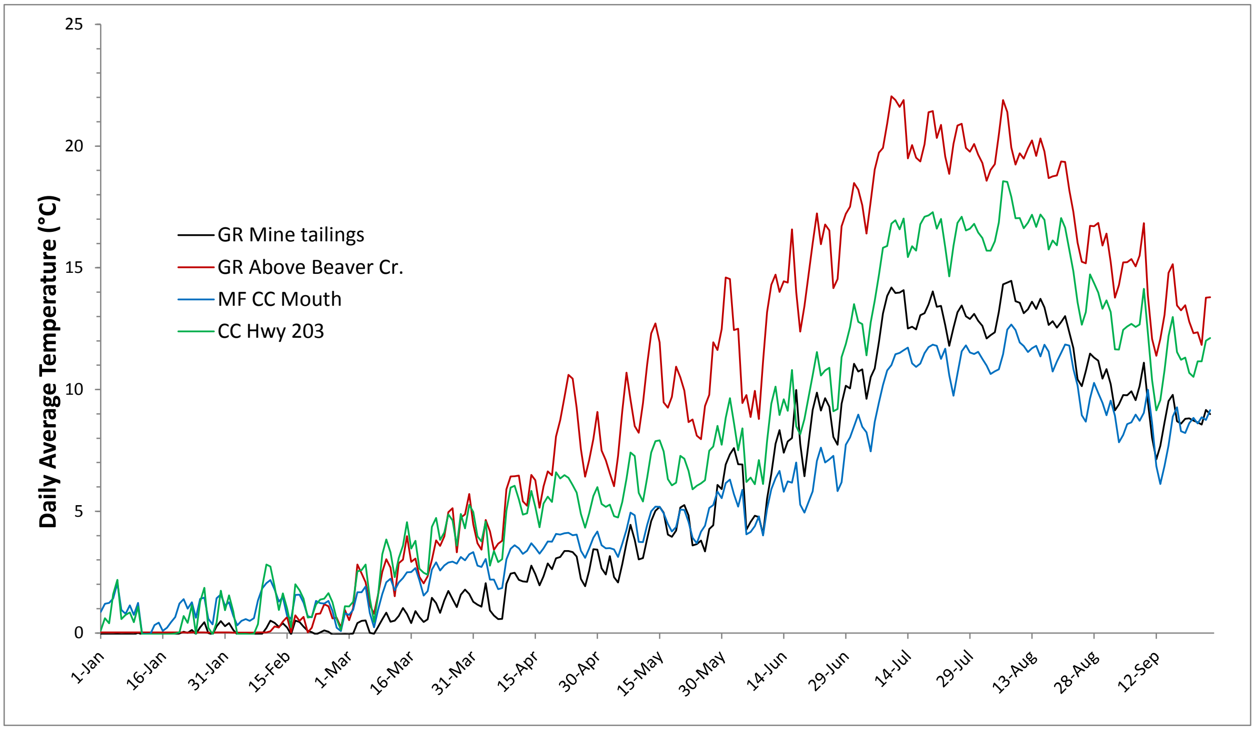

Figure 8. Daily average temperatures (°C) for four sites – two on the Upper Grande Ronde River and two on Catherine Creek from Jan 1 – Sept 15, 2012. GR Mine tailings was one of our highest elevation Upper Grande Ronde River sites and GR Above Beaver Cr. was one of the lowest. Middle Fork Catherine Creek (MF CC Mouth) was one of our highest elevation temperature logger sites (with a complete temperature record) on Catherine Creek and CC Hwy 203 was one of the lowest elevation sites.

Table 6. Summary of stream temperatures (°C) at 45 sites in Catherine Creek and Grande Ronde River during the summer of 2012 (starting between July 1st and 4th and extending through September 15th). Temperature metrics include average daily temperature for the summer period (Avg), the lowest instantaneous temperature recorded during summer (Min), the highest instantaneous temperature recorded during the summer (Max), the maximum weekly average temperature (MWAT), the maximum weekly maximum temperature (MWMT), and the number of days that the daily maximum temperature exceeded thresholds of 16, 18, 20, and 24°C. Values exceeding the ODEQ temperature standard of 17.8°C MWMT are highlighted in gray.

							Days Daily Max Exceeded			
Stream	**Site**	**Avg**	**Min**	**Max**	**MWAT**	**MWMT**	**16 °C**	**18 °C**	**20 °C**	**24 °C**
Catherine Creek Basin										
MF Catherine Creek	CBW05583-109994	9.3	4.0	12.9	10.8	12.3	0	0	0	0
MF Catherine Creek	MF_CC_mouth	10.3	4.5	14.4	12.1	13.7	0	0	0	0
SF Catherine Creek	CBW05583-013226	9.9	3.4	14.6	11.5	13.8	0	0	0	0
SF Catherine Creek	CBW05583-381866	10.4	3.3	15.5	12.2	14.8	0	0	0	0
NF Catherine Creek	NF_CC_above_MF_CC	10.7	4.5	15.9	12.6	15.1	0	0	0	0
SF Catherine Creek	CBW05583-512938	10.8	3.5	16.0	12.7	15.4	1	0	0	0
SF Catherine Creek	CBW05583-086954	11.2	3.4	16.5	13.2	15.9	7	0	0	0
NF Catherine Creek	CBW05583-531882	11.5	4.5	17.1	13.3	16.2	6	0	0	0
SF Catherine Creek	SF_CC_mouth	12.5	4.2	18.3	14.8	17.3	37	2	0	0
NF Catherine Creek	CBW05583-138666	11.9	4.5	18.4	13.9	17.5	29	1	0	0
NF Catherine Creek	NF_CC_mouth	12.0	4.5	19.1	14.2	18.1	38	5	0	0
Catherine Creek	CBW05583-368042	12.5	4.6	19.4	14.7	18.4	46	10	0	0
Little Catherine Creek	CBW05583-155818	13.7	6.9	19.0	16.1	18.4	43	11	0	0
Catherine Creek	CBW05583-456106	13.2	5.1	19.7	15.5	18.7	46	20	0	0
Catherine Creek	CBW05583-527786	13.2	5.1	20.0	15.5	18.9	47	24	0	0
Catherine Creek	dsgn4-000010	13.9	5.4	20.4	16.3	19.5	50	35	2	0
Catherine Creek	CBW05583-417962	14.3	5.6	21.4	16.6	20.4	58	45	7	0
Catherine Creek	CC_Hwy_203	15.0	5.9	22.7	17.5	21.6	67	49	35	0
Catherine Creek	ORW03446-137980	15.1	5.9	22.7	17.4	21.6	66	49	33	0
Catherine Creek	CBW05583-217258	16.7	8.8	23.2	19.0	22.2	72	59	43	0
Catherine Creek	CBW05583-340138	16.5	7.7	23.6	18.9	22.3	70	57	44	0
Average		12.6	5.0	18.6	14.7	17.7	33	17	8	0
Minimum		9.3	3.3	12.9	10.8	12.3	0	0	0	0
Maximum		16.7	8.8	23.6	19.0	22.3	72	59	44	0

Stream	Site	Avg	Min	Max	MWAT	MWMT	Sum Days Daily Max Exceeded			
							16 °C	18 °C	20 °C	24 °C
Grande Ronde River Basin										
Clear Creek	Clear_Cr_mouth	11.7	3.4	17.4	13.9	16.7	19	0	0	0
Grande Ronde River	dsgn4-000009	11.9	4.2	18.2	13.8	17.7	37	3	0	0
Sheep Creek	CBW05583-453946	12.0	3.6	18.3	14.3	17.8	38	6	0	0
Grande Ronde River	CBW05583-280042	12.0	4.1	18.6	13.9	18.1	40	5	0	0
Sheep Creek	CBW05583-228666	12.3	3.5	18.9	14.6	18.4	44	15	0	0
Grande Ronde River	CBW05583-206314	13.0	4.1	19.8	15.2	19.2	47	31	0	0
Grande Ronde River	CBW05583-148970	12.4	0.0	22.8	14.6	20.3	62	34	5	0
Sheep Creek	CBW05583-490810	13.5	3.9	21.2	15.7	20.5	63	45	22	0
Sheep Creek	CBW05583-138554	15.1	4.4	24.0	17.3	22.9	71	61	44	0
Sheep Creek	Sheep_Cr_below_5160_Rd	14.9	3.9	24.4	17.1	23.0	71	62	46	1
Sheep Creek	CBW05583-335162	14.5	4.1	28.5	16.7	23.0	68	56	40	1
Rock Creek	CBW05583-487322	15.3	5.3	24.0	18.5	23.2	59	52	44	1
Grande Ronde River	CBW05583-235322	16.5	5.7	24.6	19.5	23.8	70	57	48	5
Grande Ronde River	CBW05583-321338	16.5	4.5	25.7	19.2	24.2	75	70	52	14
Fly Creek	CBW05583-506682	16.2	6.3	25.4	19.1	24.6	73	70	55	9
Grande Ronde River	GR_below_Vey	16.8	4.4	26.1	19.2	24.7	77	72	67	29
Grande Ronde River	dsgn4-000202	17.5	5.9	26.9	20.5	25.9	77	75	69	30
Grande Ronde River	CBW05583-269114	17.6	7.3	27.0	20.6	26.0	77	73	65	36
Meadow Creek	Meadow_Cr_mouth	17.9	7.1	27.7	21.2	26.8	74	67	53	32
Grande Ronde River	dsgn4-000245	18.3	6.1	28.1	21.1	26.8	77	73	69	43
Meadow Creek	CBW05583-285498	17.4	4.9	27.9	21.1	27.0	73	68	59	38
Meadow Creek	CBW05583-498490	17.4	5.0	28.3	21.2	27.7	74	71	61	39
Grande Ronde River	GR_above_Five_Points_Cr	20.1	7.6	30.0	22.8	28.2	77	77	74	59
Meadow Creek	CBW05583-514874	18.4	6.3	29.5	21.8	28.7	77	75	70	51
Average		15.4	4.8	24.3	18.1	23.1	63	51	39	16
Minimum		11.7	0.0	17.4	13.8	16.7	19	0	0	0
Maximum		20.1	7.6	30.0	22.8	28.7	77	77	74	59

When water temperature data from 2007 and 2009 were evaluated using the model for median mortality, it was found that assuming acclimation to temperatures experienced hourly in the previous 24-hour period, there were six 2-day periods in July where sufficient thermal loads were accumulated that would provide greater than 100% of the load needed to cause 50% mortality of the population (Table 7). If thermal loads were accumulated for 3- and 4-day periods, there were 10 and 15 days, respectively, in July that were able to produce at least 50% mortality. In August 2007, 50% mortality was expressed in two 2-day periods. By contrast, in 2009, there were no days that resulted in cumulative mortality.

Contrasting July and August water temperatures for the Upper Grande Ronde River mainstem above Fly Creek in 2007 and 2009, assuming that juveniles acclimate to the thermal history of the past 72 hours, shows a similar pattern in which there are seven 2-day periods that produce at least 50% mortality. Again, no multiple consecutive days existed in 2009 where cumulative exposure resulted in 100% of the dose that would produce 50% mortality.

When it was assumed that acclimation occurs in relation to the average of the previous three day's maximum and mean temperatures, it was not possible to show the median mortality effect in either 2- or 3-day cumulative exposures in 2007 or 2009. However, in 2007 there were eight 4-day periods where cumulative thermal doses were sufficient to produce 50% mortality.

Table 7. Number of 2-, 3-, and 4-day periods in which a median lethal dose was accumulated after spring Chinook were acclimated to previous temperature conditions in the Upper Grande Ronde mainstem above the mouth of Fly Creek. Acclimation was to the mean temperature for the previous 24 hours, the mean temperature for the previous 72 hours, and a temperature that was the average of the previous 72-hour MAX+MEAN. Coefficients *a* and *b* were taken from Brett (1952) for acclimation to temperatures closest to 5, 10, 15, 20, and 24°C.

Year	Month	2-day	3-day	4-day
Acclimation to previous 24 hours				
2007	July	6	10	15
	Aug	2	2	2
2009	July	0	0	0
	Aug	0	0	0
Acclimation to previous 72 hours				
2007	July	7	11	15
	Aug	2	2	2
2009	July	0	0	0
	Aug	0	0	0
Acclimation to previous 72 hours avg of (MAX+MEAN)				
2007	July	0	0	8
	Aug	0	0	1
2009	July	0	0	0
	Aug	0	0	0

Another way to evaluate the July and August water temperatures for 2007 and 2009 in the Upper Grande Ronde above Fly Creek is to compare them statistically. The average of the daily maximum temperatures for July was 25.46°C in 2007 and 21.76°C in 2009 (Table 8). The average of the daily mean temperatures was 19.59 and 17.48°C, respectively. The maximum of the daily maximum temperatures was 27.85 and 25.53°C, respectively. While the computational method for estimating median lethal loads provides uncertain levels of mortality in the field, if we assume that these calculations are biologically meaningful, one would conclude that in locations where the average of the daily maxima for the month exceed approximately 25°C (note the water temperature statistics for the Upper Grande Ronde above Fly Creek in 2007 vs 2009 cited above), temperature conditions could be expected to result in a sufficient number of days that could produce 50% mortality. EPA (2003) set a temperature of 20°C as a 7-day average of the daily maximum as a threshold beyond which increasing negative impacts occur to salmonids. McCullough (1999) and McCullough et al. (2001) found, in reviews of scientific literature, that temperature maxima between 22 and 24°C are frequently related to salmonid populations reaching zero population densities in stream reaches. Temperatures greater than about 25°C (the UUILT value at 20°C acclimation temperature) are sufficient to produce mortality according to the formula in Armour (1991) when Chinook are acclimated to 20°C. Acclimation to colder water temperatures would produce greater estimated mortality when Chinook are exposed to 25°C. This explains why the estimated number of multiple days where lethal loads are reached (Table 7) is greater under the assumption of acclimation to the average temperature in the previous 72 hours as opposed to the average of the MAX and MEAN of the same period.

Because the site on the mainstem Grande Ronde River sampled by the USFS was 4.18 km upstream of CHaMP site dsgn4-000202, we can compare the survival estimates from the USFS site to the temperature statistics found at CHaMP sites to assess to what extent the impacts to estimated survival are able to be generalized spatially. CHaMP site dsgn4-000202 has the following water temperature statistics in 2012 (Table 6): MWAT—20.5°C, MWMT—25.9°C, and maximum daily maximum—26.9°C. These maximum 7-day average temperatures are very similar to the monthly average of the daily maximum and daily mean, and monthly maximum of the daily maximum and daily mean found on the Upper Grande Ronde above Fly Creek (Table 8). By contrast, the Grande Ronde mainstem above Five Points Creek has a MWAT of 21.8°C and a MWMT of 28.7°C, indicating that rearing conditions are apt to be non-existent from Fly Creek mouth on the Upper Grande Ronde downstream.

Armour (1991) reported that an MWAT of 18.2°C for spring Chinook can be computed from optimum and upper incipient lethal temperatures from Brett (1952) with the formula recommended by EPA (1973). This temperature has often been taken as an upper temperature considered to be a safe threshold for chronic exposure. However, by use of the survival coefficients from the literature reported in EPA (1973) for spring Chinook with hourly water temperature data from the Grande Ronde above Fly Creek, and with the assumptions of multiple day exposure histories, it is easy to show the thermal hazard to growth and survival presented in the mainstem where thermal doses accumulate on hourly exposures to temperatures above approximately 25°C. The river downstream to the mouth of Five Points Creek is even more extreme in its water temperatures and is, therefore, more inhospitable. With an MWAT of only 20.5°C above Fly Creek, it is easy to see that small changes in MWAT can result in potentially significant impacts to survival. The relatively moderate MWAT of 20.5°C above Fly Creek mouth is coupled with a high MWMT of 25.9°C. It appears that MWMT is a more sensitive indicator of potential lethality.

Table 8. Water temperature statistics for the Upper Grande Ronde mainstem above the mouth of Fly Creek, calculated from USFS data.

Year	Month	Avg of daily MAX	Avg of daily MEAN	Max of daily MAX	Max of daily MEAN
2007	July	25.46	19.59	27.85	21.72
	Aug	22.73	16.08	27.85	18.63
2009	July	21.76	17.48	25.53	20.30
	Aug	20.98	17.00	27.06	22.03

A similar analysis was done in the Upper Grande Ronde mainstem above the mouth of Beaver Creek. Location of this site was 45.268103° lat, -118.365708° long. Using the same acclimation thresholds, assuming acclimation to the mean water temperature of the previous 24 hours, and that lethal doses can be accumulated in exposure periods of 2 days, it was calculated that in 2010 there were 3 days in July and 1 day in August where a sufficient thermal dose was accumulated to kill 50% of the population (Table 9). (See Figure 8 to compare temperatures for this site with those found in 2012.). Comparing the water temperature statistics of these two months in 2010 shows that July had 84 hours where temperatures were above 24°C and August had 65 such days. July and August had 14 and 11 hours, respectively, with maximum temperatures greater than 26°C (Table 10). This appears to be a small difference in temperature statistics, but the difference in number of days that could cause mortality is greater.

Table 9. Number of occasions in which a median lethal dose was accumulated in 2-, 3, or 4-day periods in the Upper Grande Ronde mainstem above the mouth of Beaver Creek.

Month	2-day	3-day	4-day
July	3	6	8
August	1	3	4

Table 10. The sum of hours per month in which water temperatures exceeded critical levels (24, 25, 26, and 27°C) in the Upper Grande Ronde mainstem above the mouth of Beaver Creek.

	Sum of hours T>24°C	Sum of hours T>25°C	Sum of hours T>26°C	Sum of hours T>27°C
July	84	34.5	14	4
August	65	37	11	1

Maximum daily temperatures that are above 20°C produce increasing stress. Optimum temperatures for Chinook are in the range of 10 to 15.6°C. EPA identified 16°C as the temperature at the upper end of optimal for salmonids. As temperatures rise above 20°C, the incidence of warmwater diseases increases, which could lead to increasing levels of sublethal stress and eventual mortality of exposed juveniles. In addition, increased inability to compete for food with warmwater fish and decreasing appetite as temperatures reach 25°C, would lead to reduced growth rates, reduced ability to smolt, decreased size at smolting and thereby lowered survival during emigration, all of which have probable impacts to

future success in returning adults to the specific habitat if spawning and rearing occurred there. It is unknown how long the sublethal effects would have to be active to produce delayed mortality in the population. But, downstream migration and rearing through increasingly adverse thermal exposures would likely be impairments to population success. These concerns may manifest themselves in advance of temperatures reaching daily maxima of 24°C in the downstream extent of prime rearing areas. But in stream reaches such as the mainstem UGR above Fly Creek and above Beaver Creek, there are frequently years in which cumulative days of thermal exposure can be assumed to produce significant mortality. These days are associated with occurrence of water temperatures exceeding 25°C.

USFS temperature data were evaluated to assess the frequency of summertime thermal doses that were experienced by spring Chinook in the Upper Grande Ronde mainstem above Fly Creek sufficient to kill 90% of the population. It was determined that there were eight 2-day periods in which it was possible to accumulate 100% of the thermal load to kill 90% of the population (Table 11). In August, there were only 2 such periods of 2-days each. Again, the differences in water temperature statistics are related to the calculated potential mortality. Good evidence of the biological impact of these temperatures would be to show how juvenile fish numbers observed in snorkeling are correlated. Salmonid densities are likely a result of direct thermal death and numerous sublethal effects, including behavioral emigration from the area. Also, the rate of immigration to the study reach is currently unknown. Fish densities are apt to respond at rates dependent upon the maximum temperatures. Even thermally induced death can take two or more days, depending upon the maximum temperatures achieved, and sublethal effects can have even greater lag effects. These effects could make interpretation of salmonid densities difficult in relation to water temperature patterns.

Table 11. Number of occurrences of sufficient thermal load to produce 90% mortality of spring Chinook in the Upper Grande Ronde River mainstem above Fly Creek. Acclimation was to the previous hourly temperatures over 3 days.

	2-day	3-day	4-day
July	8	14	21
August	2	3	3

Collection of solar radiation data (direct beam solar radiation) using the Solmetric SunEye device was added in the 2012 field season to replace the Solar Pathfinder. The SunEye device proved itself to be easier to use and provided more rapid quantitative measures. Water temperature is directly linked to solar radiation (W/m^2) and streamflow. Solar radiation reaching the stream is linked to topographic shading and vegetative shading. Vegetative shading for any given site has a potential maximum value associated with the potential natural vegetation (PNV) for the site (i.e., the mature, vegetation community type found on sites with the same physical conditions), but is also highly controlled by land use actions.

Because there were questions about the accuracy of solar radiation measurements and the ability to monitor solar radiation over the long-term to follow trends in riparian shade, we conducted a number of validation procedures to assess the utility of the SunEye (see Appendix C). These analyses yielded the following observations:

(1) SunEye measurements of solar access from the same location were nearly identical from 2011 to 2012.
(2) SunEye measurements of solar access averaged for the entire study site were very similar from 2011 to 2012, despite there being measurements only on 5 transects in 2011 and 11 in 2012.

(3) It is not possible to this analysis to conclude that only 5 measurements are sufficient because of probable differences in certain study sites in riparian cover heterogeneity and length.
(4) SunEye measurements of solar access based on 11 transects was very similar to the solar radiation estimates made in the Heat Source model, which used the CRITFC LiDAR data to represent streamside riparian canopy and topography and 10-m DEM data to represent surrounding topography in creating effective shade. The SunEye derived its W/m^2 estimates from only direct beam radiation, whereas the Heat Source model calculated direct and diffuse radiation. In addition, the SunEye collected data at a somewhat finer resolution than used in Heat Source, which calculated output data for every 100 m along the stream (from samples at every 50 m).
(5) While it is desirable to conduct a validation test of a method by reference to a more standard method, the fact that the SunEye and Heat Source produced very similar results lent encouragement for continuing to use the SunEye for following trends at the site level. Heat Source appears to have greatest application in following trends at a basin scale in riparian shade and solar access to the stream.

Air Temperature—Air temperature was collected in 2012 using high quality radiation shields and temperature loggers in all annual sites. Because there were questions about the utility of air temperature data and the quality of air temperature data, we conducted a study of air temperature data (see Appendix D).

Analysis of the air temperature data revealed:

(1) There was a high level of correspondence between air temperature recorded by NOAA at the La Grande airport and by CRITFC at the upper end of the Grande Ronde basin (site dsgn4-000009). This correspondence lends validity to these measurements made using CHaMP protocol.
(2) The adiabatic lapse rate measured from the air temperatures and elevation differences between the study site and the La Grande airport was very consistent with standard rates used in the literature.
(3) The Heat Source model uses a standard adiabatic lapse rate in modeling water temperature in both the Upper Grande Ronde and Catherine Creek. It is likely, however, that site specific rates that could be assessed from collecting site specific air temperatures throughout the basin would provide greater accuracy in water temperature modeling.
(4) There was a significant correlation between mean daily water temperature at the study site and the mean daily air temperature collected at the same site.
(5) Although air temperature data collected at the study site in the Upper Grande Ronde and that obtained from the La Grande airport (NOAA) were significantly correlated, the differences in pattern could be related to factors such as local cloud cover, precipitation, or barometric pressure. This can make it worth measuring local air temperature to more accurately model water temperature. Also, local irrigation withdrawal can affect water temperature, making it important to measure streamflow frequently and extensively in order to accurately model water temperature.

Streamflow—In 2012 we continued monitoring stream flow at two gages installed by CRITFC in 2010—Sheep Creek (Upper Grande Ronde) and South Fork Catherine Creek—by making routine visits to gages, measuring actual discharge, and cataloging continuous water level heights with automatic loggers. We compiled records for both gages from all three years to generate flow rating curves in order to extrapolate streamflow for unmeasured time periods (Gore 2006). For this summary report, we plotted the predicted flow for 2012 water year for South Fork Catherine Creek (Figure 9) and Sheep Creek (Figure 10).

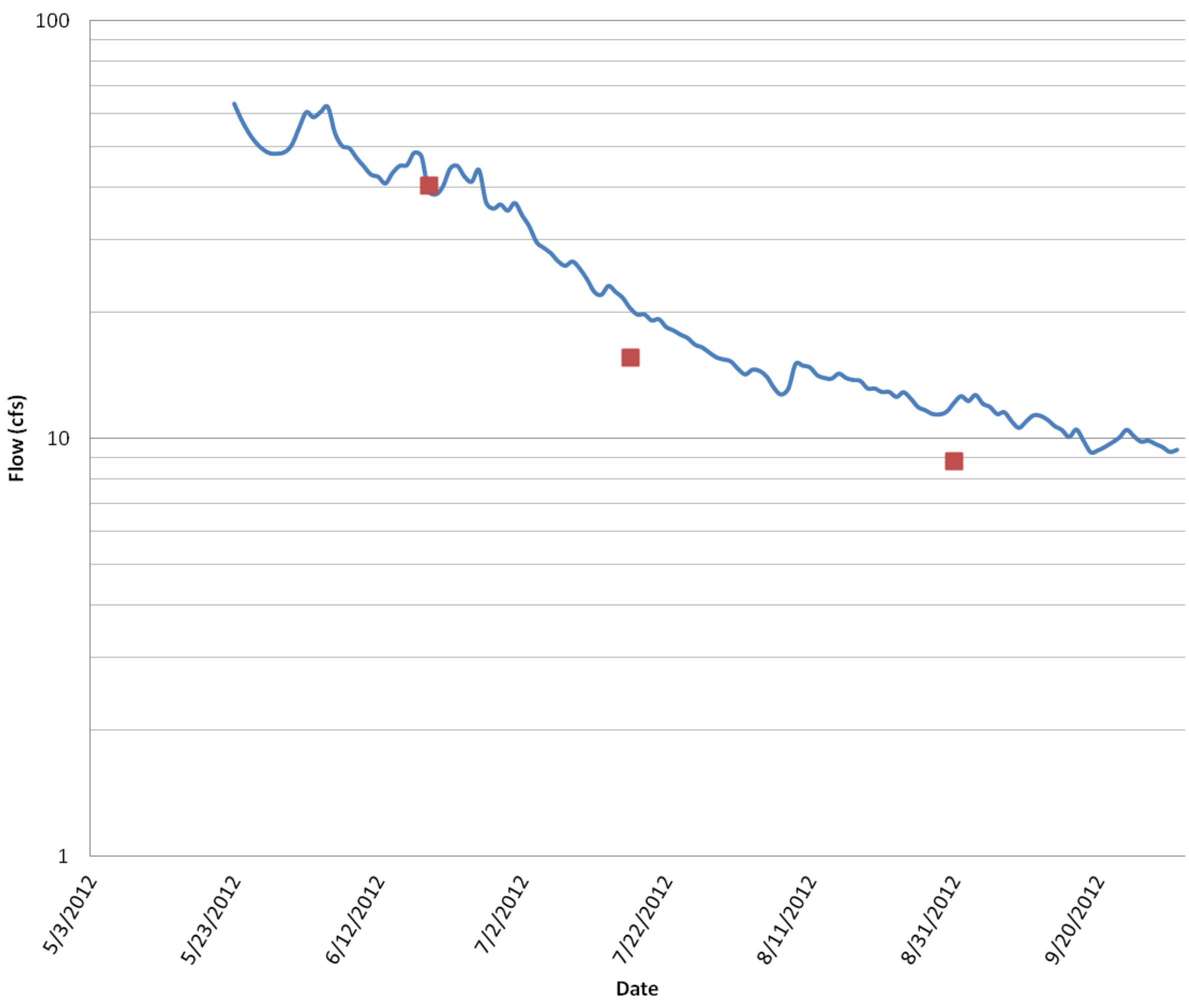

Figure 9. Flow estimate for South Fork Catherine Creek water year 2012 (solid line) and actual discharge measurements (solid squares) (flow rating curve is Q [cfs] = 223.51 x $^{.946}$, where x is barometric pressure-corrected water level).

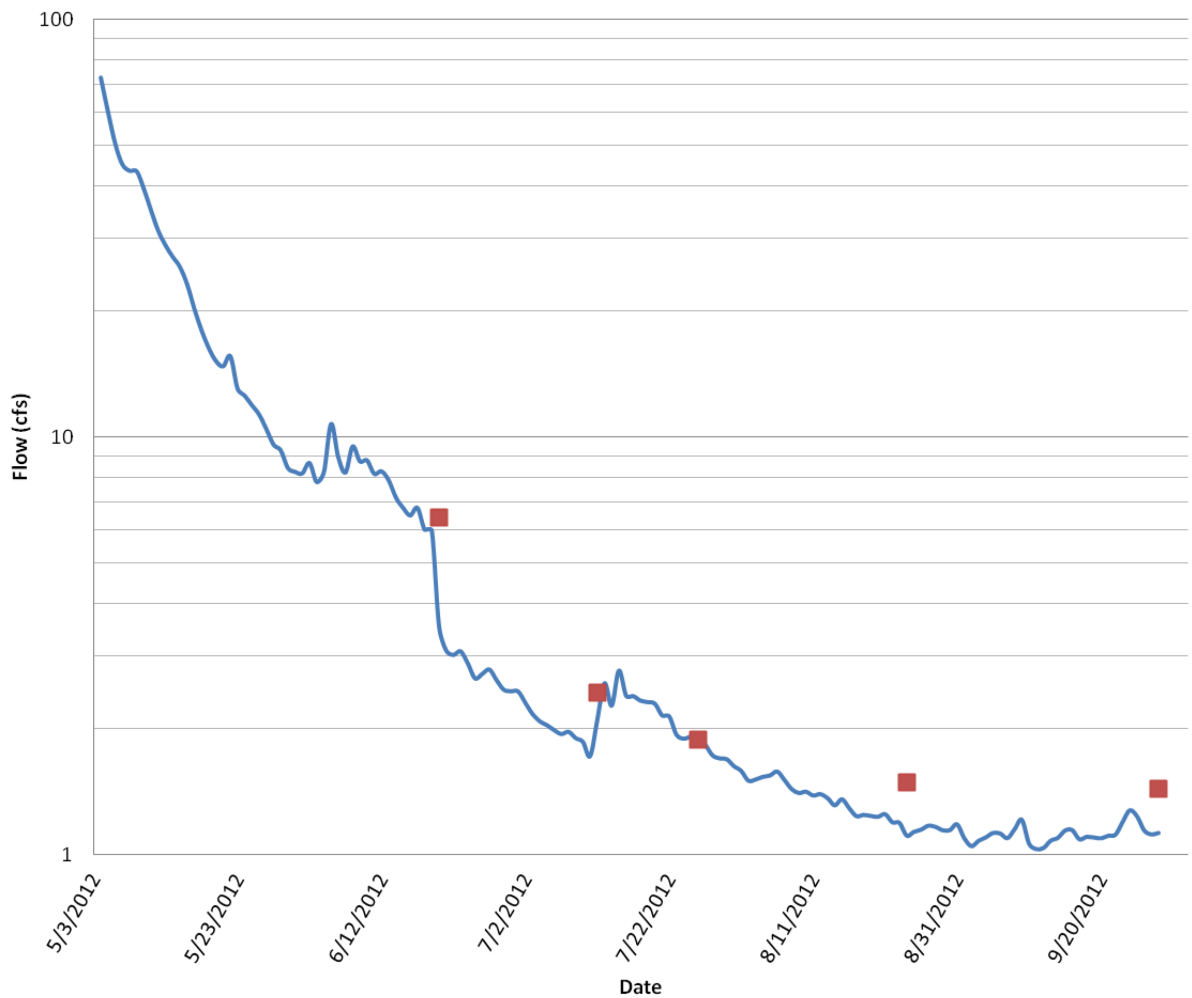

Figure 10. Flow estimate for Sheep Creek water year 2012 (solid line) and actual discharge measurements (solid squares) (flow rating curve is Q [cfs] = 1E-06x $^{20.561}$, where x is barometric pressure-corrected water level).

Watershed Conditions—Although we have made progress in several areas regarding collecting and analyzing watershed conditions (Table 5), this report focuses on road densities because they are likely to be a significant factor affecting localized habitat quality—especially fine sediment.

Given the available databases (USFS road system and TIGER), we found that the USFS database has the greatest ability to be used to infer relative abundance of roads of various surface types. However, an inspection of the overall mapping of roads in the UGR shows that neither database is sufficient alone. As an example, the South Fork Spring Creek (shown in yellow in Figure 11) has roads along its mainstem. These are part of both the USFS and TIGER files. In some cases, the lines representing roads in each map layer perfectly overlap, but other times the level of coincidence can differ by a few meters and other times by many 10s of meters for the same segment. In some cases, road segments are shown only in the USFS layer; other times only in the TIGER layer (Figure 12).

It is also obvious on further inspection of the NAIP imagery that serves as the orthorectified background to the road layers that there are many secondary roads that are not mapped in either system (Figure 12). Roads that are not mapped have a great significance when they are within a riparian corridor due to

the direct impact on fine sediment in the adjacent reach. This places a high importance on having a comprehensive map available so that road density values by basin are meaningfully linked to existing conditions in stream channels.

If all road characteristics could be fully known, such as road surface material, age of the road, traffic type and volume, surface steepness, maintenance level, etc., it would be feasible to develop a reasonable sediment delivery model. Without having comprehensive information on these road characteristics, the next best thing is to know the complete road density. This means not simply relying on only the USFS road layer or the TIGER road layer, but to combine and condense both layers (eliminate duplicate road segments) and to supplement this with all unmapped roads, whether they may be in localized logging areas (Figure 13), or as extensions to other forest and rangeland road systems. In addition, because it is physically significant whether a road segment is located accurately in space so that we can distinguish streamside roads from hillslope roads, or so we can properly associate road segments with hillslope gradient or forest cover, it will be necessary to move mapped road segments so that they occupy the correct location against NAIP imagery.

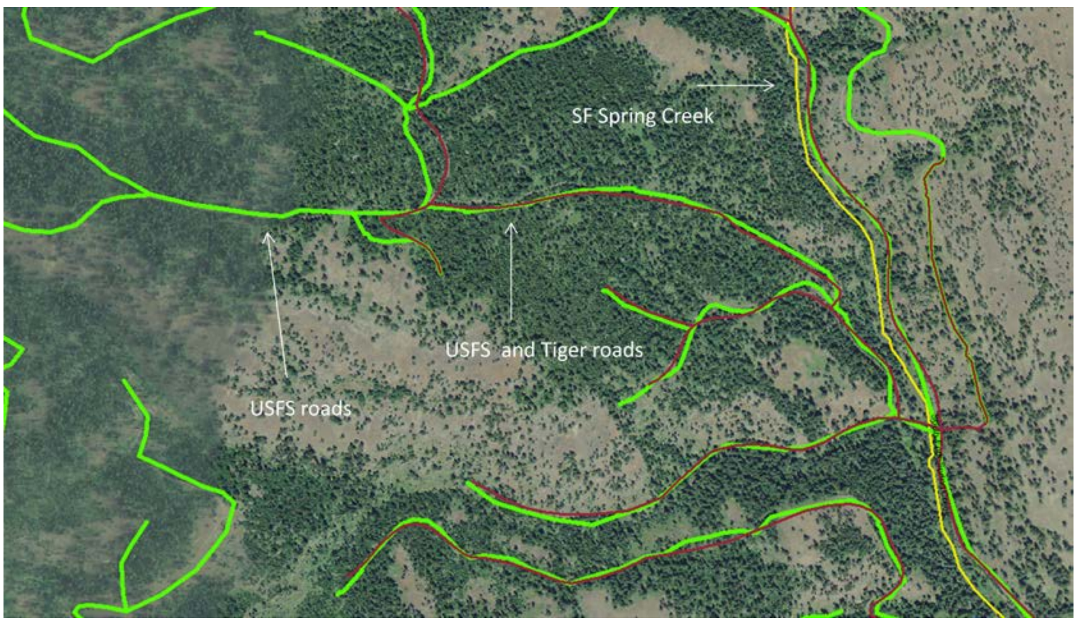

Figure 11. USFS and Tiger roads in the South Fork Spring Creek drainage in the Upper Grande Ronde basin.

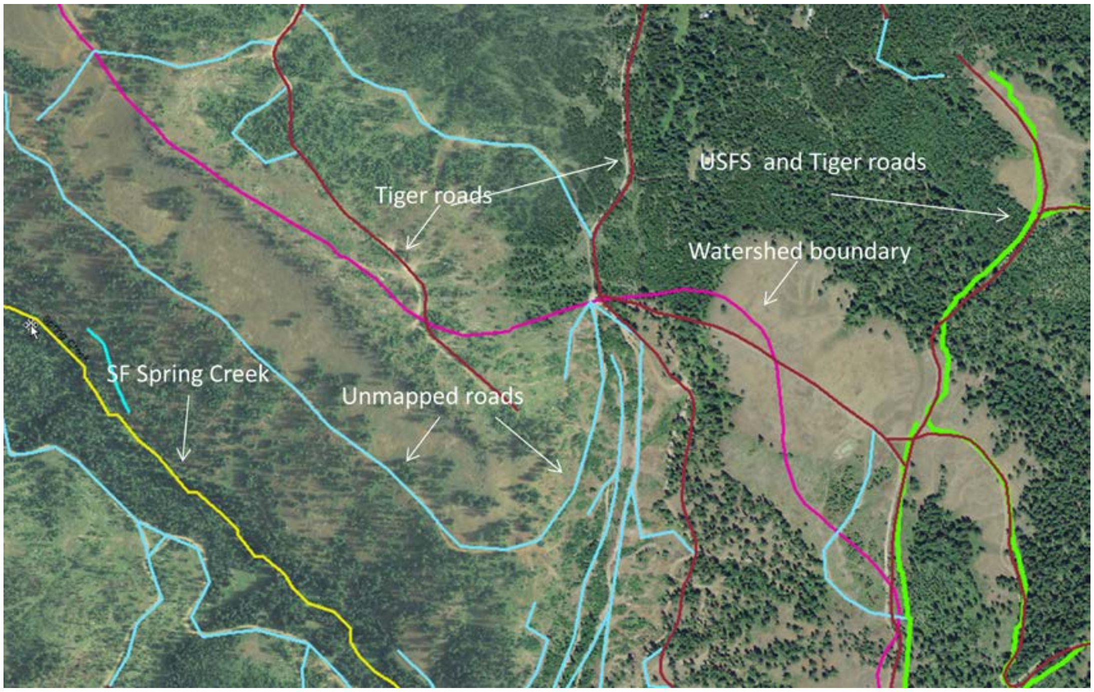

Figure 12. USFS and Tiger roads, plus unmapped roads in the South Fork Spring Creek drainage in the Upper Grande Ronde basin. USFS (green), TIGER (red), unmapped roads (light blue), unnamed streams (dark blue), named stream (yellow), basin boundary (magenta).

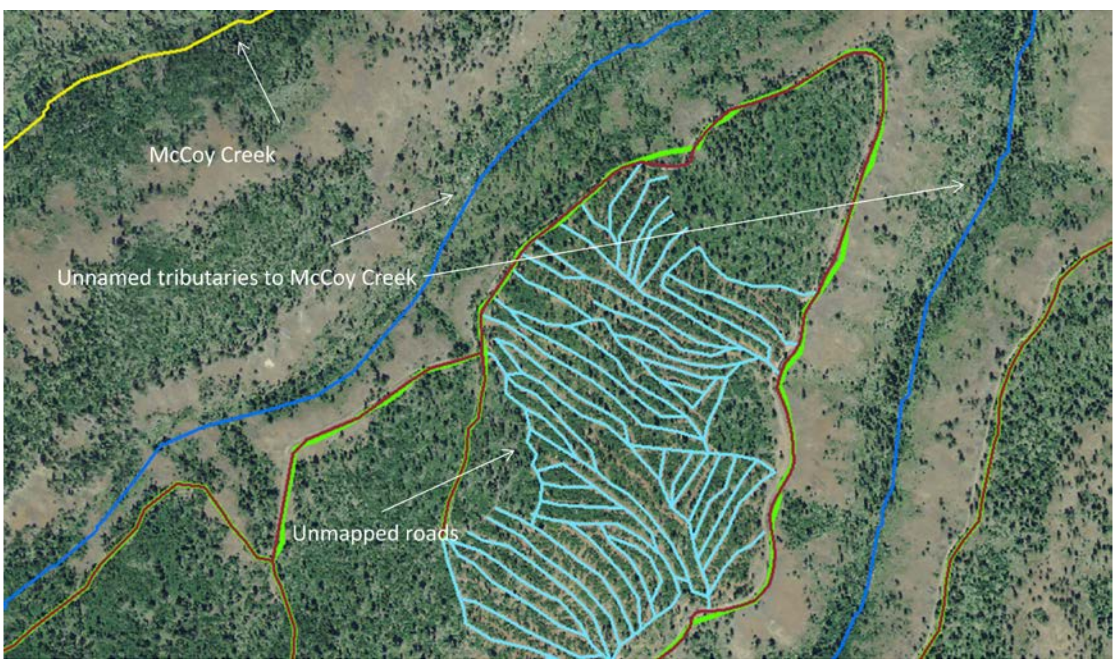

Figure 13. USFS and Tiger roads, plus unmapped roads in the McCoy Creek drainage in the Upper Grande Ronde basin. USFS (green), TIGER (red), unmapped roads (light blue), unnamed streams (dark blue), named stream (yellow).

Also in 2012, we worked out methods for using Government Land Office (GLO) records from the late 1800s to describe historical vegetation and stream complexity (Figure 14). The GLO surveys, conducted in the late 1800s, involved surveyors walking section lines and recording the instances and locations of riparian and upland vegetation, width and depth of water bodies (including streams) crossed, and encounters with trails, roads, habitations, or land use (White 1983). This project is ongoing with planned completion in fall of 2013.

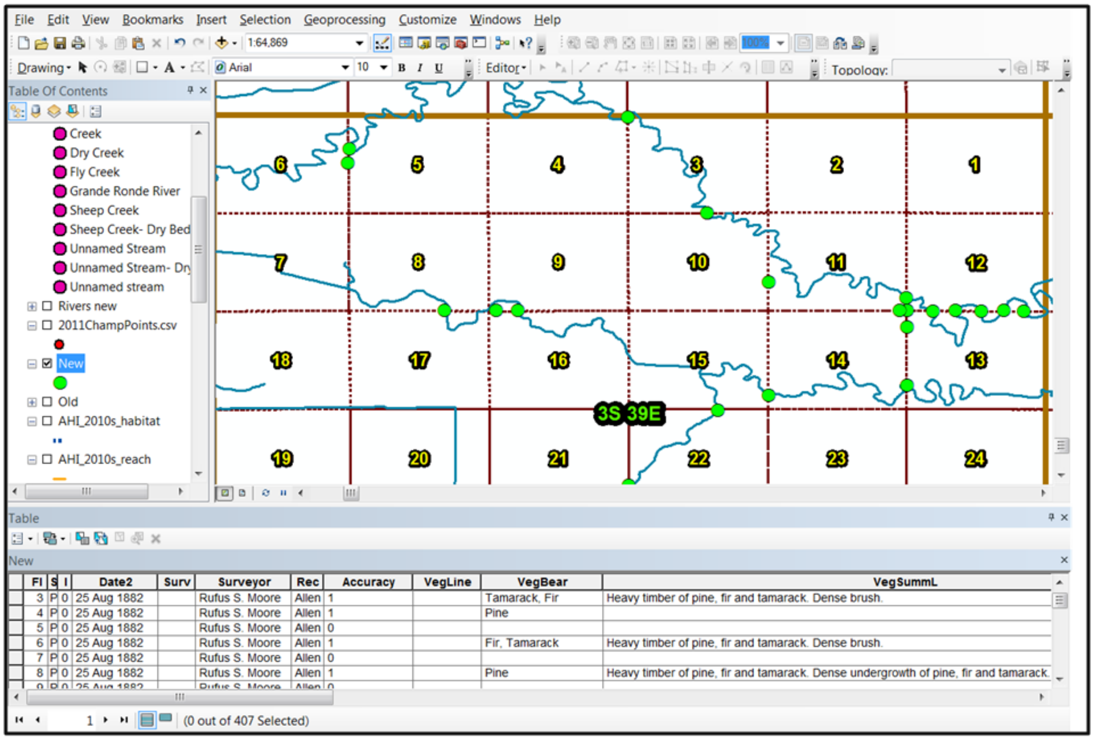

Figure 14. Mapping historical riparian vegetation and stream complexity attributes in GIS from Government Land Office (GLO) surveys. Shaded circles represent where surveyors mapped locations of riparian vegetation or stream crossings.

<u>Work Element E 157: Collect benthic macroinvertebrate samples and process</u>

Benthic insect samples were processed by ABR, Inc. (Alaska Biological Research, Inc.) from collections made in 2011 and 2012. CRITFC and ODFW collected benthic macroinvertebrate samples from 52 sites in 2012. An abbreviated table of BMI metrics calculated by ABR is provided in Table 12. In addition to the standard water quality indices, our database also holds detailed information on raw counts and biomass of taxa by length category in 0.5-1 mm size bins.

Beyond calculating standard BMI metrics, our analyses include describing relationships among fish, habitat, and BMIs. By calculating the maximal information coefficient for the best bivariate relationships (Table 16), we discovered several interesting relationships between environmental characteristics and benthic macroinvertebrates (see fish habitat analysis section for MIC methodology). For example, the weighted average (WA inference temperature model based on benthic macroinvertebrates increases with July maximum air temperature in a linear fashion (Figure 15a) as expected. However, the number of piercing herbivores in a site decreased rapidly moving west to east (increasing longitude, Figure

15b)—possibly a basin effect moving from the Upper Grande Ronde basin to Catherine Creek. This group of macroinvertebrates pierces the cell walls of filamentous algae for nutrition, so it is not surprising to see their numbers decrease rapidly to zero from the open, sunny Upper Grande Ronde basin to the shady canyons of Catherine Creek where autochthonous production is likely limited. These results are examples of how strong, broad-scale patterns can be found in the data that can help provide context for future analyses.

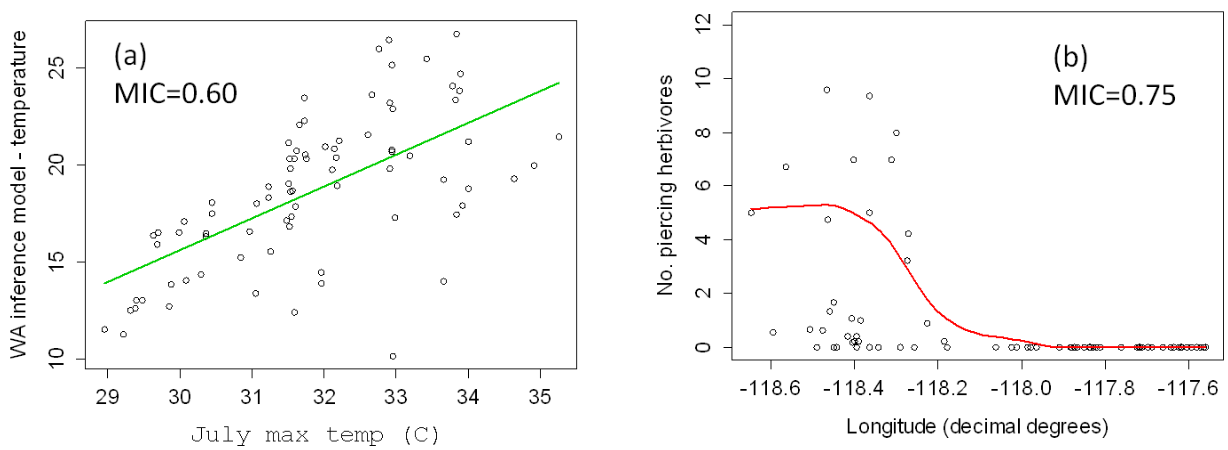

Figure 15. Example best relationships between benthic macroinvertebrate indices (BMIs) and landscape-scale features (a) July maximum temperature and (b) longitude. Solid green line indicates best linear fit. Solid red line indicates LOESS regression fit to non-linear relationship.

Table 12. Table of selected benthic macroinvertebrate indices calculated for CHaMP sites in 2012 (table sorted by PREDATOR score).

Stream name	Station ID	Taxa Richness	Grande Ronde IBI Total Score	Whole sample density (indiv/m^2)	Ash Free Dry Mass (mg)	PREDATOR Model O/E (P > 0.5)	WA_inv (Temp C)	Untrans WA_Inv (% Fine Sediment)
Catherine Creek	CBW05583-527786	47	48	3662	2515.0	1.30	16.3	2.5
Grande Ronde River	DSGN4-000009	51	50	2843	1724.3	1.28	15.9	3.0
South Fork Catherine Creek	CBW05583-086954	55	44	4611	1258.3	1.25	13.9	1.4
Burnt Corral Creek	ORW03446-077704	64	50	1335	1345.4	1.22	18.8	13.3
Sheep Creek	CBW05583-453946	59	46	14144	2209.0	1.18	17.1	6.4
Gordon Creek	CBW05583-135615	54	48	778	879.8	1.15	17.3	6.0
Catherine Creek	dsgn4-000204	39	42	8444	9594.4	1.11	18.6	7.7
Sheep Creek	CBW05583-228666	53	46	10702	4422.7	1.11	16.8	8.7
North Fork Catherine Creek	dsgn4-000001	48	48	2095	851.0	1.11	14.0	0.8
Chicken Creek	ORW03446-159368	45	42	3012	409.1	1.09	18.3	11.0
Meadow Creek	CBW05583-514874	50	36	21272	3729.2	1.08	23.8	12.2
Catherine Creek	dsgn4-000010	52	46	5318	6247.4	1.05	17.5	2.4
North Fork Catherine Creek	CBW05583-531882	48	50	3498	1092.4	1.05	12.6	0.6
Rock Creek	CBW05583-240730	45	34	1232	934.2	1.03	26.0	10.2
Little Phillips Creek	ORW03446-108270	38	36	440	259.0	0.98	14.5	4.2
South Fork Catherine Creek	CBW05583-073130	31	44	157	55.9	0.97	14.0	3.8
North Fork Catherine Creek	dsgn4-000168	44	50	523	246.7	0.97	12.5	1.1
South Fork Catherine Creek	CBW05583-013226	42	42	5116	1564.3	0.97	12.4	1.4
Catherine Creek	CBW05583-405674	46	42	8380	9716.0	0.95	20.3	8.1
Catherine Creek	CBW05583-340138	41	42	10596	11363.9	0.95	19.0	6.5
Clark Creek	ORW03446-130030	42	36	24259	16819.4	0.95	22.9	6.0
West Chicken Creek	dsgn4-000006	41	42	488	92.9	0.94	19.0	19.8
Spring Creek	ORW03446-065720	25	30	145	272.2	0.92	19.2	4.5
Burnt Corral Creek	CBW05583-382778	43	42	432	222.0	0.90	17.9	20.3
Burnt Corral Creek	ORW03446-120904	41	30	630	195.8	0.89	17.4	28.5

Stream name	Station ID	Taxa Richness	Grande Ronde IBI Total Score	Whole sample density (indiv/m^2)	Ash Free Dry Mass (mg)	PREDATOR Model O/E (P > 0.5)	WA_inv (Temp C)	Untrans WA_Inv (% Fine Sediment)
Fly Creek	CBW05583-506682	48	36	25618	19494.9	0.87	20.8	6.9
Clark Creek	ORW03446-059352	46	40	2184	1965.8	0.87	22.3	2.2
Grande Ronde River	dsgn4-000205	42	30	3056	983.3	0.87	26.4	8.7
South Fork Catherine Creek	dsgn4-000161	43	44	1332	268.2	0.86	11.6	2.1
Sheep Creek	CBW05583-335162	54	46	10616	4179.9	0.86	20.5	9.2
South Fork Catherine Creek	CBW05583-381866	44	50	5217	1976.7	0.85	11.3	0.8
Catherine Creek	CBW05583-417962	46	46	5371	10846.7	0.84	18.1	2.8
McCoy Creek	CBW05583-015162	58	26	29762	21431.2	0.82	23.5	32.6
Catherine Creek	ORW03446-137980	41	42	10757	6199.6	0.81	18.9	5.2
Grande Ronde River	CBW05583-486202	47	44	1786	476.1	0.77	20.5	2.8
Spring Creek	dsgn4-000092	26	32	222	1110.9	0.77	20.0	13.6
Meadow Creek	CBW05583-252730	42	30	14235	3650.4	0.77	24.7	19.3
Grande Ronde River	DSGN4-000202	46	34	20384	4777.9	0.77	20.8	6.0
Catherine Creek	CBW05583-086186	46	46	835	1102.8	0.77	21.2	9.0
Meadow Creek	CBW05583-285498	37	28	7037	2307.5	0.74	23.4	6.4
Meadow Creek	dsgn4-000213	45	28	3539	1380.1	0.73	26.7	14.7
East Phillips Creek	ORW03446-177134	28	34	207	76.0	0.72	15.3	3.3
Middle Fork Catherine Creek	CBW05583-109994	41	42	11602	2674.8	0.71	10.2	0.7
Rock Creek	CBW05583-421786	38	26	13536	7974.7	0.69	21.3	24.3
Grande Ronde River	dsgn4-000277	44	42	6043	3128.1	0.68	20.3	9.2
Fly Creek	dsgn4-000094	57	42	5177	1729.5	0.67	23.6	15.9
Grande Ronde River	DSGN4-000245	50	38	17405	7737.4	0.66	25.1	11.4
Meadow Creek	CBW05583-498490	43	34	6193	6388.8	0.65	24.1	6.4
Clark Creek	CBW05583-142490	32	28	242	131.9	0.64	21.1	7.7
Rock Creek	CBW05583-487322	37	22	14370	1118.9	0.59	21.0	27.7
Meadow Creek	dsgn4-000093	42	26	5368	1755.0	0.45	25.4	13.3
McCoy Creek	CBW05583-095642	26	20	421	486.9	0.37	21.5	44.3

Work Element F 157: Collect McNeil sediment core samples and process

Subsurface fine sediment levels measured at all 34 survey sites were generally low to moderate with the Upper Grande Ronde River basin having the highest proportion of fines among the 3 basins surveyed. The proportion of fine sediment < 2 mm ranged from 0.06 to 0.23 (mean = 0.13) across all sites (Table 13). The proportion of fines < 6.35 mm ranged from 0.07 to 0.44 (mean = 0.28). The proportion of fines < 6.35 mm averaged 0.25, 0.25, and 0.30 in Catherine Creek, the Minam River, and the Upper Grande Ronde River, respectively. Note that only two sites were surveyed in the Minam River basin, so fine sediment values reported here may not be representative of the basin average.

Variability in average fine sediment levels across all sites was moderate with a CV of 33% for fines < 2 mm and 28% for fines < 6.35 mm (Table 13; Figure 16). Spatial variability in fine sediment levels did not appear to be related to landscape characteristics such as gradient, forest cover, and road density according to a preliminary analysis conducted in 2012 (Justice et al. 2012(b); unpublished technical report). However, efforts to refine our calculations of landscape characteristics are ongoing, and updated analyses may shed new light on the relationship between landscape characteristics and fine sediment.

Most survey sites in the Upper Grande Ronde and Catherine Creek had fine sediment concentrations below what might be considered a critical threshold level for survival of incubating eggs (Figure 17). In a laboratory study of Chinook egg survival relative to fine sediment conducted by Tappel and Bjornn (1983), egg survival remained very high (i.e., 96%) until the fraction of fine sediment < 6.35 mm exceeded approximately 30%, after which, survival declined rapidly, approaching 0 at about 60% fines. Median values for fine sediment < 6.35 mm were below the 30% level in both Catherine Creek and the Upper Grande Ronde River basins (Figure 17). Median egg-to-fry survival rates, as predicted by a model described in Irving and Bjornn (1984), were 90.8 and 87.2% for Catherine Creek and the Upper Grande Ronde River basins, respectively (Figure 18).

Correlations between 9 different fine sediment metrics were generally weak to moderate, with the exception of McNeil fines < 2 mm versus McNeil fines < 6 mm (r = 0.89), ocular fines in pools versus ocular fines in all habitat types (r = 0.96); and pool tail fines < 2 mm versus pool tail fines < 6 mm (r = 0.98) (Table 14). It is not surprising that these metrics were strongly correlated as they utilized the same methodology and differed only in terms of the size criteria used to define fines or in the location where fines were measured (e.g., pools versus all channel unit types).

Fine sediment at depth (i.e., McNeil fines) was moderately correlated to ocular estimates of surface fines as well as pool tail fines, but was not correlated to cobble embeddedness or percent fines in riffles as estimated from pebble counts (Table 14). According to a linear regression model, there was a statistically significant positive relationship between McNeil fines < 2 mm and ocular fines in pools (p = 0.003; Equation 2), although this model explained only approximately 27% of the variation in McNeil fines (Figure 19). McNeil fines < 2 mm was also significantly correlated to pool tail fines < 2 mm (p = 0.003; R^2 = 0.28; Equation 3). Similarly, McNeil fines < 6.35 mm were positively related to pool tail fines < 6 mm (p = 0.001; Equation 4; Figure 20), with pool tail fines < 6 mm explaining approximately 31% of the variation in McNeil fines < 6.35 mm.

Equation 2: ***mnfines2* = 0.104 + 0.184*ocfinespools**

Equation 3: ***mnfines2* = 0.114 + 0.161*ptfines2**

Equation 4: ***mnfines6* = 0.234 + 0.268*ptfines6**

Table 13. Summary statistics for McNeil fine sediment samples collected in Catherine Creek, Minam River, and Upper Grande Ronde River basins between 2010 and 2012.

	Basin			
	Catherine Creek	Minam River	Upper Grande Ronde River	Total
Fines < 2mm				
Min	0.06	0.10	0.06	0.06
Max	0.19	0.12	0.23	0.23
Mean	0.13	0.11	0.14	0.13
Count	13	2	19	34
StdDev	0.04	0.01	0.05	0.04
StdErr	0.01	0.01	0.01	0.01
CV	0.30	0.13	0.35	0.33
95% CI Lower	0.10	0.00	0.11	0.12
95% CI Upper	0.15	0.24	0.16	0.15
Fines < 6.3mm				
Min	0.07	0.22	0.17	0.07
Max	0.40	0.27	0.44	0.44
Mean	0.25	0.25	0.30	0.28
Count	13	2	19	34
StdDev	0.09	0.03	0.07	0.08
StdErr	0.02	0.02	0.02	0.01
CV	0.34	0.14	0.23	0.28
95% CI Lower	0.20	0.00	0.27	0.25
95% CI Upper	0.30	0.55	0.33	0.30

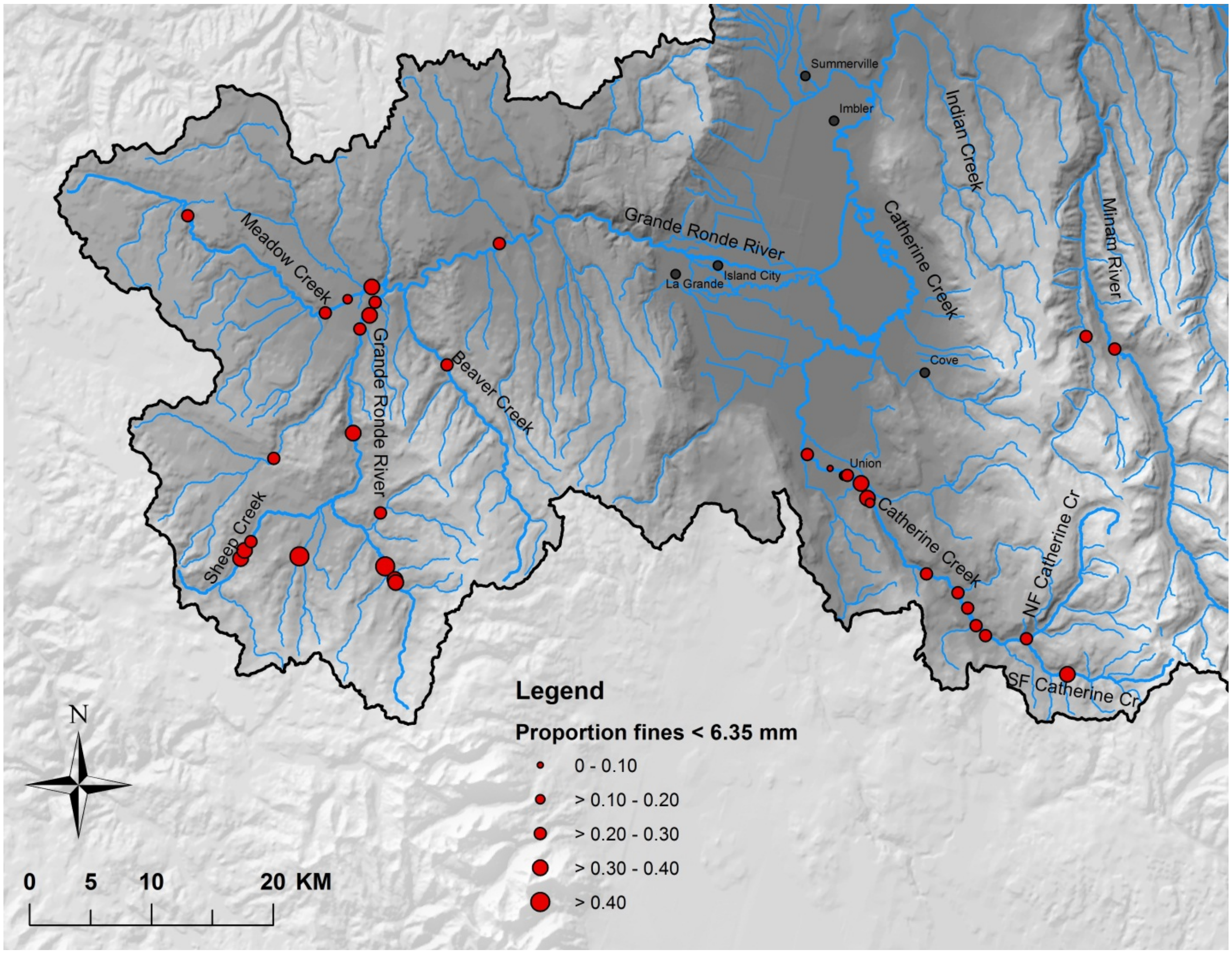

Figure 16. McNeil sediment sampling sites in the Upper Grande Ronde River, Catherine Creek, and Minam River basins during summer, 2010-2012. The size of each red circle is proportional to the amount of fines < 6.35 mm measured at each site.

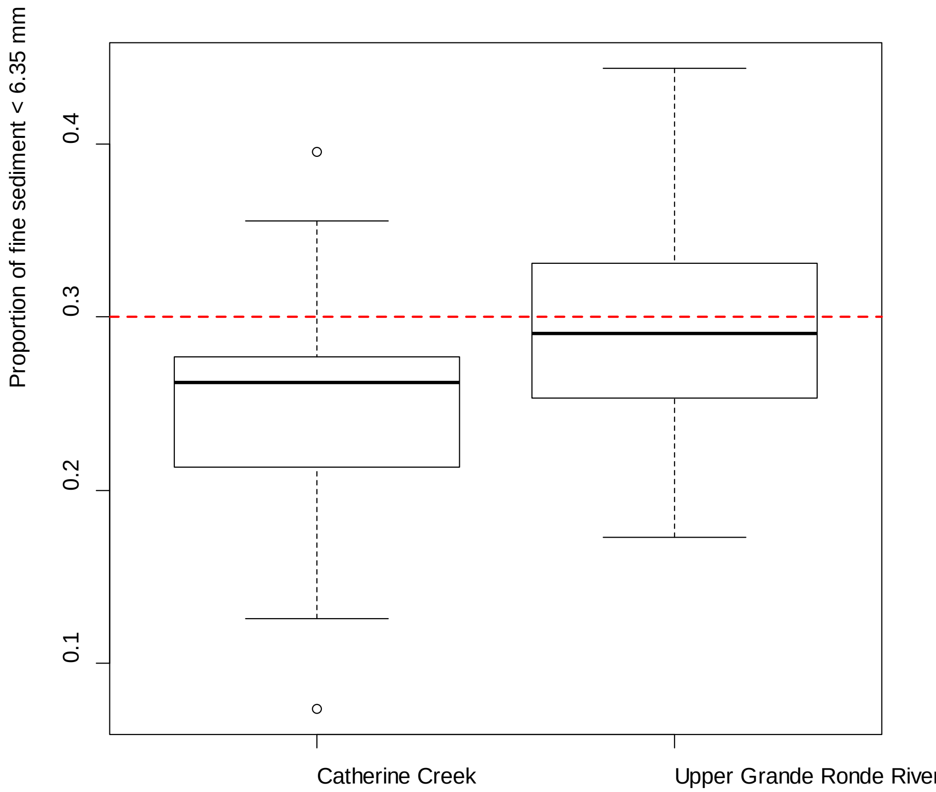

Figure 17. Proportion of fine sediment < 6.35 mm in McNeil samples collected in Catherine Creek and the Upper Grande Ronde River basins from 2010 to 2012. The red dashed line represents a critical threshold level of 30% fines < 6 mm based on data from Tappel and Bjornn (1983).

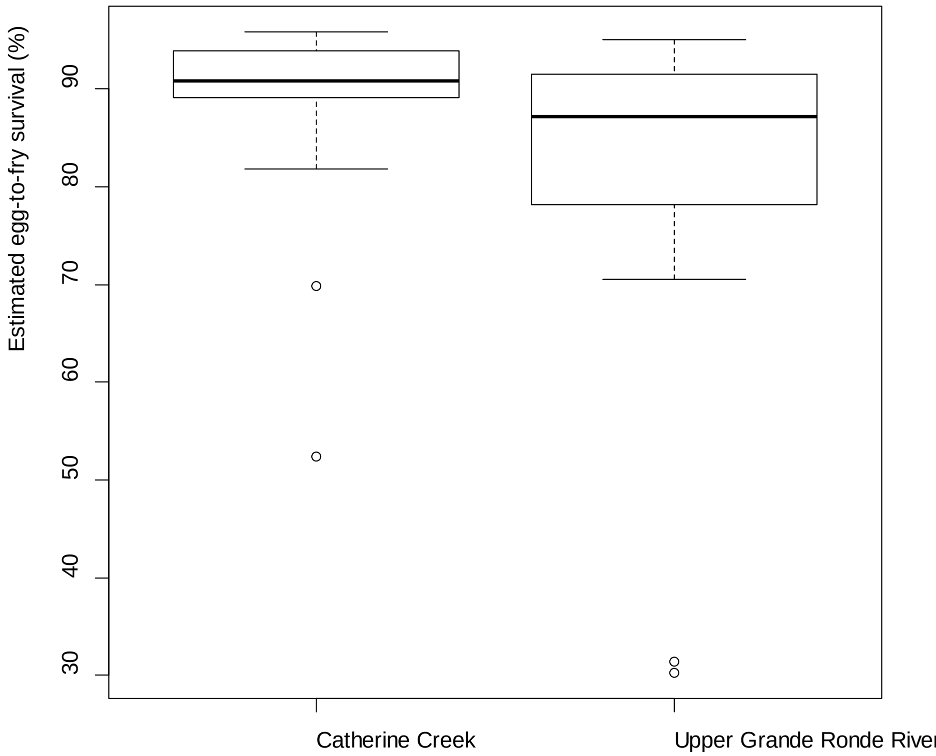

Figure 18. Predicted egg-to-fry survival for Chinook salmon at all sites where McNeil core samples were collected. Survival rates were predicted from a relationship developed from a lab study of Chinook egg survival (Tappel and Bjornn 1983).

Table 14. Pearson correlation coefficients (*r*) for comparisons among 9 different fine sediment metrics calculated from sediment samples collected in the Upper Grande Ronde River and Catherine Creek basins during summer 2010-2012. Pairwise comparisons with correlation coefficients exceeding 0.5 are highlighted.

	embed	*mnfines2*	*mnfines6*	*ocfinesall2*	*ocfinespools2*	*pebble2*	*pebble6*	*ptfines2*	*ptfines6*
embed	1	0.25	0.44	0.05	0.15	0.03	0.39	0.21	0.28
mnfines2		1	0.89	0.54	0.53	0.14	0.29	0.53	0.58
mnfines6			1	0.39	0.39	0.11	0.35	0.51	0.56
ocfinesall2				1	0.96	0.53	0.37	0.29	0.40
ocfinespools2					1	0.57	0.41	0.33	0.45
pebble2						1	0.36	0.40	0.46
pebble6							1	0.57	0.62
ptfines2								1	0.98
ptfines6									1

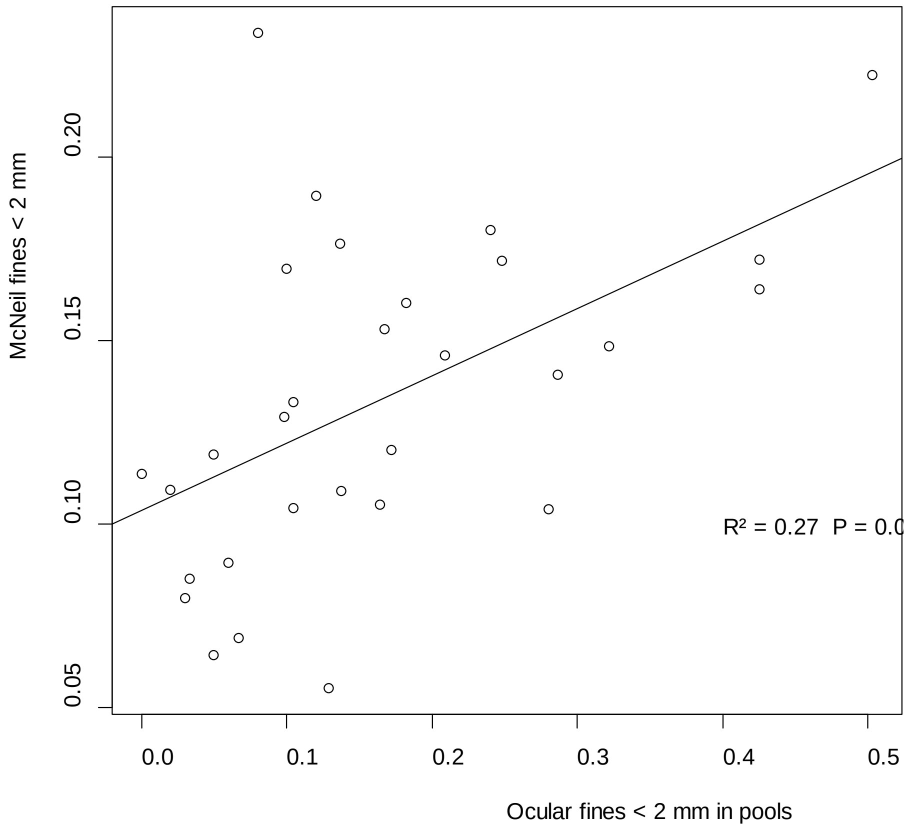

Figure 19. Relationship between ocular fines < 2 mm in pools and McNeil fines < 2 mm from 30 sites surveyed in the Upper Grande Ronde River and Catherine Creek basins from 2010 to 2012.

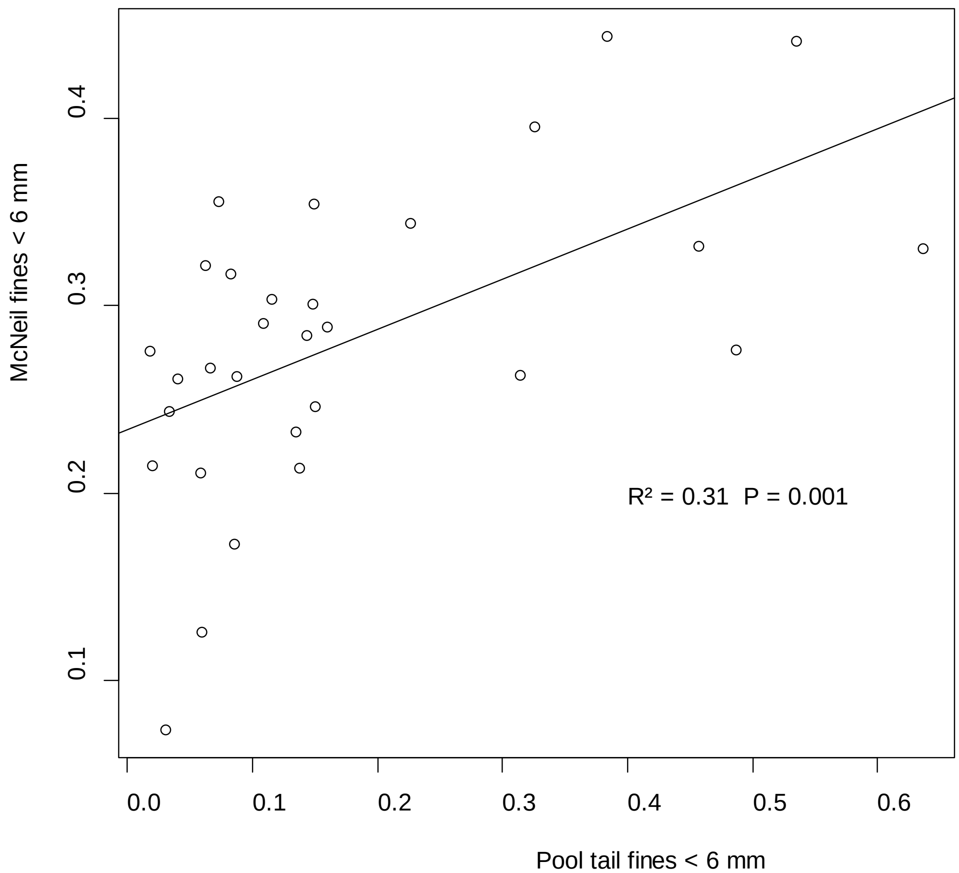

Figure 20. Relationship between pool tail fines < 6 mm and McNeil fines < 6.35 mm from 30 sites surveyed in the Upper Grande Ronde River and Catherine Creek basins from 2010 to 2012.

Work Element I 162 C: Hydrological analysis

This CRITFC/USGS hydrological analysis project is focused on characterizing low-flow regime as a primary feature of habitat quality for salmon spawning and juvenile rearing areas in the Upper Grande Ronde River Basin. Initial results indicate that out of 61 originally-considered gages, a subset of regional flow gages (N = 41) is appropriate for modeling in the study area. This subset of gages was determined based on excluding basins with drainage area > 500 mi^2, sites with period of flow record < 10 years, and records where significant ($p<0.01$) trend detected in 7-day low flow. After determining baseflow index (BFI) (annual 7-day low flow/mean annual flow), low flow metrics were derived from a theoretical frequency distribution (Figure 21).

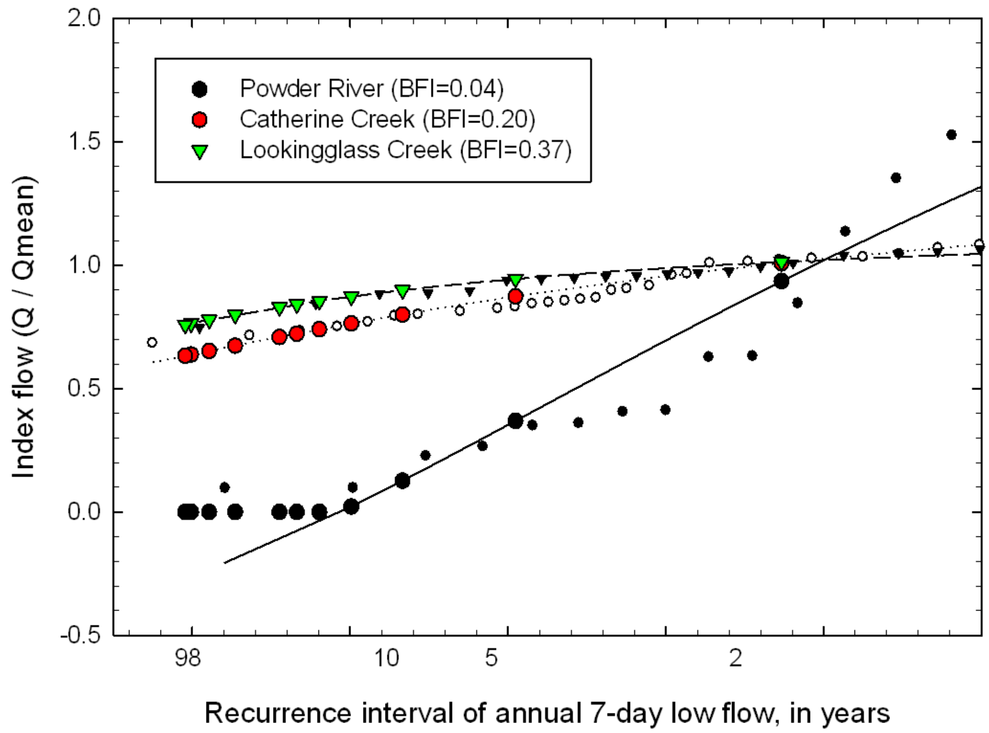

Figure 21. Comparison of theoretical distribution of annual 7-day low flow for streams across a range of baseflow index (BFI).

Multivariate analysis (CCA) was conducted to tease out the strongest factors driving both streamflow and watershed conditions at the 41 gaged sites, and to find the strongest patterns linking flow metrics and watershed metrics. The analysis revealed three key components as main elements of the low-flow regime: low-flow variability (measured by Q98 or rare low-flow event), influence of groundwater (measured by BFI), and timing of low flow (measured by mean Julian day for onset of 7-day low flow). Significant watershed attributes associated with key low flow metrics include elevation, precipitation, and stream density. CCA analysis based on these sets of variables shows significant results ($p<0.0001$). Canonical correlation between watershed (V1) and flow (W1) dimensions = 0.79 (explains 63% of variability) (Figure 22). Data are pooled from hydrologic neighborhood to generate a regional curve for ungaged sites, and metrics are then derived from the regional curve.

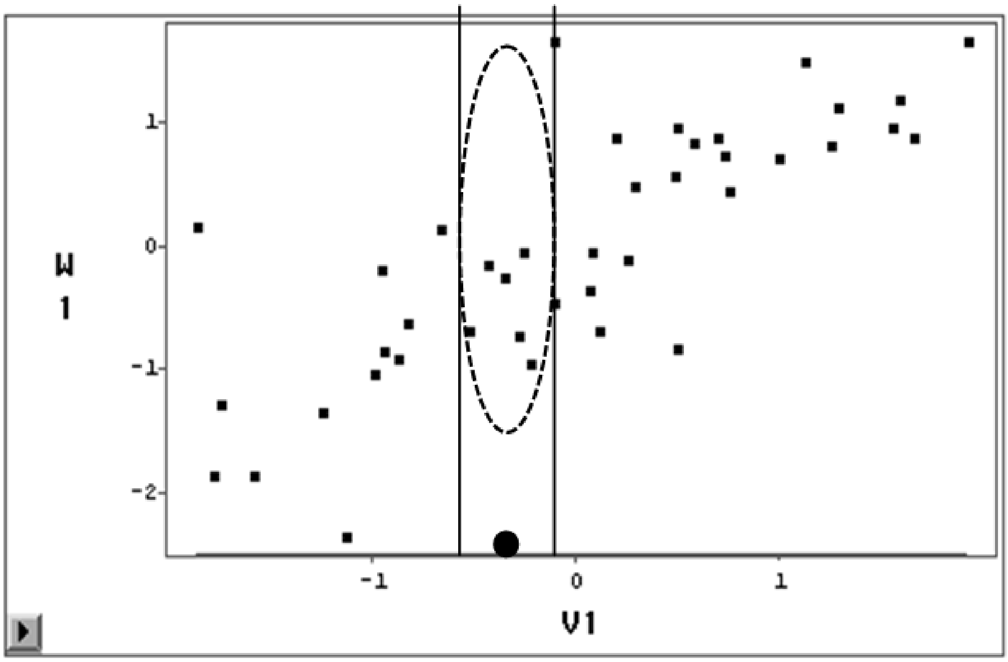

Figure 22. Canonical correlation between watershed (V1) and flow (W1) dimensions, explaining 63% of variation. Solid circle indicates hypothetical score on watershed dimension for ungaged site. Dotted ellipse indicates group of gaged sites with similar score on watershed dimension, or the "hydrological neighborhood" for the hypothetical ungaged site.

Additional watershed attributes for the 41 gaged sites are being determined by CRITFC personnel in order to improve the CCA associations with low flow metrics, if possible. These include basin shape metrics, stream order metrics, and underlying geology descriptors from the Basin Tools software (Appendix C). These metrics are of interest because they have been found to explain the majority of variance for peak flow magnitude, and we are interested to explore how they may be related to low flow. Adding these metrics to the analysis may provide a stronger association between watershed and flow regime, which will improve the capacity of the CCA analysis to identify appropriate gaged sites for the target stream reaches.

Work Element I 162 F: Develop draft life cycle model

The life cycle aspect of Catherine Creek spring Chinook modeling is operational. Spatial calibration and resource allocation components are currently under development. The resource allocation component has been prototyped for sensitivity to riparian planting efforts. A range of planting scenarios was examined such that the rate of growth of trees and the current state of riparian areas could be tested for recovery potential under different scenarios of planting intensity. Under assumed growth and shade accumulation, simulation results indicate that depending on the initial average age of riparian growth, benefits to production from the intensity of planting efforts are not commensurately larger with larger intensity of planting. Results indicate that the timing and intensity should be carefully considered in recovery planning. More details about the life cycle model are provided in Appendix A.

Work Element J 162: Heat Source Model Expansion

The spatial distribution of current water temperature conditions in the Upper Grande Ronde River and Catherine Creek basins as predicted by the Heat Source model (based on calibration from 2010) is summarized in Figure 23 and Figure 24 respectively. These figures show the maximum weekly maximum temperature during the summer (MWMT; the maximum of the 7-day running average of the daily maximum temperature) at points spaced every 100 meters throughout the entire Chinook distribution area. Water temperatures in excess 17.8°C, the sublethal limit for juvenile Chinook salmon as defined by ODEQ (2000), may cause a decrease or lack of metabolic energy for feeding, growth or reproductive behavior, encourage increased exposure to pathogens, and decrease food supply and increase competition from warm water tolerant species. Temperatures exceeding 21°C, the incipient lethal limit, may cause breakdown of physiological regulation of vital bodily processes, namely: respiration and circulation. We estimated that 87% of the total area used by Chinook salmon in the Upper Grande Ronde River basin exceeded the sublethal limit of 17.8°C and 76% exceeded the incipient lethal limit of 21°C. Similarly, 58% of the Chinook distribution area within Catherine Creek exceeded the sublethal limit, and 24% exceeded the incipient lethal limit. In general, high water temperature is a significant limiting factor for Chinook salmon production in both of these watersheds, but to a lesser extent in Catherine Creek compared with the Upper Grande Ronde River.

Heat Source model results are presented in Figure 25 representing predicted water temperatures in the Grande Ronde River that could be expected for each of the following scenarios: 1) current conditions (based on calibration from 2010); 2) increased streamflow by 50%; 3) reduced streamflow by 50%; 4) no water diversions; 5) increased air temperature by 2 °C; 6) riparian vegetation restored to 100% of its natural potential (i.e., potential natural vegetation (PNV)); and 7) PNV plus no diversions. Estimates of PNV done by the Oregon Department of Environmental Quality in 1999 (ODEQ 2000) were used to predict the effect of PNV restoration throughout the drainage on water temperature distribution. The restoration of PNV creates conditions that make it feasible to provide water temperatures that remain below 15°C from rkm 20 to 96 (Figure 25). This represents a recovery of the entire mainstem to thermal conditions that are conducive to salmonid production.

At this point, we have not been able to run scenarios of climate change or PNV restoration with the newly calibrated, expanded temperature model. This model was calibrated for July 10 through September 20, 2010. We intend to apply the same ODEQ PNV model to the expanded Heat Source predictive model to see what the resultant water temperatures are for various points within the model period. When the riparian vegetation mapping of current and PNV is completed by the riparian contractors, we will have a firmer ecological basis for prediction of water temperature recovery.

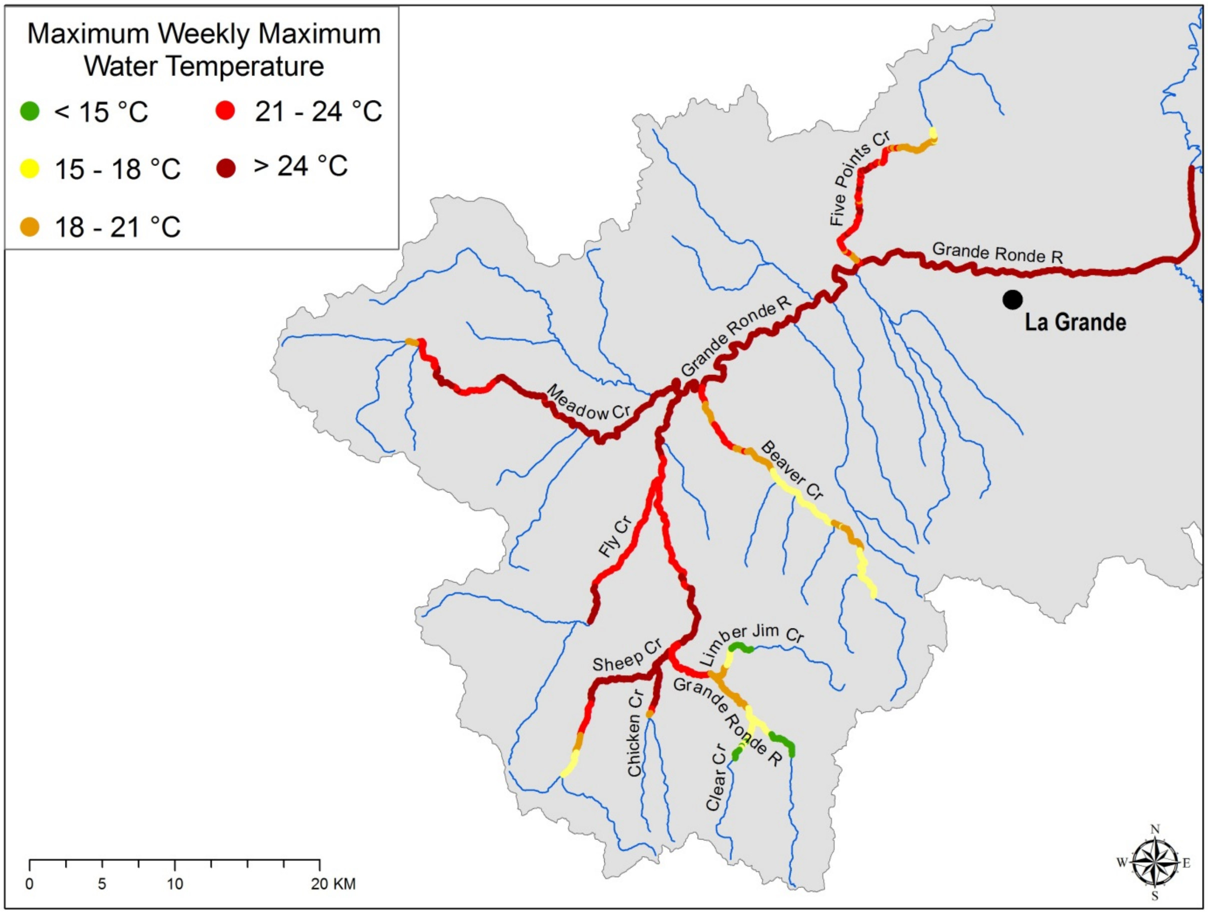

Figure 23. Maximum weekly maximum water temperature (maximum 7-day running average of the daily maximum temperature; °C) in the Upper Grande Ronde River basin during summer 2010. These data were simulated using the Heat Source water temperature model for the period July 10 – September 20.

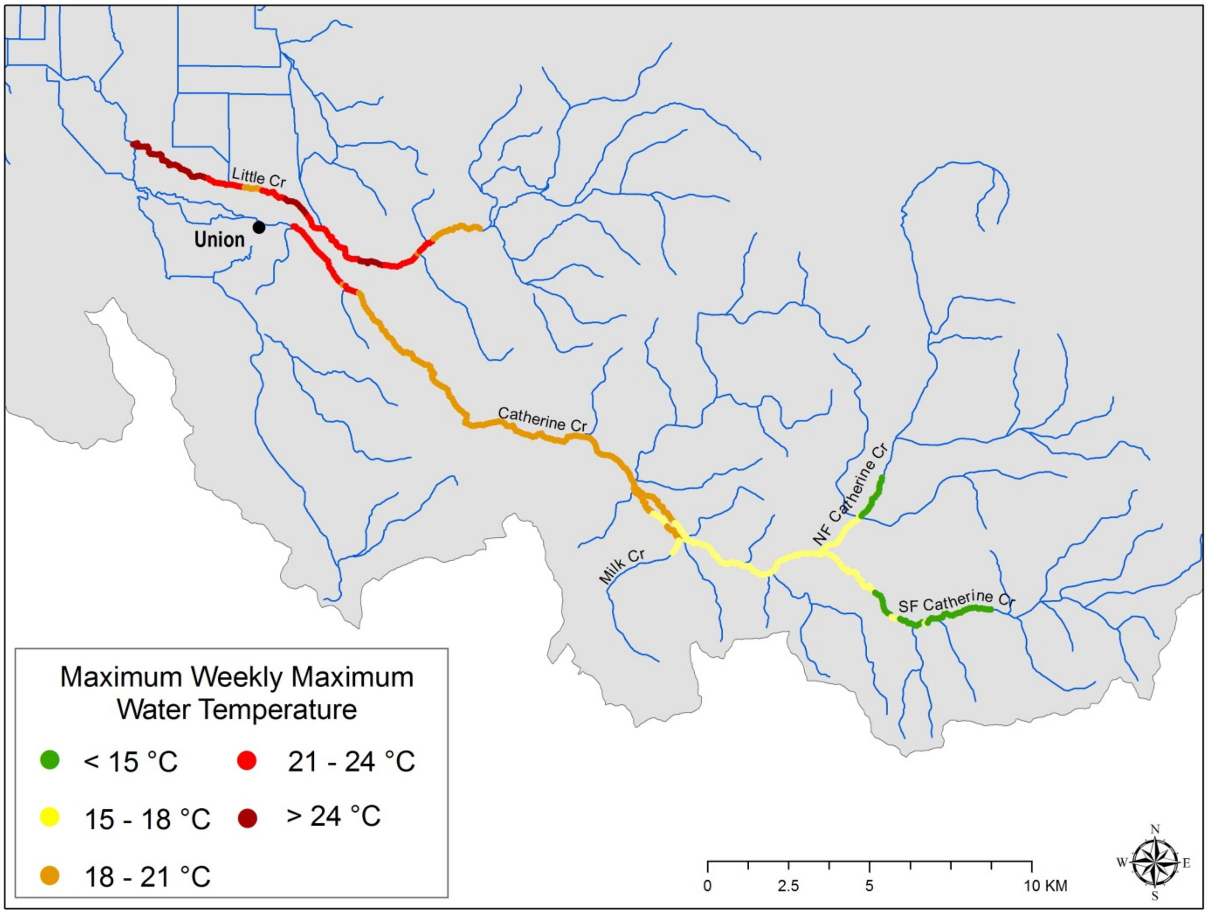

Figure 24. Maximum weekly maximum water temperature (maximum 7-day running average of the daily maximum temperature; °C) in the Upper Grande Ronde River basin during summer 2010. These data were simulated using the Heat Source water temperature model for the period July 10 – September 20.

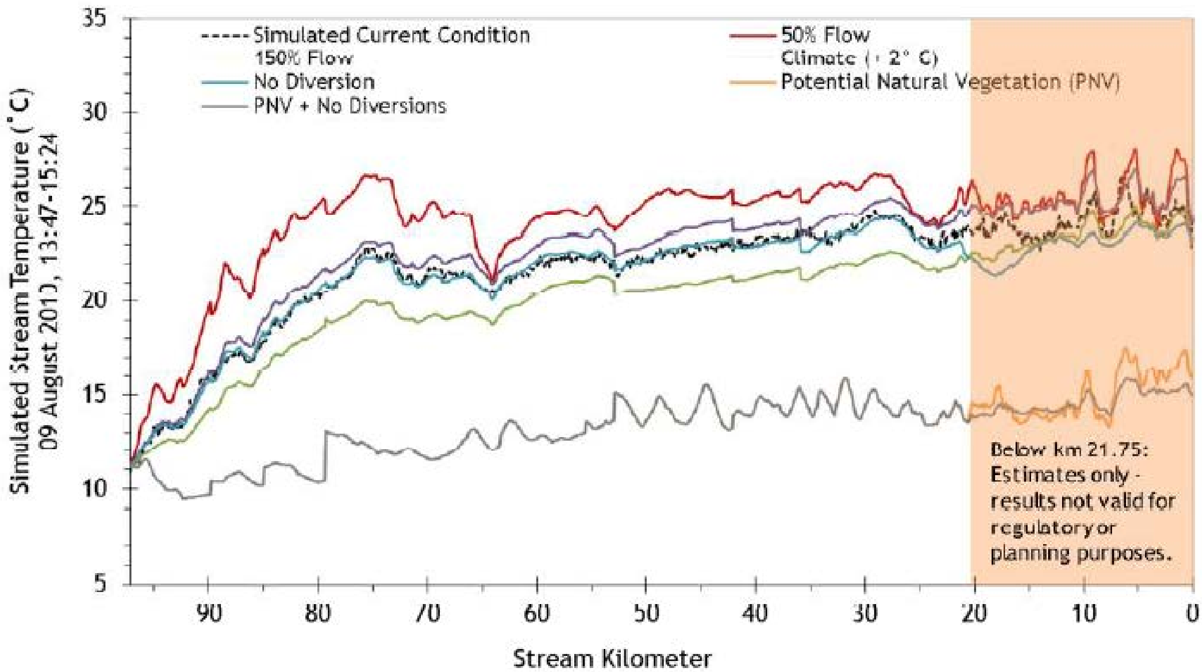

Figure 25. Grande Ronde River simulated scenario results (from WSI).

Work Element P 157: Current and potential riparian vegetation mapping of Catherine Creek

CRITFC staff has been compiling and updating a geodatabase with natural resources data layers over the course of our Accords work (see CRITFC 2010, 2011). These data are being made available to the riparian subcontractors mapping potential natural vegetation (PNV) in Catherine Creek and the Upper Grande Ronde. In addition, the subcontractors have been assembling data for their uses in mapping and agreeing upon a list of needed map layers that will be their standards for mapping. CRITFC is also supplying the riparian subcontractors with LiDAR data and high resolution aerial imagery collected during the forward looking infrared (FLIR) flight in 2010 to aid in their analysis of potential natural vegetation.

Detailed results from the riparian vegetation mapping project will be not be available until project completion in 2014.

Work Element Q 157: Current and potential riparian vegetation mapping of Upper Grande Ronde

See Work Element P 157 above.

Work Element K 161: Present findings and procedures in professional meetings

White, S.M., A. Puls, and T. Sedell. 2013. Exploring the relationships among macroinvertebrates, habitat, and fish productivity for better monitoring outputs. *Speaker and session convener*, Macroinvertebrates and Fish Habitat session, Oregon Chapter of the American Fisheries Society, Bend, Oregon.

Abstract: Freshwater macroinvertebrate (MI) assemblages, especially those collected in the benthic zone of streams, have an established history of providing indicative value of in-stream habitat quality, and demonstrating the effects of restoration activities. Members of the Macroinvertebrate Planning Group (MIPG) of the Pacific Northwest Aquatic Monitoring Partnership (PNAMP) Habitat Data Sharing Project, as well as others, are interested in exploring the use of benthic MIs as an additional indicator of habitat quality and expected fish productivity. This interest stems partially from a need to better assess conditions for ecologically, culturally, and economically important salmonids listed under the Endangered Species Act (ESA). In addition, there is growing recognition that for ESA-listed fish simply assessing the in-stream physical habitat conditions without accounting for their more comprehensive ecology—for example trophic relationships—is over-simplistic and bound to fail. This presentation frames these larger issues and introduces a special session exploring the relationships among macroinvertebrates, habitat, and fish productivity for better monitoring outputs. We present a brief history of bioindicators and their value; highlight examples of using benthic macroinvertebrates and other biota to demonstrate impairment to streams and restoration effectiveness as it relates to fish productivity; and list challenges in pursuing this topic, including a lack of standardized taxonomic effort for MIs in the Pacific Northwest. We provide an overview of how the MIPG is planning to overcome some of these challenges and present likely avenues for future work. As an example, a monitoring program is described for the Upper Grande Ronde River of NE Oregon. One of the objectives of the Upper Grande Ronde project is to demonstrate relationships among land use and watershed characteristics, site-level fish habitat metrics, rearing abundance of juvenile Chinook salmon, and drifting and benthic MIs.

White, S.M., C. Justice, and D. McCullough. 2012. The landscape context of fish-habitat relationships: implications for restoring wood recruitment processes in U.S. Pacific Northwest rivers. *Speaker and session chair*, Landscape Ecology session, European Society for Ecological Restoration, České Budějovice, Czech Republic.

Abstract: Literature on the connections between freshwater biota and river geomorphology have long emphasized the need to link landscape-scale processes to in-stream habitat, yet restoration practitioners have been slow to adapt. This presentation describes a monitoring program in the Pacific Northwest, U.S.A., designed to evaluate whether aggregate restoration activities can positively affect threatened spring Chinook salmon. Commonly cited impediments to salmon survival are high water temperatures, fine sediment in spawning gravel, loss of riparian vegetation, channelization, lack of large woody debris, loss of large pools, and depletion of summer streamflows. However, these factors are often inter-correlated and can be difficult or impossible to tease out using classic univariate statistics. A multivariate ordination was conducted of reach-scale habitat characteristics across eight watersheds in the Pacific Northwest to discover an appropriate landscape-level classification, which in turn helped reveal patterns of anthropogenic impacts on site-level fish habitat. In the Upper Grande Ronde River, estimates of juvenile Chinook salmon density (via snorkeling) were linked to landscape classification and site-level habitat conditions. Across the entire basin, large woody debris and pools positively affected

fish density through direct and indirect pathways, but were also dependent upon mean annual streamflow. These relationships varied across landscape classes, with high elevation mountain reaches behaving differently than lower elevation floodplain and constrained reaches. Results indicated a weak but significant link between riparian condition and recruitment of large woody debris. These findings have direct management implications for guiding the location and type of restoration within the landscape context.

White, S.M. 2012. A holistic approach to salmonid habitat monitoring on Tribal ceded lands in the Columbia River basin. *Invited speaker and panelist*, Native Lands, Native Ways Symposium, The Wildlife Society, Portland, Oregon.

Abstract: We describe a monitoring program in the Upper Grande Ronde River of Northeast Oregon designed to evaluate whether aggregate habitat restoration actions can positively affect ESA-listed spring Chinook salmon. Common impediments to salmon survival are high water temperatures, fine sediment in spawning gravel, loss of riparian vegetation, channelization, lack of large wood in the channel, loss of large pools for adult fish to hold in prior to spawning, and depletion of summer streamflows. The cumulative effects of these factors are difficult to tease apart, and are also intimately connected with the surrounding watershed. Therefore, monitoring approaches that focus on in-stream habitat characteristics alone while ignoring landscape context are likely to provide spurious or irrelevant results. We describe a holistic approach to habitat monitoring on Tribal ceded lands that incorporates in-stream habitat conditions, riparian areas, the surrounding watershed, food webs, and the interactions among these factors. Specifically, we describe methods of in-stream habitat monitoring, the development of a stream temperature model and map of potential natural vegetation, streamflow analyses to determine the importance of groundwater for buffering the effects of climate change, and a pilot food web study—all designed to inform a life cycle model for spring Chinook salmon that will help identify limiting habitat factors and prioritize restoration actions. Preliminary results indicate that incorporating information about watershed position and streamflow are necessary for understanding fish habitat at local scales, such as the relationship between pool formation, large wood, and juvenile salmon rearing density. Other findings indicate that increased shade via restoration of riparian vegetation has a strong potential to cool water temperature well within the preferred tolerance of salmonids. This holistic approach is complementary to the First Foods concept employed by other Tribal organizations in the basin, which draws on principles of traditional ecological knowledge.

Work Element L 183: Produce draft journal publications on fish/habitat relationships

White, S.M., Justice, C., and McCullough, D. (In prep) The landscape context of fish-habitat relationships: implications for restoring wood recruitment processes in U.S. Pacific Northwest rivers. Intended for *Ecological Restoration*.

This paper is waiting on quality control checks and modifications to 2011-2012 CHaMP data before further analyses or writing can proceed.

Abstract: Literature on the connections between freshwater biota and river geomorphology have long emphasized the need to link landscape-scale processes to in-stream habitat, yet restoration practitioners have been slow to adapt. This paper describes a monitoring program in the Pacific Northwest, U.S.A., designed to evaluate whether aggregate restoration activities can positively affect threatened spring Chinook salmon. Commonly cited impediments to salmon survival are high water temperatures, fine sediment in spawning gravel, loss of riparian vegetation, channelization, lack of large

woody debris in, loss of large pools, and depletion of summer streamflows. However, these factors are often inter-correlated and can be difficult or impossible to tease out using classic univariate statistics. A multivariate ordination was conducted of reach-scale habitat characteristics across eight watersheds in the Pacific Northwest to discover an appropriate landscape-level classification, which in turn helped reveal patterns of anthropogenic impacts on site-level fish habitat. In the Upper Grande Ronde River, estimates of juvenile Chinook salmon density (via snorkeling) were linked to landscape classification and site-level habitat conditions. Across the entire basin, large woody debris and pools positively affected fish density through direct and indirect pathways, but were also dependent upon mean annual streamflow. These relationships varied across landscape classes, with high elevation mountain reaches behaving differently than lower elevation floodplain and constrained reaches. These findings have direct management implications for guiding the location and type of restoration within the landscape context.

White, S.M., G.R. Giannico, G.R. and Li, H.W., (in prep). The behaviorscape of salmonids in a wilderness stream: application of a multi-species habitat selection theory. Intended for *Ecological Applications*.

The data for analysis in this paper was not generated under this project, but many commonalities in the research themes exist. To be submitted by second quarter 2012.

Monitor and evaluate the status and trends of juvenile fish productivity in tributaries relative to habitat quality improvement targets.

Are tributary actions achieving the expected biological and environmental improvements in habitat?

Work Element D 157: Snorkel sample to estimate fish densities by reach

As a first order comparison of fish densities by year, basin, and Tier I habitat unit type (see CHaMP protocol), mean juvenile Chinook densities (fish/m^2) are reported in Table 15. Although high variability exists among estimates of mean juvenile Chinook density, some trends are apparent. Notably, juvenile Chinook densities were always highest in slow water (pools), medium in fast water non-turbulent (glides or runs), and lowest in fast water turbulent (riffles, rapids, cascades, and falls). Fish densities were higher in 2011 than 2012 indicating a year effect, and higher in Catherine Creek than upper Grande indicating a basin effect. There are likely more factors in need of investigation to explain the large variability and annual differences in fish densities—such as stream size, position in the watershed, or annual spawner abundance, for example—but these initial comparisons indicate that fish densities at least scale to habitat types in a predictable fashion.

Table 15. Mean juvenile Chinook density by year, basin, and habitat type in the Upper Grande Ronde River and Catherine Creek.

Year	Basin	Channel unit type	Mean juvenile Chinook density (fish/m^2)	Std. Dev.	N
2011	Catherine Creek	Fast water non-turbulent	0.49	0.66	7
		Fast water turbulent	0.16	0.19	15
		Slow water	0.61	0.88	15
	Grande Ronde	Fast water non-turbulent	0.08	0.12	26
		Fast water turbulent	0.08	0.12	34
		Slow water	0.23	0.28	32
2012	Catherine Creek	Fast water non-turbulent	0.23	0.28	9
		Fast water turbulent	0.10	0.19	15
		Slow water	0.49	0.50	15
	Grande Ronde	Fast water non-turbulent	0.04	0.12	33
		Fast water turbulent	0.02	0.06	39
		Slow water	0.09	0.28	38

Findings from exploratory analysis of bivariate relationships indicate that strong correlations (as determined by MIC value, Reshef et al. 2011) exist between landscape-level intrinsic characteristics, human pressures, site characteristics, and aquatic biota, with most relationships having a high degree of non-linearity (Table 16). Fish were correlated slightly more strongly with intrinsic watershed factors and site-level characteristics than were benthic macroinvertebrates (BMIs), but BMIs responded more strongly to human pressure. Fish were only weakly correlated with BMIs (best MIC=0.46), and the best relationship between drift biomass density and any potential variable was also weak (best MIC = 0.40). This method will provide a valuable tool for discovering novel relationships in large datasets, and

additionally providing appropriate covariates in subsequent fish-habitat relationships when contextual landscape factors need to be accounted for.

Table 16. Best relationships based on highest maximal information coefficient (MIC) value for relationships among fish, habitat, and benthic macroinvertebrates (BMIs) in the Upper Grande Ronde and Catherine Creek. All correlations are highly significant with uncorrected *p*-values <0.001.

Response type	Predictor type	Best response	Best predictor	MIC-value	MIC-p^2 (nonlinearity)
Fish	Intrinsic	Ab. Chinook - riffles	Mean annual flow	0.76	0.58
	Human-influenced	Ab. Chinook - riffles	Percent forest cover	0.54	0.48
	Site-level habitat	Ab. Chinook - site	Thalweg depth profile	0.58	0.50
BMIs	Intrinsic	Piercing Herbivore	Longitude	0.75	0.62
	Human-influenced	WA_inv_TempC	July max temperature	0.60	0.20
	Site-level habitat	WA_inv_TempC	Large wood/100m (bankfull)	0.56	0.37
Fish	Drift or BMI	Dens. Steelhead - riffles	CollectorFilterer	0.46	0.41
Drift	BMIs	Drift biomass density	Shredder	0.35	0.34
	Any	Drift biomass density	Thalweg-centerline ratio	0.40	0.38

However, bivariate correlations do not account for interactions among more than two variables, and ecosystems are inherently complex, with multiple levels of variables interacting simultaneously. For example, in the Upper Grande Ronde River of NE Oregon, juvenile Chinook salmon rearing densities were directly affected by large woody debris and abundance of pools, but also indirectly through the influence of large woody debris and stream flow on pool formation (McCullough et al. 2012). In 2012, we expanded on this original model to include a benthic macroinvertebrate index—the Grande Ronde index of biotic integrity (GR-IBI), which is based on relative abundance of environmentally sensitive macroinvertebrate taxa.

With the inclusion of another year's data, the 2012 model verified earlier findings that large woody debris had direct positive effects on fish density, but also indirect positive effects through formation of pools (Figure 26). These mechanistic, site-scale relationships were dependent upon spatial context—with the drainage area upstream of a site having the largest effect on fish density, and also having a large influence on the site-level habitat characteristics. Benthic macroinvertebrate (GR-IBI) scores increased with increasing large wood. The GR-IBI score responded more strongly to large woody debris at the site level than did fish, indicating that macroinvertebrates may be a better near-term response variable showing habitat improvements, as compared to fish densities. GR-IBI scores and fish densities were positively correlated, but only weakly.

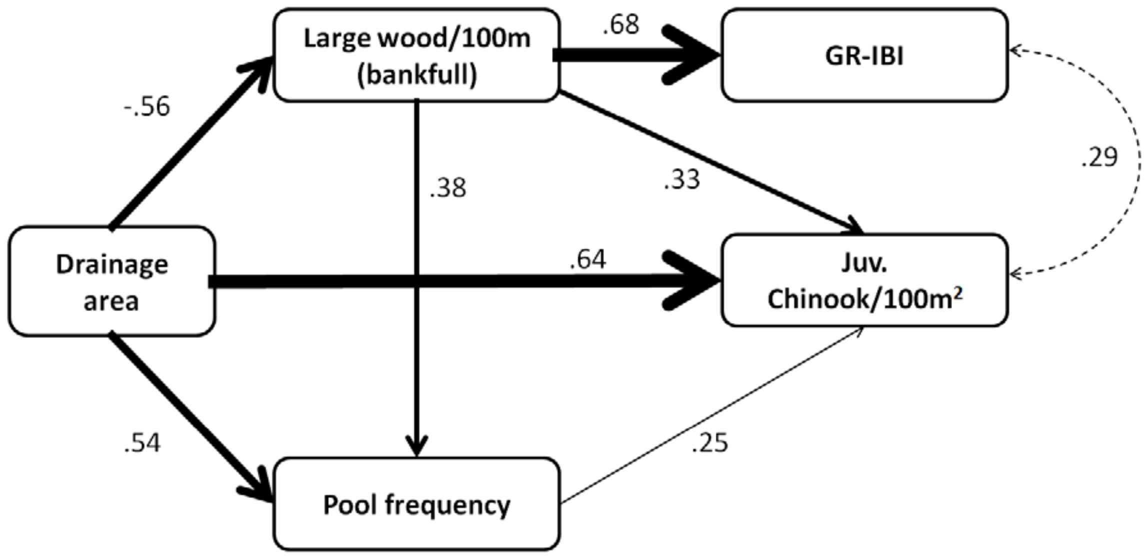

Figure 26. Structural equation modeling results for relationships among drainage area, large wood, pools, fish density, and a benthic macroinvertebrate index (Grande Ronde Index of Biotic Integrity, GR-IBI). Direction and width of arrows indicate direction of hypothesized causal influence and strength of relationship, respectively. Dashed, double headed arrow indicates correlation with no assumed causal relationship. Values at arrows are partial path coefficients.

Coordination and Data Management RM&E

Actively support the coordination and standardization of regional and Program monitoring efforts with other federal, state, and tribal monitoring programs including the development and adoption of standard requirements for metrics, sample designs, data collection protocols, data dictionary, meta-data, and data access.

How has regional coordination supported communication or the development and adoption of standard requirements for metrics, sample designs, data collection protocols, data dictionary, meta-data, and data access to support Fish and Wildlife Program strategies at http://www.cbfish.org/ProgramStrategy.mvc/ or how regional coordination support prioritization of habitat restoration or operations of hatchery facilities

Work Element B 191: Coordinate with regional agencies, tribes, and landowners

Scientists and other staff on this project have significantly contributed the coordination and standardization of regional monitoring efforts by actively participating in several working groups beyond the scope of this individual project (described below). In addition, the first annual inter-tribal habitat monitoring workshop was hosted under this project, which included representation from CRITFC's four member tribes. CRITFC continues to engage with landowners in the Upper Grande Ronde and Catherine

Creek basins through direct communication for access to private property and communication of site-specific findings via an annual letter of thanks.

Columbia Habitat Monitoring Program (CHaMP) – Project staff continue to actively participate in the development and refinement of the CHaMP protocol. Project scientists have had significant input into which habitat characteristics are quantified, and how those characteristics will be measured by crews in the field. We have also led efforts to conduct quality control checks on how CHaMP metrics are calculated. At the November 2012 post-season CHaMP workshop in Portland, project scientists gave a presentation on the comparison between solar insolation derived from Heat Source modeling vs. on-site measurements using the Sun Eye device. CRITFC field technicians and other staff continue to attend "CHaMP Camp," an 11-day training in habitat protocols conducted annually in June.

FCRPS Adaptive Management Implementation Plan (AMIP) – CRITFC's habitat and population modeling efforts are being coordinated with state and federal agencies. AMIP coordinates life cycle modeling efforts for recovery planning required by the 2008 BiOp for all Columbia River listed stocks. CRITFC is a steering committee member of AMIP, and has been coordinating Catherine Creek life cycle model development with NOAA and ODFW. CHaMP efforts are also an integral part of AMIP, and those protocols are the basis for the habitat component of CRITFC modeling efforts.

FCRPS BiOp Expert Panel and Implementation Prioritization Strategy – Project scientists remain involved in the Science Advisory Committee (SAC) for the Upper Grande Ronde and Catherine Creek basins. With oversight by the BPA, the SAC provides data for decision making and advises the prioritization of restoration projects based on scientific principles. Involvement with this group provides the opportunity to have a direct impact on where, when, how much, and what kind of restoration occurs in the basins. Other organizations represented on the SAC include CTUIR, ODFW, NOAA, USFS, and Grande Ronde Model Watershed.

Pacific Northwest Aquatic Monitoring Partnership (PNAMP) – Project scientists are actively engaged with PNAMP staff in an effort to make use of the past and existing benthic macroinvertebrate (BMI) data collected in the Pacific Northwest, in addition to shaping the way BMIs are collected in the field, how they are processed in the laboratory including standard taxonomic effort, and how data can be shared across organizations. In February 2013, CRITFC & PNAMP co-hosted a special symposium at Oregon Chapter of the American Fisheries Society in Bend, titled "Macroinvertebrates and Fish Habitat Quality." The symposium focused on the linkages between fish habitat, macroinvertebrates, and fish productivity, and consisted of seven presentations and a panel discussion with experts throughout the region (see meeting program: http://orafs.org/wp-content/uploads/2013/02/ORAFS_2013.pdf).

Integrated Status and Effectiveness Monitoring Program (ISEMP) – Project scientists have engaged in several workshops and conference calls with ISEMP staff to facilitate the sharing of fish-related data across the Columbia basin. In January 2013, project scientists participated in an ISEMP workshop titled "Monitoring Fish Populations: Study Designs, Data and Analysis Review." Through interaction with ISEMP staff, CRITFC was able to gain access to regional fish datasets that will be important for future analyses.

Tribal Habitat Workshop – On 15th -16th January 2013, Project scientists convened a meeting of all key fisheries and natural resources staff from the four CRITFC member Tribes plus CRITFC in order to (a) develop a strong tribal voice on habitat conservation, (b) share lessons learned from past and current fish habitat monitoring, (c) understand regional monitoring needs, and (d) consider opportunities to coordinate future tribal fish habitat monitoring efforts. The participants were key fisheries and natural resources staff from the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), Confederate Tribes of the Warm Springs Reservation of Oregon (CTWSRO), Yakama Nation, and Nez Perce Tribe,

especially those engaged in fish habitat monitoring. Habitat scientists and policy experts from CRITFC, acting as conveners, directed the workshop discussion to assemble information about monitoring programs conducted by all tribal staff and relate it to regional efforts and needs. In addition, other agencies (NOAA, BPA, ODFW, etc.) provide relevant input. Project staff received several positive comments and notes of appreciation for the conference; plans for workshops in future years were discussed.

Work Element G 156: Review and refine monitoring protocols and statistical designs

Since the spring of 2011, CRITFC has been an active participant in the CHaMP program, providing detailed reviews and feedback on field collection and analysis methods, coauthoring various sections of the field protocol, assisting with crew training and logistics, and presenting data analyses and findings at CHaMP workshops. We believe these efforts have helped to improve the accuracy, repeatability, and validity of the data collected by other CHaMP participants and have strengthened our ability to assess status and trends in stream habitat conditions over a broad regional scale.

Work Element H 160: Develop and manage fish habitat condition database

Project staff continues to develop a comprehensive database of in-stream and landscape-scale habitat characteristics and biotic conditions that can be used for analyses of fish-habitat relationships. In 2012, we made significant advances in acquiring new datasets and improving existing ones (Table 5).

Also in 2012, advancements to the raw flow and temperature database (raFT) involved various data updates, quality assurance and quality control measures and automated data reports. The data updates included uploading data products collected or measured throughout the 2012 monitoring year. The raFT was established in 2009 using a relational database model with a two-dimensional structure of rows and columns to store data within Microsoft SQL Server 2008 R2 installed on a virtual machine with Windows Server 2008 Operating System. In addition to the yearly automated reports, other requests for data stored in raFT occurred. These data have been shared with the comprehensive regional database, which is managed by USFS at the Boise Location as well as with USGS and others as requested and approved by sharing agreements.

Snorkel Survey and Human Disturbance (SSHD) data collected during the 2012 field season by ODFW and CRITFC in the Grande Ronde Basin has been included in the SSHD. Updates to the SSHD in 2012 included creating separate tables for 2012 data to incorporate differences in the data collection method from the previous years' methods. For example, data was structured to incorporate more snorkelers, a new table of only fish counts was added and dominance of fish species was determined by reach instead of by channel unit.

Synthesis of Findings: Discussion/Conclusions

Tributary Habitat RM&E

Monitor and evaluate tributary habitat conditions that may be limiting achievement of biological performance objectives.

What are the tributary habitat limiting factors (ecological impairments) or threats preventing the achievement of desired tributary habitat performance objectives?

In the Accords (2008) (i.e., a memorandum of agreement between the Columbia River Tribes and three federal Action Agencies that resulted in funding of habitat restoration projects to improve productivity and abundance of ESA-listed Columbia River salmon) it was estimated that the current percentage function (i.e., an average condition of fish habitat, owing to the percentage survival that would be attributable to the individual effect of each of the limiting factors, measured against their optimal condition) of the Upper Grande Ronde River and Catherine Creek, respectively, was 34% and 44%. It was also estimated that the absolute change in percentage function in a 10-year period could be 10% for each watershed. The identified primary limiting factors for the Upper Grande Ronde were in-channel characteristics, riparian/floodplain, sediment, and water temperature. Water temperature was noted as the most important limiting factor. In Catherine Creek the primary limiting factors were identified as in-channel characteristics, riparian/floodplain, and water temperature. For Catherine Creek, in-channel characteristics and water temperature were equally limiting, but were not nearly as limiting as water temperature in the Upper Grande Ronde. It was estimated at the time of publication of the Accords that each limiting factor could improve by an absolute 10% in level of function.

As of the conclusion of the 2012 field season, we have two years of data collected using the combination of CHaMP protocol and the additional CRITFC monitoring protocols for monitoring. Logical questions to attempt to answer within our monitoring program include:

(1) Are the limiting factors identified in the Accords estimates still the most important limiting factors?

(2) Are there any other habitat limiting factors that have been revealed through monitoring that are as important or more important than those already noted?

(3) Is the percentage habitat function identified through intensive monitoring comparable to the rough estimates made in the Accords?

(4) Are there any better means to identify current level of function?

(5) What means are there to estimate the likely percentage improvement in habitat function based on current in-stream habitat and environmental condition, planned habitat restoration actions, and what is known about the linkage between land use, environmental condition, and in-stream habitat trends?

After the first two years of our full monitoring program, we have gained significant information about the primary habitat limiting factors in the two study basins. We singled out water temperature, fine sediment, and streamflow as three key limiting factors, based on a variety of sources. In addition, we have monitored other important habitat factors that could potentially be limiting. For example, we are monitoring pool volume and frequency, large woody debris, streambank overhang area and other fish cover elements, and food availability. At the present time, we cannot make a definitive statement that

water temperature, fine sediment, and streamflows are more or less important than the other habitat factors. We have selected all these factors to monitor on the annual and rotating panel design so that we could assess the rate of change in these factors with time. We plan to also assess the changes in relation to known levels of restoration actions. Gaining a comprehensive database of intensity and timing of restoration actions will be an important piece of information needed to compare against aggregate restoration rates. This task has been identified as a regional need, but exceeds our current funding and goals.

As described in more detail in our annual report, the full life cycle model for spring Chinook is one of our primary goals. This model will make use of our spatially explicit and spatially balanced representation of the stream system habitat quality supporting each listed population to estimate population trends in relation to habitat trends. We have made significant progress in development of this model in 2012. (Appendix A). However, at this early stage of our research, we are not able to make population predictions based on specific current instream habitat conditions, watershed conditions, and expected habitat actions.

The life cycle model derives its input data from a number of subcomponent models that are under development. The core submodels (Table 17) include the Heat Source water temperature model, sediment delivery model, fine sediment-fish survival, water temperature-fish survival model, natural potential riparian vegetation, macroinvertebrate drift, and low flow models. We described in some detail, progress on each of these components in Methods and Results for 2012.

The Heat Source water temperature model was calibrated for an extended period during the summer rearing period. This model will allow prediction of water temperatures for each 100 m linear distance along the mainstem of the Upper Grande Ronde, Catherine Creek, and their major tributaries. Availability of detailed hourly water temperatures for each of these points in the stream systems providing rearing for spring Chinook allowed prediction of survival (and in future work, may allow us to predict site-specific growth rates) on a continuous basis.

A next step we plan to make with the Heat Source model is to explore site specific restoration of riparian vegetation on the longitudinal temperature profile of the streams. Existing LiDAR data provide the current riparian effective shading values in the model. By using the model experimentally to add shade to vegetation-limited stream reaches, we will be able to assess the potential for improvement in water temperature regime, and subsequently, the potential improvement in juvenile survival.

Table 17. Individual habitat model components whose outputs are used in the overall spring Chinook life cycle model.

Habitat model	Data sources	Model output
Heat Source Temperature Model	LiDAR, FLIR, stream temperature & flow, stream channel morphology, riparian condition	Spatially-explicit predictions of water temperature under various land use & restoration scenarios
Sediment Delivery Model	Hillslope and channel gradient, road density, grazing intensity	Identification of at-risk areas in the watershed where sediment is likely to have detrimental effects on fish
Fine Sediment-Fish Survival	Literature effects of fines, field tests of incubation survival	Functional relationship between fine sediment values measured in the field and theoretical fish survival
Water Temperature-Fish Survival	Literature effects of water temperature on survival and growth	Functional relationship between stream temperature measured in the field and theoretical fish growth and survival
Natural Potential Riparian Vegetation	Historical vegetation maps, geology & soil maps, aerial photos, valley morphology, climate data	Map of current & historical vegetation as a reference condition to compare against alternative riparian management scenarios
Macroinvertebrate Drift	Drift samples, riparian condition, upstream land use, stream substrate, water temperature	Spatially-explicit predictions of energetic resources available to fish
Low Flows	USGS flow data, watershed area, geology, mean annual precipitation, drainage basin morphology	Spatially-explicit predictions of stream reaches vulnerable to detrimental low flows

Progress that we reported on mapping riparian potential natural vegetation (PNV) and the work to be done under this mapping effort in the coming two years will be used to guide restoration efforts that require riparian planting. Reliable maps of PNV are essentially considered a model of the riparian or streamside zone because they are based on a combination of existing plot data and ecological knowledge relating individual species to key environmental gradients (e.g., climatic region, valley width, soil types, and channel slope). PNV maps will provide key input data to use in modeling (1) potential effective shade in highly disturbed stream reaches, (2) sediment yield to stream channels based on streambank stability and rooting potential of PNV communities, and (3) potential terrestrial macroinvertebrate inputs to drift, measured as biomass and diversity. PNV maps could also be used to make inferences about the food base relative to assumed differences in allochthonous litter input rates and litter diversity (coniferous/deciduous balance).

We explored a method for utilizing hourly water temperatures to cause Chinook mortality. This mortality estimate was based on multiple consecutive days of exposure to adverse temperature conditions sufficient to result in cumulative thermal doses that cause mortality of 50% of the population. This modeling work revealed that adverse water temperature conditions begin to be found at least as far upstream as the mainstem Grande Ronde above the mouth of Fly Creek, as well as above the mouth of Beaver Creek. From those locations downstream, the water temperature summary data from our

temperature loggers show that maximum and average temperatures become increasingly extreme so that percentage population mortality is greater.

The biological response to habitat quantity and quality was assessed using juvenile fish abundance and macroinvertebrate data. Fish were monitored using snorkel and electrofishing surveys to count numbers and sizes by species for all salmonids, and presence/absence for all non-salmonids at all CHaMP survey sites. Benthic macroinvertebrate samples were taken at corresponding CHaMP sites and their indicator values compared with fish and habitat metrics. These biological responses reflect the habitat quantity and quality of the channel units from which the samples are taken as well as the conditions of the upstream channel, its riparian or streamside zone, and the upstream watershed. For fish response in pool channel units, the fish species, sizes, and densities observed are related to the quantity and quality of the channel unit. The quantity is a function of the pool area and volume. The quality is a function of the substrate composition, cover (boulders, wetted LWD, overhanging vegetation or wood, overhanging banks, and artificial structures), water temperature, water chemistry, streamflow regime (peak flow and low flow characteristics) and riparian cover (related to litter input composition and quantity, and terrestrial macroinvertebrate inputs).

We will soon be in a position to explore the correlation between fish densities and water temperatures at all survey sites. Information such as this will likely reveal some sublethal effects of thermal loads. These longitudinal trends in fish density related to water temperature trends will need to be distinguished from effects of other habitat characteristics, such as LWD and other cover elements. Recent analyses indicate significant relationships between amount of LWD, pools, and Chinook densities (Figure 26). In addition, fish densities appear to be related to mean annual flow, forested area, thalweg depth, and channel unit type (Table 15 and Table 16). Many previous studies have found that densities of salmonids decline steadily with increasing water temperatures until densities become near zero when maximum temperatures reach approximately 24°C.

An important aspect of our monitoring program is biological sampling, which provides information on the distribution and abundance of fish and macroinvertebrates, food sources for fish, and biotic indices that relate to watershed health. Food availability will be related to macroinvertebrate drift transport rates. Currently, benthic macroinvertebrate data are not available through the CHaMP program. In the CRITFC program we have collected benthic macroinvertebrate samples and reported basic indices. CRITFC also has participated in recent discussions with regional experts about the linkages between drift and benthic macroinvertebrate samples. We plan to integrate the temperature logger data and site-specific Heat Source hourly temperature data with food availability data to estimate fish growth rates through the use of bioenergetic modeling.

We reported continuing progress in assessing the status of subsurface fine sediment concentrations in spawning gravels in study areas. We demonstrated significant correlations between surface fine sediments (measured by the CHaMP protocol) and subsurface fine sediments (measured with the CRITFC protocol). These results lend support to the ability to conduct rapid analyses of surface fine sediment conditions as a means of identifying important trends in subsurface fines. Subsurface fine sediment concentrations provide a known connection to salmonid incubation survival rates. Because subsurface fines are more difficult and time-consuming to monitor, a good relationship to subsurface fines would help establish threshold values that could serve as uniform restoration targets for various stream sites. It would likewise provide an essential linkage that would allow CHaMP surface fines data to be used to infer incubation survival rates. We need to extend the exploration of the relationship between surface and subsurface fines to include the influence of channel gradient. If channel gradient affects the relationship between surface and subsurface fines, restoration thresholds may need to vary by gradient class.

We reported progress in mapping riparian and overall watershed road densities. The current GIS road layers are derived from the USFS and TIGER roads data. Neither of these layers is sufficiently comprehensive to be used alone to provide a reliable estimate of road density. Merging these layers is more than a matter of simply combining the line work of each because lines representing identical road segments vary greatly between map sources in accuracy of placement on the ground, necessitating that duplicate road segments be deleted and some segments repositioned to more accurately represent true location. Most striking was the magnitude of roads present on the landscape and not mapped by either mapping system.

The road density relative to every stream study reach will be analyzed by proximity to the reach. We hypothesize that levels of surface and subsurface fines in the study sites will be related to magnitude of sediment sources. The sediment yield model that we will construct will be either a correlative or predictive model that is a function of road density, proximity of the roads to the study site, condition of the streamside zones (vegetation coverage or bare ground in streamside zones), proximity of these streamside vegetation zones to the study sites, rooting potential (current and potential) for the streamside zones, and livestock levels by subwatershed and proximity to study sites.

Our CRITFC/USGS cooperative agreement has made significant progress in developing a model of low flows in the Upper Grande Ronde and Catherine Creek basins. This model is nearing completion and is based on available long-term stream gauge data from around the region in similar climates and watershed characteristics that are used predictively. Watershed conditions were developed from a combination of USGS StreamStats, NVision's BasinTools, and numerous GIS data layers present in the CRITFC geodatabase that have been documented extensively in our two previous annual reports (McCullough et al. 2011, 2012).

This model will link watershed intrinsic characteristics to low flow potential. In addition, the long-term trends in low flows linked to climate change will become critical to long-term viability of spring Chinook populations. Change in air temperature spatial distribution and depth of snowpack will lead to changing patterns of stream runoff and summertime low flow conditions. Some streams will be more or less naturally resistant to these climatic trends due to the stability of their summer low flows. This inherent potential for resistance to low flow variation can be observed in differences in recession rates during rain-free periods and in ratios in low flow statistics, such as Q7L2 and Q7L20 (7-day low flows with 2- and 20-year recurrence intervals) (Orsborn 1990)(Figure 21). Due to geologic or alluvial valley fill characteristics, some small streams are more resistant to annual variations in meteorological conditions in their influence on low flows, consequent water temperature extremes, and shrinkage in useable rearing or spawning area in August-September.

Are tributary actions achieving the expected biological and environmental improvements in habitat?

Our project is not primarily an action effectiveness monitoring project. Unless by chance we have our GRTS-selected monitoring sites established in locations where future restoration actions take place so that we have a pre-restoration baseline established and future monitoring can follow trends at a site, it may not be possible to assign improvements in habitat conditions to any specific action. However, our project does monitor trends in a wide array of habitat conditions. This can be related to the aggregate restoration actions from past and ongoing actions throughout a watershed upstream of monitoring sites. It may be that the strength of many actions will be related to proximity to sites where monitoring takes place, as well as the cumulative impact of all upstream actions. It is also likely that by classifying restoration actions by the type of limiting factor that they address we will be able to detect changes in specific habitat conditions most related to the action. For example, because fine sediment in spawning gravel or filling pools is taken as one of our most limiting factors, those actions that limit sediment yield

to stream channels will be most effective in restoring spawning gravel quality/quantity as well as pool depth, volume, and frequency. The actions that have the greatest likelihood of improving fine sediment and pool-related conditions will be those cumulative actions that address the combination of (1) road density, (2) livestock access to stream channels, (3) riparian vegetation density and maturity, or similarity to PNV conditions, (4) and general level of land disturbance that creates bare ground.

Although our project has potential to contribute to answering questions about (1) whether cumulative actions are resulting in an overall improvement in habitat conditions, (2) the rate of improvement in habitat conditions, and (3) the likely impact of habitat improvement trends to the life stages of spring Chinook and future population trends, it is still premature to draw definitive conclusions. It is well-known that the effects of restoration actions can take years to manifest in streams such as the Grande Ronde. Even if the percentage improvement in habitat productivity occurs that is described in the Accords document (an absolute 10% improvement within 10 years), it is doubtful that the level of monitoring currently funded will be sufficient to show this small an improvement in a 2-year period (i.e., the number of years of CHaMP monitoring so far). Also, because the level of effort applied to habitat restoration basin-wide may be less than needed to achieve the desired productivity targets, it would be even more difficult to detect smaller percentages of improvement. It may be easier to show significant changes in shorter timeframes for site-specific restoration directed to certain proximal limiting factors, but the more important factors controlling overall production are the basin-wide habitat conditions. For example, water temperature may change slightly from a site-specific action, but in most respects, the actions directed to the entire basin upstream of the monitoring site are more important. Water temperature trends on an entire stream network level will have the greatest potential to reveal improvements due to the precision of temperature loggers. The Heat Source water temperature model will be vital as a tool for comparing future water temperature trends under different scenarios such as climate change, restored riparian vegetation, or changes in streamflow that may occur over a longer timeframe than is afforded under this Accords project. It also provides a necessary tool to allow us to assess annual CHaMP water temperature daily data to ascertain whether apparent trends are caused by improvements in riparian condition or merely by annual variation in meteorological condition.

Coordination and Data Management RM&E

Actively support the coordination and standardization of regional and Program monitoring efforts with other federal, state, and tribal monitoring programs including the development and adoption of standard requirements for metrics, sample designs, data collection protocols, data dictionary, meta-data, and data access.

How has regional coordination supported communication or the development and adoption of standard requirements for metrics, sample designs, data collection protocols, data dictionary, meta-data, and data access to support Fish and Wildlife Program strategies at http://www.cbfish.org/ProgramStrategy.mvc/ or how regional coordination supports prioritization of habitat restoration or operations of hatchery facilities

Regional coordination and inter-agency cooperation and oversight have aided our project in significant ways. In this report we reviewed in detail CRITFC's participation in regional processes and coordination with other agencies and tribes. We refer the reader to those specific details in the Results section. To

recap, we are involved in coordination and data management with the following partners and working groups:

- Columbia Habitat Monitoring Program (CHaMP)
- FCRPS Adaptive Management Implementation Plan (AMIP)
- FCRPS BiOp Expert Panel and Implementation Prioritization Strategy for the upper Grande Ronde and Catherine Creek
- Pacific Northwest Aquatic Monitoring Partnership (PNAMP) Benthic macroinvertebrate planning group
- Integrated Status and Effectiveness Monitoring Program (ISEMP)
- CRITFC member tribes, most recently via 2013 January Tribal Habitat Workshop

CRITFC, although funded by the Accords to monitor habitat status and trends in the Upper Grande Ronde River and Catherine Creek basins, is a participant in CHaMP, a regional effort to develop uniformly applied data collection protocols. CRITFC has been an active participant in CHaMP in many ways. CRITFC has (1) contributed to protocol development by recommending new or revised methods, revisions to existing elements of the protocol, new and improved equipment, (2) made recommendations to data analysis, (3) made recommendations to RBT improvement, (4) pointed out problems with GIS analysis of Total Station survey data, (5) contributed to methods for QA/QC, (6) given presentations on the successes in application of various methods and data analysis procedures, and (7) participated in regional CHaMP and ISEMP meetings that are attended by other regional agencies.

CRITFC has benefited from this regional process (CHaMP) from (1) its assistance in developing GRTS sample site selection and creating a balance of sites between CRITFC and ODFW that meets the needs for spring Chinook and steelhead sampling, (2) assistance with application of GIS analysis and the custom tools developed for the Total Station survey data, (3) CHaMP providing the infrastructure for development of the RBT tool that, eventually, will facilitate computation of many channel metrics that will streamline habitat surveys, (4) the programming of the data logger used to collect field data, (5) the infrastructure provided to upload data to the cloud, store it, and run diagnostics to perform initial QA procedures, (6) the CHaMP website that can be used to access data from various sampling years and data from other sites.

CRITFC benefits from the systems built by PNAMP that house the monitoring metrics and protocols used regionally. This serves as a system for monitoring method cataloguing and metadata that facilitates developing more uniform methods and protocols (i.e., monitoringmethods.org).

CRITFC has been participating in the regional AMIP process by working on a life cycle model with NOAA and ODFW. This provides the tribes a means to become involved in application of habitat and fish population data to monitor potential trends in list salmon populations.

CRITFC has participated regionally by providing advice to expert panels charged with evaluating progress in address limiting factors. Some of our contributions have included 1) providing GIS analysis, maps, and monitoring data useful for prioritizing restoration actions, 2) development of a life-cycle model to assess how measured or potential habitat improvements will result in impact ESA-listed Chinook populations, and 3) collection and analysis of macroinvertebrate data in support of a food web study for the Upper Grande Ronde River basin, which has been recommended by the ISAB, and 4) development of a Heat Source water temperature model to aid in understanding the spatial patterns in water temperature across the Upper Grande Ronde and Catherine Creek basins and assess potential effects of future climate change and riparian restoration actions on stream temperature and stream biota.

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Appendix A: Catherine Creek life cycle model with policy optimization

Robert B Lessard (CRITFC) and Casey Justice (CRITFC)

Introduction

Fisheries scientists and habitat specialists at the Columbia River Inter-Tribal Fish Commission (CRITC) have been actively engaged in the monitoring of salmon spawning and rearing habitat and the evaluation of population recovery strategies. Grande Ronde basin Chinook salmon populations have declined significantly from historical levels. Spawning and rearing habitat are thought to be limiting factors to the recovery of the populations. As part of a number of Columbia River Accords projects, CRITFC scientists have been developing methods and tools to evaluate population recovery strategies. Consistent with the Columbia Habitat Monitoring Program (CHAMP), CRITFC habitat scientists have been conducting habitat surveys in Catherine Creek, Upper Grande Ronde, and the Minam rivers. Data have been collected on a variety of stream characteristics including, but not limited to: 1. flow, 2. temperature, 3. fine sediment, 4. spawning area, and 5. coarse woody debris. The CHAMP protocol provides the rational for collecting data on these and other characteristics. Attributes are monitored to ascertain spatial and temporal variability according to a rotating panel system. Population data have been collected by the Oregon Department of Fish and Wildlife.

As part of recovery planning, CRITFC's goal is to develop a version of a life cycle model that not only reconstructs population trends consistent with changes in freshwater habitat conditions, but also serves as tool for policy gaming. The model consists of three modeling components: 1. a population model, 2. a habitat model, and 3. a policy optimization model. The approach also embeds functional relationships at an additional level of complexity, i.e., the prediction of changes in habitat conditions as a direct result of management actions. For example, if the population model predicts productivity at the fry to parr stage to be sensitive to water temperature change, and if water temperature is affected by shade from tree canopy closure, then changes to riparian forest cover would indirectly predict productivity. Therefore, changes to riparian forest cover would impact population recovery. The model described here seeks to quantify the relative recovery potential from measurable management actions. One example would be riparian planting. Other examples of recovery actions include changes to stream flow conditions, which could be achieved by purchasing water removal rights and decommissioning barriers. The key element of the CRITFC model is the ability to quantify the degree to which population recovery improves with investment in critical habitat improvements. The model will be used to quantify the relative benefit of alternative management actions, both in magnitude and spatial distribution.

Population model description

The model CRITFC is developing currently focuses on the Catherine Creek population of the Grande Ronde River basin. It predicts abundances of spawners, eggs, emerging fry, juveniles rearing in different reaches of the river, parr that migrate downstream in fall to overwinter, later migrating parr, smolts, fish in the ocean, and returning adults. A simplified schematic of the model is shown in Figure A - 1. Fish return to spawn after a number of years rearing in the ocean, which is determined probabilistically such that the age distribution of returning adults is consistent with the observed age distribution. Throughout the life history, survival from one stage to the next is predicted with a Beverton-Holt (BH) survival function.

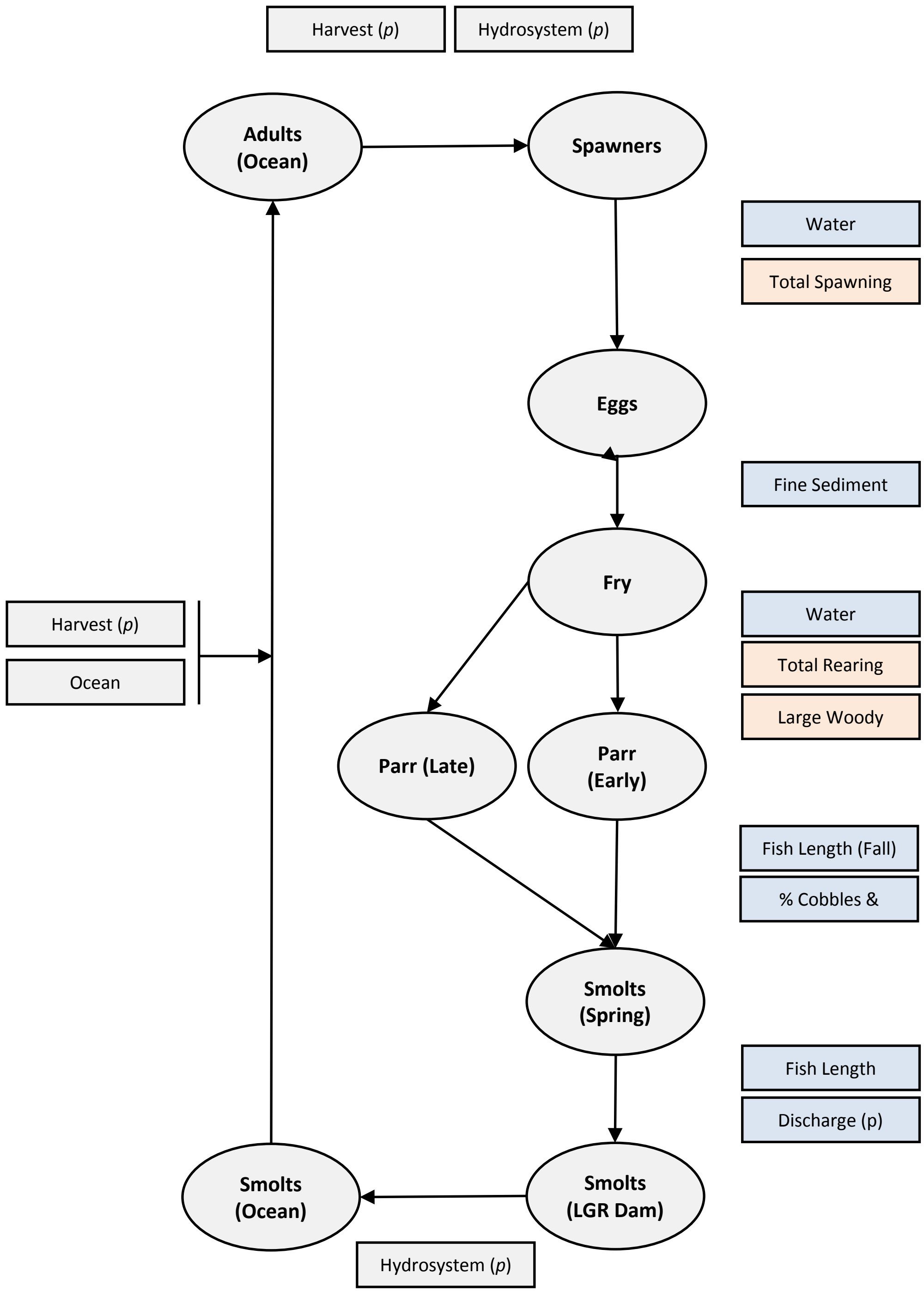


Figure A - 1. Full life cycle diagram. Each life stage has key environmental variables influencing productivity and capacity.

Figure A - 2 shows a more detailed perspective of the rationale behind predicting survival at the spawner to egg stage. Dynamically, survival is predicted by density-dependent and density-independent factors that are influenced by environmental conditions. The proximate conditions are water temperature and total spawning area, but those are driven by static factors such as geomorphic conditions that may be categorized by defined channel types or by dynamic processes such as forest growth and climate change. Forest succession has the effect of shading streams and providing coarse

woody debris that enhances spawning area. Climate change can affect discharge and temperatures. Ultimately, management actions can have an impact on those dynamic processes and can be viewed as drivers in the prediction of future environmental conditions as they pertain to the prediction of productivity and capacity, and, ultimately, survival. Thus, we can view management actions as predictors of future population trends.

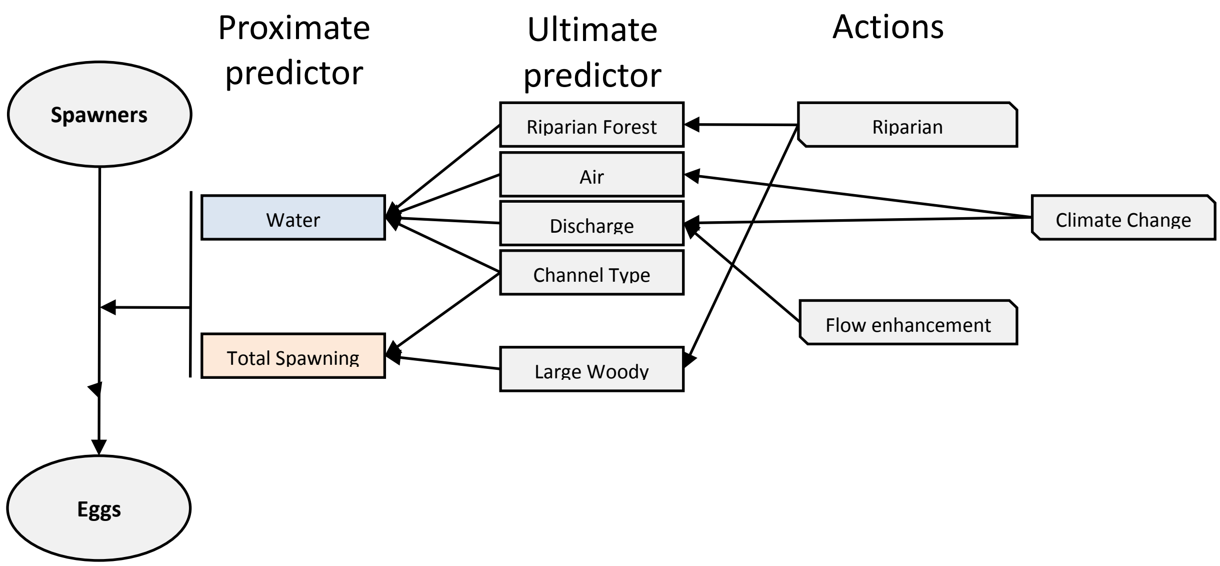
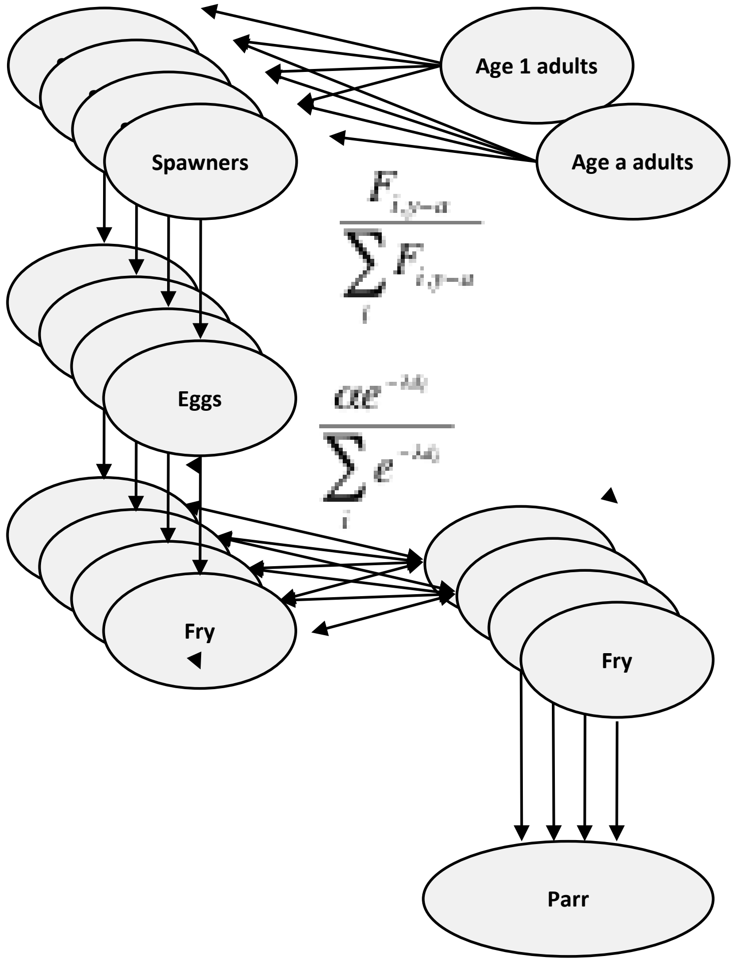


Figure A - 2. Diagram of dynamics of state variables. Dynamic processes affect main drivers of productivity and capacity.

The model also explicitly captures spatial dynamics by breaking the population down into distinct population sub-units that spawn and rear independently, but exhibit straying and dispersal behavior (Figure A - 3). Each sub-population is specific to a segment of the river. Even if no fish initially spawned in an area, fish may disperse into that area after spawning in another. Fish may also stray to an area to spawn, despite having originally been the product of spawning in a different area.



$$\frac{F_{i,y-a}}{\sum_i F_{i,y-a}}$$

$$\frac{\alpha e^{-\lambda d_i}}{\sum_i e^{-\lambda d_i}}$$

Figure A - 3. Spatial dynamics of spawning and rearing. Adults return to natal spawning areas in proportion to the number of fry that emerged the appropriate number of years prior to the age of maturation. Fry rearing and dispersal involves fry dispersing to spatial units other than the one from which they emerged from gravel. Illustration shows a distance scaled dispersal.

When fish return to spawn, fish of a given age are redistributed to natal spawning areas in proportion to the number of fry that were produced from each spawning area the year that the adult age-class returns would have reared as juveniles. Following spawning, eggs are produced, followed by fry. The model then simulates juvenile dispersal by redistributing a portion of fry to other rearing areas in proportion to the relative distances between rearing areas. If fry disperse to other areas, other fry may already be present, whether they emerged from the gravel there, or dispersed there from other areas.

Survival

Survival rates from one stage to the next are predicted with a BH survival function. The basic formula for the BH survival function is p/(1+pN/k), where N is the abundance, p>0 is the density-independent productivity and k>0 is the carrying capacity term. When N approaches k/p, survival approaches p/2. All stages of survival use this assumption, though the values for p and k are not necessarily constant. Both p and k can vary with environmental conditions such as those described in Figure A - 1. In the simplest form of predicting survival, p and k do not vary with environmental conditions and so survival does not vary either. However, for generality, survival is assumed to be predicted by productivity and capacity,

both of which have the potential to change with environmental conditions. The relationship between productivity and environmental variables is described below.

Environmental conditions

The model keeps track of environmental conditions at all stages and at all spawning and rearing sites, even if it is assumed that it conditions are constant. Let $Xi_{,j,k,t}$ be the environmental condition for the i_{th} population, j_{th} stage, k_{th} variable in the t_{th} year, where j=1,2,3 are egg, fry and rearing stages, respectively. Let Yj,t be the environmental variable for the jth stage in the t_{th} year, where j=1 is parr and j=2 is smolts. Let Zi,j,t be the jth environmental variables for the ith age of ocean residency in year t. The X, Y and Z variables are all normalized to historical means and standard deviations so that 95% of the values are on the range (-1.96,1.96). Productivity is calculated according to the following equation:

$$p = \frac{1}{1 + e^{-\beta_0 - \sum_{n=1} \beta_n V_n}}$$

where V_n is an environmental variable corresponding to one of the X, Y, or Z variables, depending on which stage or spatial location to which the productivity calculation is applied. This form predict a productivity on the order of (0,1), with a mean value of p* when β_0 = ln(p*/(1-p*)) and all other β_n = 0. Similarly, the capacity is calculated as follows:

$$k = e^{\gamma_0 + \sum_{n=1} \gamma_n V_n}$$

where the mean is k* when γ_0 = log(k*) and all other γ_n = 0. These equations predict productivities and capacities that increase or decrease with environmental variables in increments determined by the scaling coefficients β and γ. If there is deemed to be no variation with environmental conditions, only β_0 and γ_0 are non-zero. Positive values of the scaling coefficients cause productivity and capacity to increase with an increase in the value of the environmental conditions. Values of the scaling coefficients can range from negative to positive infinity, but values on the range of (-3,3) for β0 predict mean productivities between about 0.05 and 0.95 and values on the range of (0,20) for γ0 predict mean capacities between 1 and 485 million. For n>0, the scaling factors can take on any value, but a value of β0 = 0 would predict a mean of 0.5, so β1 = 1 and V = 1 would imply that when V is one standard deviation from its mean, productivity would increase from the mean value of 0.5 to 0.73, a 50% increase in productivity with one standard deviation increase in the value of the environmental factor. Capacity operates at the scale of γ0.

Spawning migration

The model predicts the number of adults returning in a given year and of a given age. Some of those fish will have spent a single year in the ocean; others will have spent several years. Fish returning as age a will have been fry a-1 years ago. If fish are aged 2, 3, 4, 5, and 6 years old, they will have come from fry 1-5 years prior. In order to allocated the total abundance of each age of fish back to the spawning areas from which they originate, the model takes into account the number of fish from each spawning area that survived to be parr for a given time lag. For example, 4 year old adults will redistribute to the spawning areas in proportion to the number of fry that emerged from each spawning area relative to the total across all areas.

Straying

The model implements straying as a function of two factors: 1. random stray rates, and 2. distance-scaled straying. The random rate merely dictates the portion of the total returns that stray outside of natal streams. The distance scaling determines the portion of the total straying to neighboring spatial areas. The model uses a distance scaling factor to make closer sites more attractive than farther sites. The relative desirability decays exponentially with distance. Rather than use physical distance, we are developing a method to define stray distance as a relative measure of accessibility. In other words, a nearby upstream site may not be as accessible as a downstream site farther away. Similarly, if a spawning group swims through a site to get to its own natal site, the transit site might be considered very close in relative terms.

Egg production

The model assumes that the number of potential eggs produced is predicted by multiplying the number of spawners at a site by a fecundity value (eggs per spawner) and applying a BH survival to those eggs. The resulting density-dependent viable eggs are a BH function where productivity depends on water temperature and capacity depends on total spawning area. Eggs are calculated at each of the spatial sites.

Fry production

Fry are predicted by a BH function where productivity is dependent on the proportion of fine sediment, i.e., β_1 is non-zero and V is fine sediment. Capacity is kept constant by setting γ_0 to a fixed value and other γ_n to zero. Fry production is predicted for each spatial site.

Fry rearing

After fry emerge from gravel, they can rear in their natal streams or disperse to other locations. The model will implement several dispersal mechanisms: 1. random dispersal, 2. distance-scaled dispersal, and 3. ideal free distribution. Random dispersal merely disperses a fixed portion of fry to rear in other spatial units in equal proportions. Distance-scaled dispersal starts with a fixed portion α of fish dispersing but scales dispersal such that the probability of dispersal decays exponentially with distance (Figure A - 3). The equation below shows the calculation of the distance scaled dispersal rate Di.

$$D_i = \frac{\alpha e^{-\lambda d_i}}{\sum_i e^{-\lambda d_i}}$$

A portion α of fry disperse and are allocated to the neighboring streams in proportion to their relative distance scaling factors.

Parr

Following fry rearing, all spatially distributed fry are collected into a common pool of late summer fry. The recruitment to fry follows a BH function with productivity varying with water temperature on rearing sites, and capacity varying with total rearing area and percent pools in rearing sites. Following the pooling of parr into a single unit, parr then migrate downstream either in fall or mid-late winter. The single pool of parr is recruited into each of the early and late parr stages with BH functions.

Smolt

Early and late migrating parr are recruited to the smolt stage using a BH function that has a fixed capacity, but has productivity varying with fish length fall and percent cobbles and boulders.

Mainstem

Smolts leaving the system are modeled with a density-independent survival rate. The mechanism for survival is currently a rate equivalent to the average passage survival in the mainstem. The intention is to implement a mechanistic model where survival varies with mainstem actions at the hydro-electric dams, as well as predicted flows, and to merge life cycle model functionality with on-going work in mainstem survival estimation.

Ocean

Fish that leave the mainstem enter the ocean in spring and spend up to four years in the ocean, making returning fish 3-6 years old. Each year at the time of spawning migration, a portion of ocean-rearing adults return to spawn. The probability that a fish returns to spawn is a fixed rate such that the number of returning adults is consistent with empirical patterns. Fish of a given number of ocean residency years that do not return to spawn spend an additional year in the ocean. After the fourth year in the ocean, all remaining fish from a brood year return to spawn. Each year in the ocean, the survival is predicted by a BH function with productivity varying with ocean conditions such as PDO, SST, or upwelling, depending on the year in the ocean. For generality, the a BH function is used so that density dependence can be incorporated, but it is not expected that ocean survival will realistically be density dependent, so capacity will effectively be assumed to be infinite.

Alternatively, a separate ocean life cycle model will be integrated with the CRITFC model. The AMIP group is set to arrive at a consensus on a standard ocean predictive model. Once this integration is achieved, the CRITFC model will no longer require explicit ocean modeling, but rather it will feed information directly into the AMIP model to obtain age of ocean returns in a given year.

Habitat condition model description

Habitat models predict the values of environmental variables that influence productivities and capacities at various stages of the population model, i.e., the X's and Y's used in BH relationship. The models predict changes in future habitat and stream conditions as functions of management actions. Take for example a stream segment (or reach) identified as a distinct population unit for the purposes of spawning or rearing. If the reach's historical water temperatures were above average and having a negative impact on spawning success or rearing survival, a management action would be to cool the reach during critical periods of survival. If, for example, the water temperature were partly predicted by shading from trees, then increased shading would decrease the water temperature. To achieve the increase in shading, the management action would be to plant more trees near the streams.

Figure A - 4 shows hypothetical functional relationships between forest age and the density-independent productivity parameter. Forest height increases asymptotically with age, shade increases asymptotically with height, temperature decreases with shade, and ultimately productivity decreases with temperature, so aging forests should have increasing productivities. Figure A - 5 shows the simulated time series of average age, height, shade and temperature for 10 levels of riparian planting. The simulation assumes that a stream segment has riparian forest covering only 30% of its length and the resulting average age of the entire reach is 30 years. Planting rates represent action on the portion of unplanted area, so a planting rate of zero does nothing and a planting rate of 1 initiates new forest on all of the currently unforested area. Age obviously increase linearly, but at a higher rate with more

planting. Height is predicted with a sigmoidal growth function and shading reaches a maximum of 100% canopy closure at a target height. Temperature drops significantly faster with increases in planting. Overall, investment in planting yields disproportionately higher dividends in productivity with each additional amount planted (Figure A - 6).

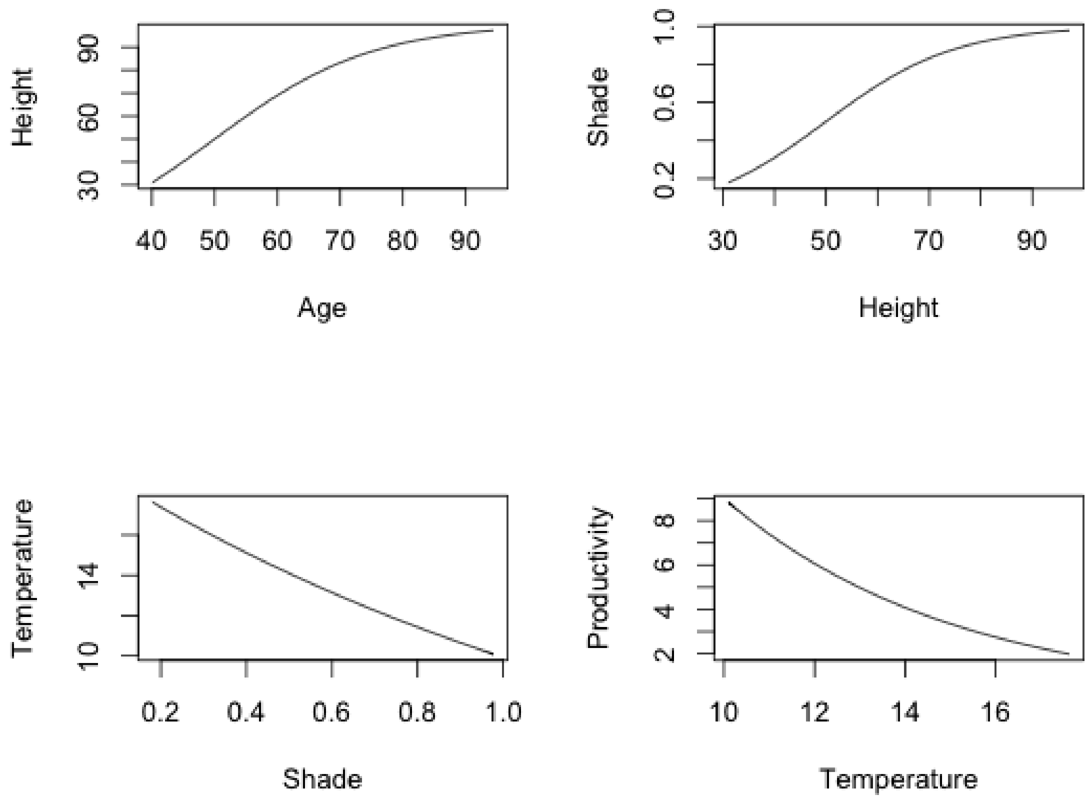


Figure A - 4. Functional relationship between forest height and productivity. The upper left panel shows forest height as a function of age. The upper right panel shows shade increasing as a function of height. The temperature shade relationship is shown in the lower left panel. Finally, the productivity is predicted to decline with temperature.

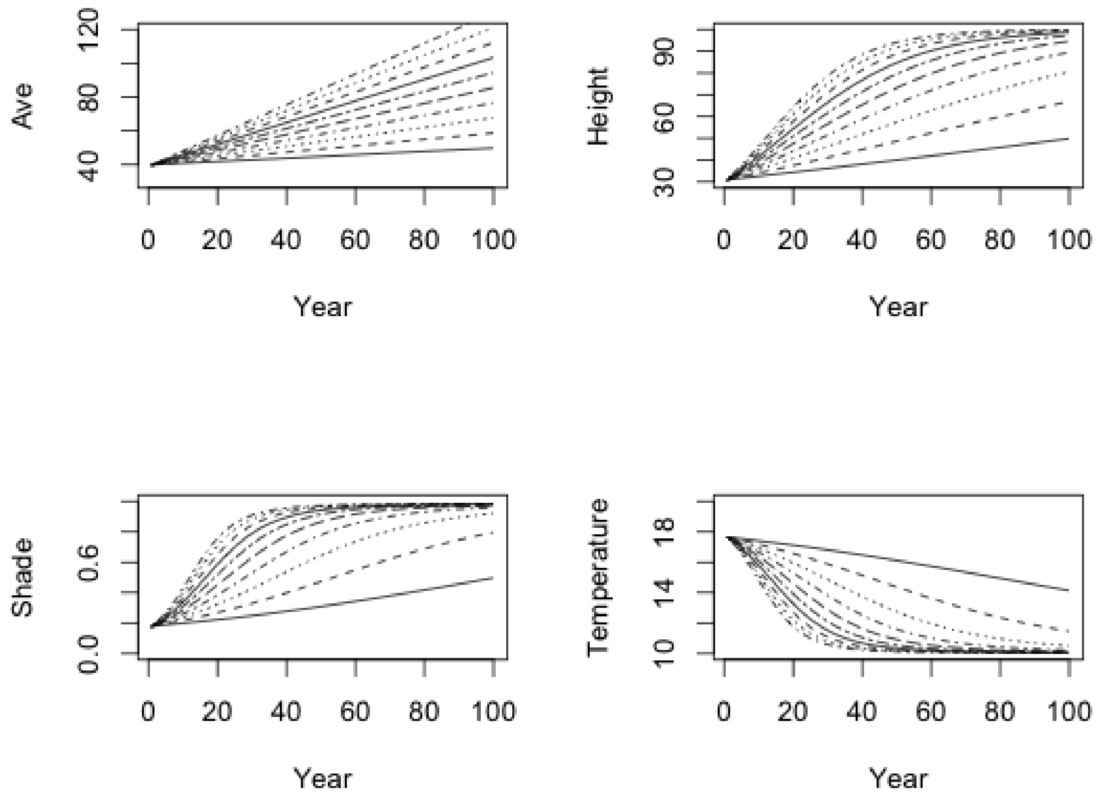


Figure A - 5. Relative increases in factors that ultimately affect productivity. The upper left panel shows the average age of the forest over time as planting occurs at ten different levels of intensity. The remaining panels show predicted height, shade and temperatures at those same levels of planting intensities.

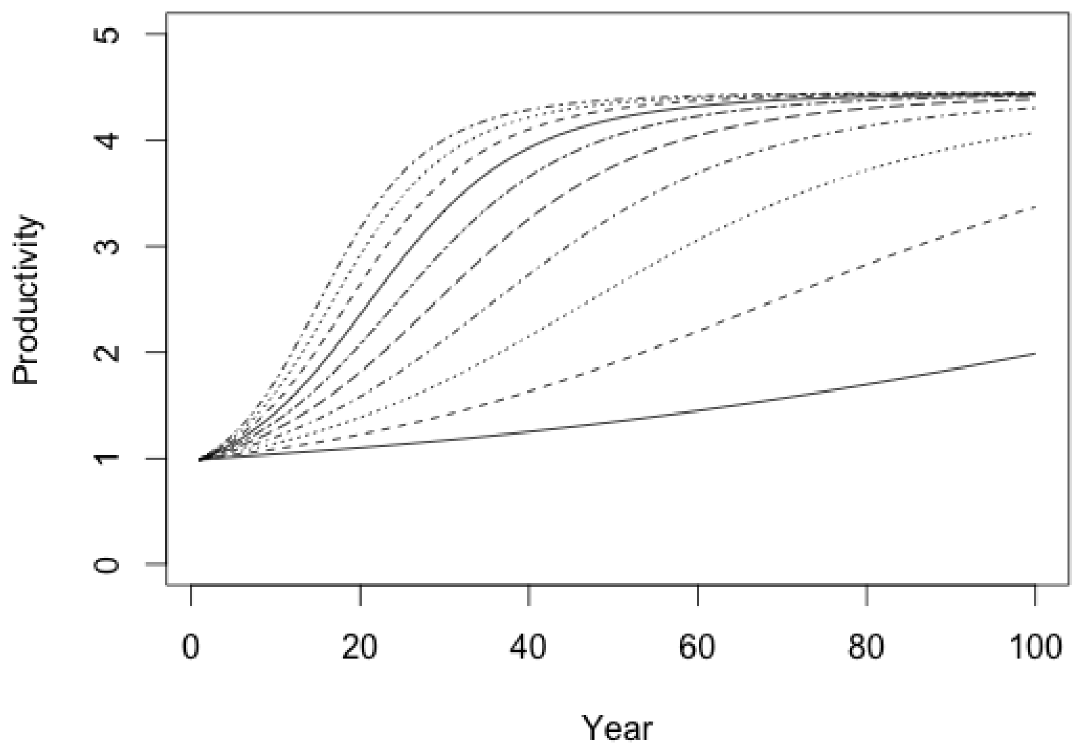


Figure A - 6. Change in productivity over time with increased riparian planting. Each line represents a different level of riparian planting.

Policy optimization

One of the main intended uses of the CRITFC model is a search for policy options. For this reason the model will be used not only as a population response predictor, but also as a management action optimizer. Since productivity and capacity can potentially be predicted by functional relationships, the assumptions and parameters that make those predictions may have some counterintuitive emergent properties when viewed from a population perspective. To examine these effects, we modeled population response to these changes across a range of management levels and examined the relative benefit of different levels of action. An example is given below where a population trend is simulated from an initial spawning density and a BH stock recruitment function that assumes only a single stage where conditions at the spawner to egg stage are variable.

Because of the non-linearity in the functional relationships that translate age into productivity, one would expect investment into planting to yield dividends in population growth. This may not be the case if density dependence is limiting recovery. Figure A - 7 shows the result of simulating the recovery across a range of assumptions. The upper left panel shows planting rates of 10-100% on a stream segment that is currently only 30% forested with an average age of 30 years (the forested area is about 100 years old). Each line shows the potential factor that the population could increase across 1-10 fold increases in the level of assumed density dependence. In all panels, more density dependence results in less benefit from planting (despite known increases in productivity). From top to bottom, and left to right, the

panels represent 30, 40, 50 and 60 year assumed starting ages. In almost all cases (though to different degrees), planting more helps with recovery, although only the forest that starts out the youngest does not reach an asymptote in its recovery rate. The extreme case in the lower left shows a situation where the forest is already fairly old and in nearing its asymptote.

The simple policy profiles contrasted in Figure A - 7 show that the potential outcomes of investment in habitat restoration may not be linear if the underlying relationships follow the hypothetical case illustrated here. This example is greatly simplified, but represents the strategic considerations that may ultimately be warranted, both in terms of the optimal magnitude of management action, as well as the potential spatial allocation of efforts. The example in Figure A - 7 shows the effect of multiple levels of management actions on four different initial forest conditions that are assumed to apply to the entire sub-population assemblage the makes up the population as a whole. Were it to represent four distinct sub-populations, then each one would have its own optimal policy, and rather than look for one value of the fraction of unplanted area that should be planted to initiate riparian forest, there would be four separate fractions that would need to be combined to predict the maximum population recovery. If one area yields less recovery potential for a single unit planted than another area, then that trade-off would be quantified with this approach. The relative gains by planting in one spatial area versus another are functions of density, capacity, and current conditions. In the example shown, the upper left panel would benefit the most from planting, and the lower right panel would not benefit from planting.

The visual representation of the benefits of planting illustrated is just one of many such relationships that CRITFC aims to address. In addition to riparian planting, the model will address flow enhancement, barrier removal, road decommissioning, and the addition of coarse woody debris. Beyond the visual illustration of the “Action/Benefit” analysis, the model will incorporate optimization, which is an analytical method of finding the steepest portions of the recovery vs. action curves. In most cases, recovery initiatives are limited by financial resources, so strategies should ultimately focus on the amount of benefit per unit investment. The trade-off analysis could then be performed using cost. An optimization routine will be developed that can search for both the amounts and the spatial allocation of habitat enhancements such that resources are allocated in such a way as to achieve the most expedient possible population recovery.

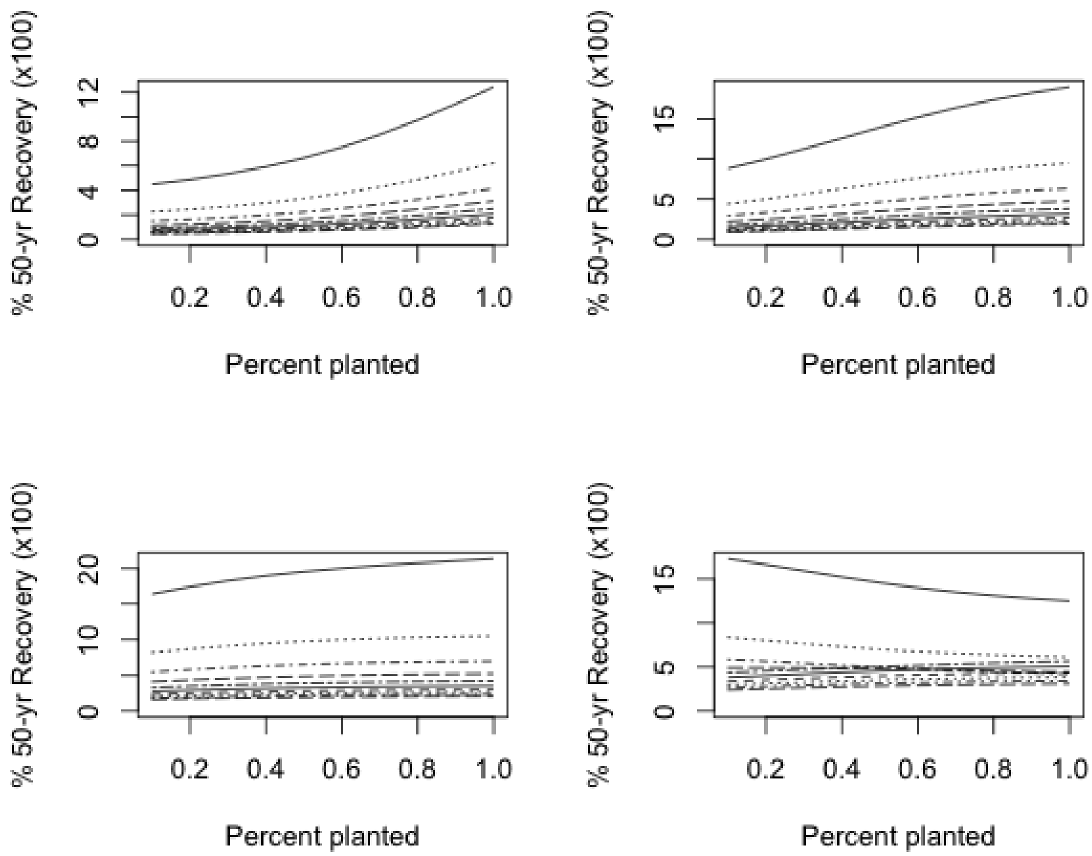


Figure A - 7. Net-fold increase in population in 50 years following planting of riparian forest. Simulations assume 30 percent currently forested. Top row is a current forest age of 30 and 40 years. Bottom row represents simulations with 50 and 60 year old average age. Each line represents and assumed increase in density dependence, with the solid line representing a minimal amount of density dependence.

Appendix B: Summary of CRITFC Monitoring Program

Dale A. McCullough (CRITFC)

Table B - 1.The summary of the CRITFC Monitoring program includes components from CHaMP, CRITFC's unique additional monitoring variables, foundational projects, major areas of monitoring planned with the Accords project, key issues for analysis identified, and calculations to be made using the CHaMP topographic survey data and RBT methods.

Aspects of Overall CRITFC Monitoring Program	Primary descriptors	Secondary descriptors
CHaMP Monitoring		
Channel Unit Level Attributes		
Channel segment	Main channel, side channel	
Channel units	Tier 1: Fast turbulent (riffle); fast non-turbulent (run); slow (pool)	Tier 2: riffle, rapid, cascade, falls; run; scour pool, plunge pool, dam pool, beaver pool,
Fish Cover	% cover for each channel unit	Woody debris, overhanging vegetation and live tree roots, aquatic vegetation and algae; artificial structures; % no fish cover
Ocular channel unit substrate composition	bedrock, boulders, cobbles, coarse gravel, fine gravel, sand, fines	
Particle size distribution	Phi size classes measured with gravelometer	18 size classes
Particle embeddedness	% of vertical depth; % surrounded by fines	
Pool tail fines	Particles < 2mm; < 6mm as % of total count	150 points per pool tail, up to 10 pools
LWD	Individual pieces; jams	4 length categories; 4 diameter categories
Undercut banks	GPS position, association with channel unit and L/R bank; mean width; mean length; mean water depth	
Site Level Attributes		
Site map	Benchmarks, monuments, control points, stream temperature logger, air temperature logger; pools, bars, fences, roads, trees	
Photos	Site overview; Transect photos at T1, 6, 11, 16, 21 on L/R	
Solar input	SunEye solar radiation input at T1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21	
Riparian structure	Canopy cover (%) at T1, 6, 11, 16, and 21	Cover by vegetation type and size (dbh) at Ground, Understory, Canopy levels

Aspects of Overall CRITFC Monitoring Program	Primary descriptors	Secondary descriptors
Water temperature	Hobo temperature logger	Hourly readings
Air temperature	Hobo temperature logger	Hourly readings
Water chemistry	Alkalinity, conductivity	
Macroinvertebrate sampling	Drift	2 drift nets (40x30cm each); 3-hour+ collection; measure volume filtered
Discharge	m3/sec at a single transect	15+ points/transect
Calculations to be Done with CHaMP Topographic Survey Data		
Bank Angle Standard Deviation		
Bankfull Width Constriction Profile		
Bankfull Width Profile		
Bankfull Width-To-Depth Ratio Profile		
Centerline Profile		
Channel Unit		
Channel Volume to Bankfull		
Gradient Profile		
Habitat Summary		
Habitat Unit area: % of total wetted area		
Habitat Unit volume: % of total wetted volume--summer		
Integrated Bankfull Width		
Integrated Wetted Width		
Site Area (Bankfull)		
Site Area (Wetted)		
Site Area		
Site Bank Angle		
Site Gradient		
Site Length (Bankfull)		
Site Length (Centerline)		
Site Length (Thalweg)		
Site Length (Wetted)		
Site length-center of bottom cross-section to center of top cross-section		
Site Sinuosity		
Site Wetted Volume		
Thalweg Depth Standard Deviation		
Thalweg Profile		
Wetted Width Constriction Profile		
Wetted Width Profile		
Wetted width standard deviation		

Aspects of Overall CRITFC Monitoring Program	Primary descriptors	Secondary descriptors
Wetted Width To Depth Ratio Profile		
Additional Monitoring in CRITFC Program		
Benthic macroinvertebrate sampling	Benthic samples from riffles	8 samples of 1-ft2 each composited
Snorkel sampling of salmonids and non-salmonids	1 or 2 lane snorkel sampling of each channel unit type	Sample all pools and representative samples of all other units
Streamflow gauges	Continuous streamflow gauging--stage height	Sheep Creek (UGR); SF Catherine Cr.
Depth substrate sediment composition in spawning gravel	McNeil core sampling	9 samples in pool tails and spawning patches
Foundational Projects in CRITFC Program		
LiDAR data collection	Riparian zone and stream channel data collection	1-m^2 pixels, 200-m buffer each side, entire mainstem and major tributaries
FLIR	Riparian zone and stream channel data collection to capture water surface temperature	1-m^2 pixels, 200-m buffer each side, entire mainstem and major tributaries
HeatSource water temperature model	Predictive model relating water temperature to flows, meteorological conditions, riparian/topographic shading	July 15-September 20 calibration
Riparian natural potential and current vegetation mapping		100-m buffer width each side, entire mainstem and major tributaries
USGS/CRITFC cost share: low flow modeling	Development of correlative model of low flows based on watershed topographic indices, streamflow statistics of long-term gauges	
Development of life cycle model	Predict population growth rate from estimates of survival and habitat carrying capacity based on habitat quality/quantity.	
Benthic macroinvertebrates	Species abundance, spatial distribution, species diversity	Diversity indices
Planned Future Research Work		
Spring chinook egg survival to emergence	Effect of substrate fine sediment	
Spring chinook juvenile growth rates		
Food availability	Intensive monitoring of macroinvertebrate drift	Relate to growth rate

Aspects of Overall CRITFC Monitoring Program	Primary descriptors	Secondary descriptors
Food electivity	Stomach contents of juvenile spring chinook	Gut lavage
Intragravel DO	Measure IGDO in relation to subsurface fine sediment concentrations and organic matter	
Embed LiDAR data within 10-m DEM to allow accurate analysis of floodplain morphology		
Planned Data Analysis		
Streamflow gauge statistics	Relate streamflows from 2 CRITFC gauges to nearby USGS gauges; relate low flows to USGS low flow model predictions	
Parr to smolt survival	Use PIT tag data to measure survival rates of CC population	
Calculate potential summer rearing survival for a site based on hourly or daily stream temperature statistics	Use continuous thermal exposure history and coefficients for thermal tolerance to calculate parr survival by site	
Calculate potential summer rearing survival for the entire stream system based on hourly or daily stream temperature statistics	Use continuous thermal exposure history, coefficients for thermal tolerance, and longitudinal pattern of water temperature to integrate survival potential for an entire stream system	
Correlation of drift macroinvertebrates with benthic		
Analysis of watershed topographic characteristics		
Relate watershed topographic characteristics with streamflow statistics; channel unit distribution.		
Predict subsurface fine sediments from surface fines		
Predict subsurface fine sediment concentration from stream reach, upstream watershed characteristics (intrinsic), road density (watershed, riparian), livestock density		
Predict spring chinook juvenile growth rates from food availability, water temperature, fish density		
Validate HeatSource water temperature model for various combinations of streamflows and meteorological conditions	Compare model predictions from the model calibrated to a range of streamflows and meteorological conditions found in 2010 to conditions found in subsequent years	
Predict water temperature restoration potential from specific riparian vegetation recovery scenarios using Heat Source model		

Aspects of Overall CRITFC Monitoring Program	Primary descriptors	Secondary descriptors
Calculate stream power for all study sites		
Relate stream power to substrate conditions		
Predict LWD input rates from current tree cover in riparian zone		
Validate HeatSource modeling prediction of solar input from LiDAR data against SunEye measures		
Predict survival to emergence of eggs/alevins from subsurface fine sediment concentrations		
Relate LiDAR estimates of riparian canopy height and density with ocular estimates of canopy cover and canopy height		
Evaluate potential groundwater storage from alluvial depth and volume		
Evaluate potential impact of global climate change on annual hydrograph; timing of snowmelt; potential water temperature increase		
Evaluate potential impact of watershed road density on heating stream water temperature		
Compare PRISM air temperature model with air temperature data collected by logger network		
Relate current vegetation cover (ocular CHaMP) to LiDAR height indices		
Relate current vegetation cover to streambank stability		
Relate embeddedness to percentage surface fines		
Relate surface substrate composition to bed roughness		
Relate drift species diversity to benthic species diversity		
Relate drift species relative abundance to relative abundance of species in the benthos that are prone to drift		
Relate channel bankfull width to drainage area		

Aspects of Overall CRITFC Monitoring Program	Primary descriptors	Secondary descriptors
Extrapolate surface and subsurface sediment characteristics to channel slope and drainage area by stream reach		

Appendix C: Evaluation of Solmetric SunEye and Heat Source Analysis of Solar Radiation Inputs

Dale A. McCullough (CRITFC)

Questions posed for solar radiation calculations--CHaMP protocol calls for the use of the Solmetric SunEye to measure trends in direct beam solar radiation to study sites. Several practical questions have been raised in regard to the use of the SunEye to take such measurements:

(1) How many measurements are necessary to characterize a study site?
(2) How reproducible are SunEye measurements?
(3) Can trends in riparian canopy be distinguished from annual variations in SunEye measurements?
(4) Can SunEye measurements be validated against another reliable method, such as Heat Source, where LiDAR and surrounding DEM data provide the topographic and vegetative shade components?
(5) What are the best uses for SunEye measurements vs. Heat Source analysis?

At this time, CRITFC is the only participant in the CHaMP program that has two years of data using the SunEye device for measuring direct beam solar radiation. Consequently, CRITFC is in a position to begin to answer questions 1-3 above. Also, CRITFC is using Heat Source programming to produce a water temperature model. Because the Heat Source program makes use of CRITFC's LiDAR data for the streamside zone in the Chinook spawning and rearing stream reaches for the two study basins, it was able to model topographic and vegetative shade effects on water temperature. LiDAR data provide information on maximum vegetation canopy height at a 1-m pixel resolution. Assessing daily solar radiation from scanning LiDAR and surrounding terrain DEM data at solar azimuths of SE, E, NE, N, NW, W, and SW and to the corresponding solar altitudes indicates whether direct beam radiation is reaching the center of the channel at points spaced in 50-m increments. These data are then used to produce hourly solar input data (direct and diffuse radiation) for 100-m increments in the stream. These data from Heat Source were then compared to measurements of direct solar radiation made using the SunEye for method validation. This comparison allows us to produce an answer to question 4. Recognition of the technical computation procedures inherent to the SunEye and Heat Source solar radiation methods provide a means to answer question 5 above.

Methods--CHaMP site dsgn4-000009 is in the headwaters of Upper Grande Ronde mainstem 0.75 km above Muir Creek, which is upstream of Clear Creek. This site has a bankfull width of 8m. Given the CHaMP protocol, the site length is 20x bankfull width, or 160 m. The lower portion of the site and the upper portion are shown in Figure C - 1, a and b, respectively. In 2011 the CHaMP methodology called for taking solar insolation measurements at 5 transects spaced every 40 m. In 2012 solar measurements were taken every 16 m on 11 transects. [Note: although 2012 CHaMP solar data collection was made on 11 transects, these transects were every odd transect from transect 1 to 21, or T1, T3, T5….T21. For simplicity, here when discussing the measurements for 11 total transects, we will call them T1, T2….T11.]. CRITFC recorded solar measurements with the SunEye, so comparisons between years can be made.

The layout of transects and collection of SunEye data are represented in Figure C - 2. The panel showing the plan view indicates the direction from mid-channel to the sun early in the morning, corresponding to the upstream photo (Figure C - 3). The horizontal compass angle to the sun is the solar azimuth. This is shown as 110° in early morning in summer. This line passes through a small stand of riparian trees. The right panel shows the side view. This illustrates the line to the sun drawn as an acute angle from the horizontal line. This angle is the solar altitude (Figure C - 4). This angle changes with every increment of solar movement along its arc in the sky. Heat Source methodology computes solar azimuth and altitude for every hour of solar movement (Figure C - 4, Figure C - 5). The SunEye computes these values for every 15 minutes of solar movement on its arc.

Effective shade is calculated in Heat Source according to the formula given below. In addition, Heat Source outputs for any day of the season for which the model is calibrated include potential radiation above the topography, radiation directly above the stream, and radiation received by the stream. These metrics are interpreted as ϕSRB1, ϕSRB4, and ϕSRB5, respectively, from the Heat Source manual (Boyd and Kasper 2003)(Table C - 1). Radiation above the topography represents the W/m^2 that is not affected by either topographic or vegetative shading. The radiation directly above the stream is W/m^2 resulting from both topographic shading (including streambank shading) and vegetative shading (including riparian cover and emergent vegetation). The radiation received by the stream accounts for the percentage of the radiation above the stream that is reflected by the water surface.

$$\text{Effective Shade} = \frac{(\text{Potential daily direct beam solar}) - (\text{Daily direct beam solar at stream surface})}{(\text{Potential daily direct beam solar})}$$

Table C - 1. Solar radiation, direct beam measurements made in Heat Source (Boyd and Kasper 2003).

ϕSRB1	Direct Beam Solar Radiation above Topographic Features
ϕSRB2	Direct Beam Solar Radiation below Topographic Features
ϕSRB3	Direct Beam Solar Radiation below Land Cover
ϕSRB4	Direct Beam Solar Radiation above Stream Surface
ϕSRB5	Direct Beam Solar Radiation Penetrating the Stream Surface

The SunEye collects data from a hemispheric image where the lens is held horizontally and oriented to 180° (due south). Digital interpretation of the image superimposed on the daily arcs across the sky made by the sun records, at 15-minute intervals of solar travel (Figure C - 5, Figure C - 6,), the presence (1) or absence (0) of a clear path to the sun. That is, if the solar altitude is greater than the topographic or vegetation shade angle at any point in time, a 1 is recorded for that solar azimuth (i.e., compass orientation, corresponding to 15 minute intervals in solar position). If the solar altitude is less (i.e., if the sun is below the topography or canopy level), a 0 is recorded for that 15-minute interval. After multiplying a 0 or 1 by the solar radiation (W/m^2) at each interval taken from the TMY3 climatic averages for the nearest weather station (Solmetric, Inc.), the radiation load for a day is computed by adding each of the 15-min thermal loads.

The Heat Source model used the LiDAR data collected for the Upper Grande Ronde in 2010. LiDAR data from 2008 and 2009 were used for the lower portion of the Upper Grande Ronde above the mouth of Catherine Creek. The Heat Source program searches through the 1m^2 pixel data in the 500-m band on each side of the stream covered by the LiDAR flight on compass bearings of SW, W, NW, N, NE, E, and SE at 15-m intervals for wide streams and 10-m intervals for narrow streams (Figure C - 6). Beyond the DEM coverage created by the LiDAR flight, the 10-m DEM coverage (USGS) was used. At each point spaced at 15-m (or 10-m) intervals, an area of 3x3 pixels was sampled to determine whether there was vegetation at this location along the path to the sun. Vegetation presence was interpreted as a difference in elevation between the ground return and the first return. If vegetation is present to intercept direct beam solar radiation, the angle to the vegetation intercept point was calculated and compared with the solar altitude.

Although the SunEye computes presence or absence of vegetation in the solar path at each 15 minutes of solar travel on its arc, a TMY3 direct solar radiation intensity for each hour interval of each day is multiplied by the 0 or 1 for each 15-min interval. Inspection of the TMY3 data, which gives the direct beam solar radiation above the topography and vegetation, but adjusted for average daily climatic conditions (i.e., cloud cover, humidity, etc.), shows that the same direct beam radiation is applied for every 15-min interval of each hour (i.e., W/m^2 is identical for 3:00, 3:15, 3:30, and 3:45pm, for example). Inspection of these data also shows that at each 15-min interval, there are 4 consecutive days that have the same average direct beam solar radiation (W/m^2). The values computed for an individual day in the field with the SunEye give a current assessment of solar access, reflecting the percentage interception of available direct beam radiation by topography and vegetation. However, the actual direct beam radiation for the monitoring day (e.g., August 1, 2012) reflects only a long-term average for August 1. That is, multiplying the % solar access for August 1, 2012 by the TMY3 long-term average W/m^{2}gives only the long-term average W/m^2 under the topography and canopy for all August 1 values.

Results—

The SunEye hemispherical images (Figure C - 3) made at Transect 1 illustrate that the instrument can be positioned in a comparable manner from year to year (2011 to 2012) with respect to the electronic compass and leveling device to record nearly equivalent images. Changes in canopy cover can occur due to riparian growth or wind damage, timber harvest, or mortality. A color photo made from mid-channel at transect 1 (Figure C - 2) looking directly upstream is very nearly aimed due south. The LWD spanning the channel can be seen in the overhead Google Earth image at the downstream end of the site (Figure C - 1).

Apart from issues of taking images from the same location in the same manner from year to year, it is important to then evaluate whether the instrument produces analyses of the data captured in a similar manner. Differences could occur due to variations in cloud cover, solar flare occurrence, and interpretation of open sky from obstructions. These issues will now be explored.

Direct beam solar radiation (W/m^2) was measured using the SunEye device in 2011 and 2012 in CRITFC's monitoring program. At CHaMP site dsgn4-000009, we measured solar access (% of potential direct

beam radiation above the stream surface, where potential is the long-term average for each day of the summer period taken from the TMY3 climatic summaries available from the nearest weather station). A comparison of the solar access values for the site can be made between 2011 and 2012 data. In 2011, CHaMP protocol prescribed taking solar readings on 5 equally spaced transects. This 160-m long site had transects spaced at 40-m intervals, starting from T1 and the downstream end of the site at 45.05513° lat, -118.29779° long. In 2012, CHaMP protocol required taking SunEye data on 11 transects, equally spaced at 16-m intervals. A comparison of hemispheric images shows a high degree of similarity in images at T1 (Figure C - 3). This is anticipated because T1 location was clearly marked in the field with a metal tag, similar to the mark placed at the upstream end of the reach (i.e., T5 in 2011, or T11 in 2012). The intermediate transects were located each year by measuring interval spacing with a tape, so they are not as likely to be perfectly matched.

Comparison of solar access data from 2011 with 2012 shows that the 5 transects in 2011 yielded nearly the same value for August 1-31 as found in 2012 (i.e., 74.88% vs. 72.24%). For the period September 1-20, the values were 72.53% and 66.98%, respectively (Table C - 2). A comparison of T1 in 2011 vs. T1 in 2012 showed a very high similarity (i.e., 69.69% vs. 70.22%, respectively, for August 1-31, and 74.33% vs. 75.06% in September 1-20). These comparisons appear to indicate that evaluating solar access for a known point that can be accurately re-occupied annually (i.e., T1, which is flagged in the field with a marker) yields very similar inter-annual values. In addition, mean solar access calculated for the study site using either 5 or 11 transects to take measurements yielded very comparable values. It is difficult to say that only 5 solar measurements are sufficient as a rule on all study sites rather than 11 because variations in riparian heterogeneity and variable site length may make it necessary to take more samples on long, heterogeneous sites as opposed to short, homogenous sites.

Given that the SunEye measurements have great consistency from year to year (2011 to 2012), we wanted to evaluate how SunEye solar access measurements compared to solar radiation estimates made using the Heat Source model with CRITFC LiDAR data collected in 2010. Heat Source analysis computes five different direct beam solar radiation estimates (Table C - 1. Solar radiation, direct beam measurements made in Heat Source (Boyd and Kasper 2003). Heat Source output in its Excel spreadsheet identifies output as potential above topography, directly above stream, and received by stream. We interpret these output columns as including ϕSRB1, ϕSRB4, and ϕSRB5. In addition, Heat Source computes diffuse radiation at each of the five levels, so that total radiation at each level is equal to direct beam and diffuse radiation. For this reason, we anticipate that total W/m^2 directly above the stream is equal to ϕSRB4 + ϕSRD4 (i.e., direct beam and diffuse solar radiation above the stream). The total solar radiation above topographic features would be ϕSRB1 + ϕSRD1. The equivalent to solar access in Heat Source would then be (ϕSRB4 + ϕSRD4)/ (ϕSRB1 + ϕSRD1), which we computed as solar radiation directly above the stream ÷ potential above topography.

SunEye measurements made in 2012 at T1-T11 with interpretation from the hemispheric photos showed that the estimated solar access for August 1-31 would be 72.24% for the 160-m site length (Table C - 2). Heat Source estimates for nearly the same stream length (200 m) spanning rkm 91.5 to rkm 91.7 (where rkm 91.5 is located at 45.05525° lat, -118.297259° long, a location nearly identical to T1), was 79.27% for the same time period (Table C - 3). In 2012, SunEye data showed that the average of 11

transect measurements of solar access for September 1-20 was 66.98%, whereas that calculated with Heat Source was 66.23%. The high degree of correspondence between these measurements seems to indicate that Heat Source analysis of LiDAR riparian data is comparable to analysis using the SunEye. However, if the percentage reduction in diffuse radiation from above the topography to the stream surface is different from the reduction affecting direct beam radiation (Figure C - 7), one might expect differences between Heat Source and SunEye data, where SunEye data are based only on direct beam radiation and Heat Source includes direct and diffuse. Diffuse radiation is a function of sky view (% of the sky that is unobstructed). On the surface, this might indicate that the use of the SunEye to monitor changes in riparian canopy cover and resultant solar loading would provide data for a site that is as good or better than provided by Heat Source analysis, given the great number of measurements being averaged. LiDAR analysis of riparian canopy, however, has the advantage of being able to estimate solar access for the entire stream instead of just a site. Also, a DEM of difference based on riparian zone differences between first returns (canopy tops) and ground returns would likely be able to provide trends in total riparian canopy volume.

A comparison of W/m^2 at T1, computed from the SunEye, against the same estimate from Heat Source (

Table C - 4) showed that the SunEye predicted a mean direct beam solar radiation above the topography for August 1-31, 2012 of 6098.4 W/m^2, whereas Heat Source estimated a total solar radiation value (direct + diffuse) above the topography of 6728.6 W/m^2 in 2010, based on LiDAR data collected in 2010 and the 2010 hourly meteorological values. Solar access values estimated from the two contrasting methods were 70.20% and 71.84%, respectively. Potential solar radiation, or solar radiation intensity above the topography, estimated for each method was different. The SunEye values were long-term averages for each day across years. Heat Source data were based on hourly meteorological values for each day. Although the Upper Grande Ronde has many rainless days in August, the daily variation in potential radiation considered on both an average multi-annual and an annual basis, introduces variation in daily measures of solar access. This makes it more meaningful in following trends to calculate mean monthly solar access.

a.

b.

Figure C - 1. CHaMP site dsgn4-000009 in the Upper Grande Ronde mainstem, showing the downstream portion of this 160-m long study reach (a) and the upstream portion (b). The downstream extent of the site is the location for Transect 1.

Figure C - 2. CHaMP site dsgn4-000009 on the Upper Grande Ronde mainstem, looking upstream from mid-channel (i.e., the position at which a SunEye solar radiation access image was taken in 2011 and 2012.

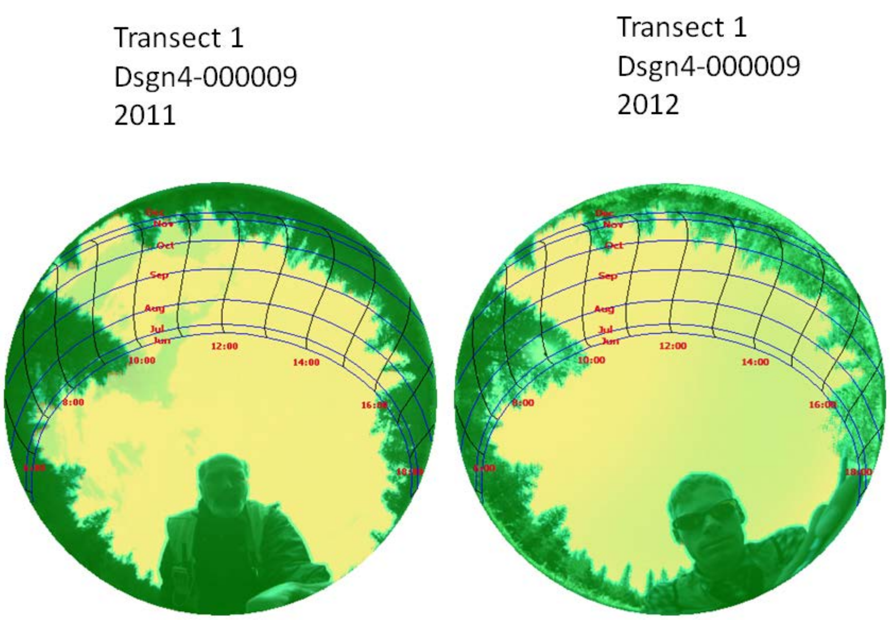


Figure C - 3. The SunEye images taken at Transect 1 on CHaMP site dsgn4-000009 on the Grande Ronde River mainstem in 2011 and 2012.

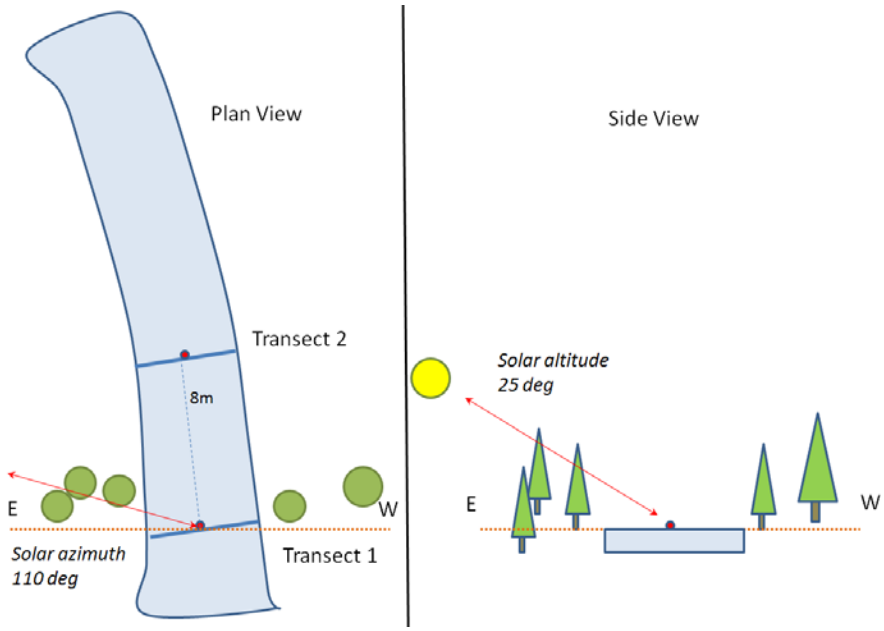


Figure C - 4. Representation of the process of taking a SunEye image from the mid-point of Transect 1 of study site dsgn4-000009. The plan view shows the view from above the transect, looking down at the channel and canopy. The line oriented to the horizontal compass direction to the sun is at 110°C solar azimuth. The side view represents looking upstream (and south) from the channel mid-point as is essentially the case in . The vertical angle from the horizon to the sun is the solar angle, shown as 25° in the side view.

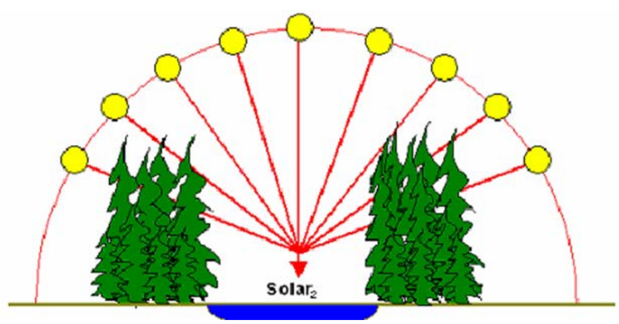


Figure C - 5. A sequence of solar altitudes as the sun moves through sky. From WSI.

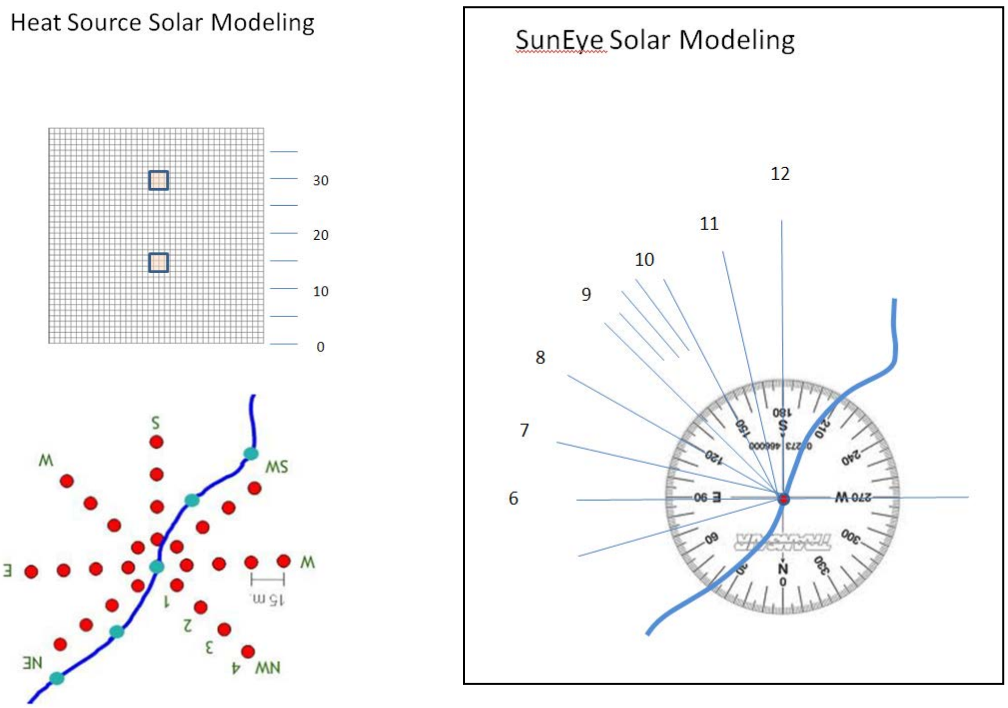


Figure C - 6. The comparative means of computing the percentage of potential solar radiation received by the stream, using Heat Source modeling with LiDAR data and the SunEye device, using analysis of a hemispheric image and digital interpretation of shading at 15-min intervals of solar movement for every day of the summer period.

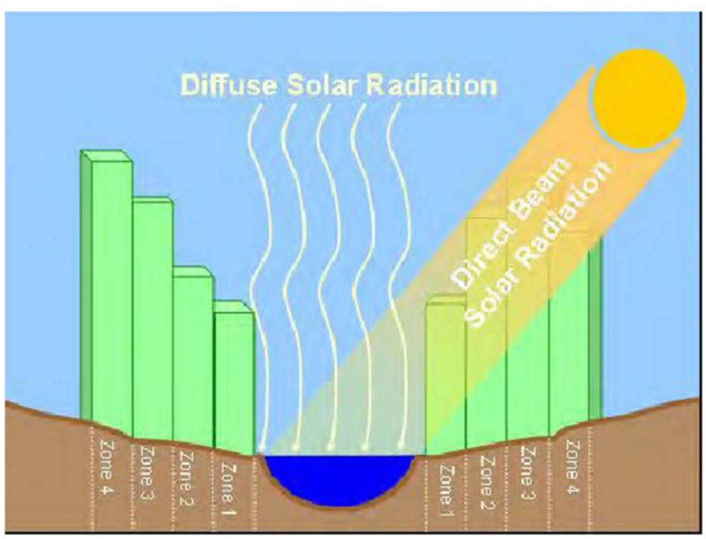


Figure C - 7. Representation of the calculation of total solar radiation load to a point in a stream. Total solar radiation (W/m^2) is the sum of direct beam solar radiation filtered through a sequence of vegetative zones in the riparian or streamside zone and diffuse solar radiation. The direct beam radiation is attenuated by 75% for interception in canopy in each streamside zone. Direct beam interception by topography is also accounted for by use of land surface DEMs. From WSI.

Table C - 2. Daily Solar Access (%) at Stream Surface--Calculation for Aug 1-31 and Sept 1-20, 2011 compared with Aug 1-31 and Sept 1-20, 2012 . Note: The SunEye data were collected on 5 equally spaced transects for the 160-m long study site (dsgn4-000009) in 2011. Transects were spaced at 40-m intervals in 2011. In 2012 the same site was surveyed at 11 transects, equally spaced at 16-m intervals.

SunEye calculation		**Year 2011**			**SunEye calculation**		**Year 2012**	
Transect		Aug 1-31	Sept 1-20		Transect		Aug 1-31	Sept 1-20
T1		69.69	74.33		T1		70.22	75.06
T2		61.34	62.66		T2		61.52	47.53
T3		77.82	68.32		T3		70.01	66.77
T4		82.83	77.97		T4		67.20	71.25
T5		82.71	79.39		T5		80.07	79.54
					T6		86.02	76.52
	Mean	74.88	72.53		T7		85.20	76.51
					T8		52.33	43.53
					T9		79.17	70.48
					T10		64.70	53.34
					T11		78.21	76.23
						Mean	72.24	66.98

Note: see file HeatSource solar radiation for CHaMP sites.xlsx

Table C - 3. Daily Solar Access (%) at Stream Surface--Calculation for Aug 1-31 and Sept 1-20, 2012 compared to calculations made in Heat Source with the LiDAR data collected in 2010 for the same site. Note: The SunEye data were collected on 11 equally spaced transects for the 160-m long study site (dsgn4-000009). Transects were spaced at 16-m intervals. The Heat Source point locations encompassed a total of 200 m, starting from approximately the location of T1 and extending 200 m upstream.

SunEye	**Year 2012**			**Heat Source**	**Year 2010**	
Transect	Aug 1-31	Sept 1-20		Rkm	Aug 1-31	Sept 1-20
T1	70.22%	75.06%		Rkm91.5	72.03%	44.48%
T2	61.52%	47.53%		Rkm91.6	95.48%	94.20%
T3	70.01%	66.77%		Rkm91.7	70.30%	59.99%
T4	67.20%	71.25%				
T5	80.07%	79.54%		Mean	79.27%	66.23%
T6	86.02%	76.52%				
T7	85.20%	76.51%				
T8	52.33%	43.53%				
T9	79.17%	70.48%				
T10	64.70%	53.34%				
T11	78.21%	76.23%				
Mean	72.24%	66.98%				

Note: see file HeatSource solar radiation for CHaMP sites.xlsx

Table C - 4. Comparison of daily and monthly average W/m^2 computed by SunEye (2012) and Heat Source (2010) for August 1-31.

	SunEye	SunEye	Heat Source calculations using LiDAR data at rkm 91.5				
	T1 is at: Latitude 45.05513; Longitude - 118.29779		Rkm 91.5 is at: 45.0552514616, -118.297259082				
	See: Sky01DailySolarAccess.xlsx	see: 137722_Sky01Insolation.xlsx based on TMY3 weather station	See: GrandeRonde_River_2012.xlsm; data source for Heat Source results		See: HeatSource solar radiation for CHaMP sites.xlsx		
August day	Daily solar access	TMY3 solar radiation data	Potential Above Topography	Directly Above Stream	Received by Stream	% potential W/m2 above stream	%potential W/m2 received by stream
	W/m^2, Year 2012	W/m^2; Year 2012	W/m^2; Year 2010	W/m^2; Year 2010	W/m^2; Year 2010		
1	70.01	4736.8	7825.3	6696.2	5470.6	85.57%	69.91%
2	70.01	4736.8	7766.9	5984.9	4866.7	77.06%	62.66%
3	70.01	4736.8	7769.0	5965.1	4849.6	76.78%	62.42%
4	70.01	4736.8	7740.0	5950.4	4829.8	76.88%	62.40%
5	71.84	6715.1	7673.2	5946.4	4818.9	77.50%	62.80%
6	71.84	6715.1	7650.2	5884.9	4771.5	76.92%	62.37%
7	71.84	6715.1	7649.4	5904.4	4776.4	77.19%	62.44%
8	71.84	6715.1	6496.0	5295.1	4276.3	81.51%	65.83%
9	68.70	7453.4	6238.8	4535.8	3702.7	72.70%	59.35%
10	68.70	7453.4	6271.2	4745.1	3819.0	75.66%	60.90%
11	68.70	7453.4	5185.8	4585.3	3720.2	88.42%	71.74%
12	68.70	7453.4	6540.1	4303.2	3575.4	65.80%	54.67%
13	67.72	6712.6	7451.6	5211.9	4216.7	69.94%	56.59%
14	67.72	6712.6	7422.0	5195.4	4196.3	70.00%	56.54%
15	67.72	6712.6	7388.5	5107.1	4138.1	69.12%	56.01%
16	67.72	6712.6	7354.6	5092.7	4116.7	69.25%	55.97%
17	71.37	6258.7	7320.1	5042.4	4064.6	68.88%	55.53%
18	71.37	6258.7	5242.3	2872.5	2315.3	54.79%	44.17%
19	71.37	6258.7	7250.3	5002.5	4050.1	69.00%	55.86%
20	71.37	6258.7	7214.3	4987.0	4013.0	69.13%	55.63%
21	70.48	4589.3	6683.0	4441.1	3553.6	66.45%	53.17%
22	70.48	4589.3	6375.6	4662.8	3751.4	73.14%	58.84%
23	70.48	4589.3	7102.8	4938.5	3952.8	69.53%	55.65%
24	70.48	4589.3	7064.3	4921.5	3937.2	69.67%	55.73%
25	70.91	6169.5	7025.2	4904.5	3913.9	69.81%	55.71%
26	70.91	6169.5	6222.0	4064.4	3225.6	65.32%	51.84%
27	70.91	6169.5	6944.7	4101.5	3247.3	59.06%	46.76%
28	70.91	6169.5	4787.0	2928.1	2323.6	61.17%	48.54%
29	70.91	6169.5	5883.8	4125.3	3291.9	70.11%	55.95%
30	70.91	6169.5	3822.0	2798.8	2239.4	73.23%	58.59%
31	70.91	6169.5	5226.1	4054.7	3218.5	77.59%	61.59%
Mean	70.20	6098.4	6728.6	4846.8	3911.1	71.84%	57.94%

Note: see file Calculation of solar radiation on Aug 1-2012-dsgn4-000009.xlsx

Appendix D: Evaluation of the Use of Air Temperature Data Collection in the CHaMP Protocol

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Questions posed for air temperature measurements--CHaMP protocol in 2012 called for measurement of air temperature at each annual site. In 2013 it was questioned what the value would be in continuing to measure air temperature. CRITFC employs Heat Source as a water temperature modeling tool. Heat Source uses a general adiabatic lapse rate to allow it to estimate air temperatures at various altitudes within a basin based on the nearest climatic station. For the Upper Grande Ronde, the nearest climatic station is the La Grande Airport, which is 45.4 km (air distance) to the furthest CHaMP site on the Upper Grande Ronde River and 40.3 km to the furthest site on Catherine Creek. It is questionable to what degree the air temperature and other meteorological measurements recorded at the La Grande airport reflect the weather at these remote mountainous locations. If more accurate climatic data are available, it is possible that more accurate predictions can be made using the Heat Source model.

An important use of the Heat Source temperature model will be to aid in assessing whether observed changes in water temperature from year to year are attributable to mere climatic or streamflow variation or to desired improvements in stream function. Key functional changes that are desired include improvements in riparian canopy, integration of the floodplain into hyporheic channel flows, road density effects on surface water heating, irrigation withdrawal impact on surface flow volume and return flow temperature. The Heat Source model can be a tool for entering annual climatic variables and streamflows into the model and predicting water temperatures. Deviations can then be attributed to desired functional improvements. In addition, there is a question about the relationship between air temperature and water temperature. Major sorts of deviations in the daily relationship between air and water temperature could be attributable to factors such as precipitation events, variation in cloud cover and nighttime cooling rates, variation in irrigation withdrawal.

Results—Air temperature was measured at CHaMP site dsgn4-000009 concurrently with solar radiation and water temperature measurements. The CHaMP monitoring site dsgn4-000009 is located at 45.05513° lat, -118.29779° long on the Upper Grande Ronde 0.75 km above Muir Creek, which is immediately upstream of Clear Creek. This is the same site as used to evaluate the SunEye and Heat Source solar radiation measurements (see Appendix C).

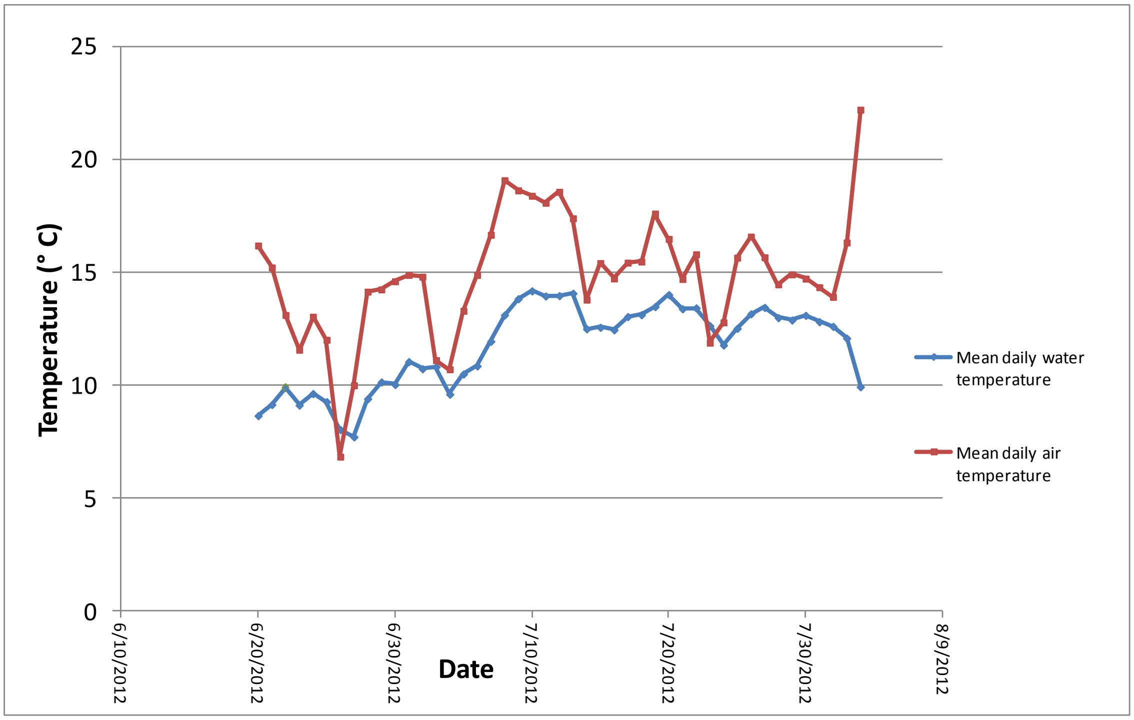
The correspondence of air and water temperatures can be seen in the plot of mean daily water temperature vs. mean daily air temperature for data taken at CHaMP site dsgn4-000009 (Figure D - 1). (See Figure 8 for 2012 water temperature patterns at this site). This relationship is also evident from the regression (R^2 = 0.3355) of the site water temperature on the air temperature (Figure D - 2).

Air temperatures at dsgn4-000009 were also related to air temperatures recorded at the La Grande Airport (NOAA) (http://cdo.ncdc.noaa.gov/qclcd/QCLCD) (Figure D - 3). The large decline in water temperature on approximately July 24, 2012 (Figure D - 1, Figure D - 3) corresponds to a 1.37 inch rainfall that occurred on July 23, 2012 at the La Grande airport. This close correspondence between air

temperatures at the CHaMP site and the La Grande airport climate station (Figure D - 3) makes it appear that under current conditions of riparian vegetation shade, channel orientation, and topographic shade, it is feasible to predict water temperature from air temperature at a regional climatic station. However, the regression between mean daily air temperatures of the La Grande airport for July 1-31, 2012 against the CHaMP site is $y = 1.0163x + 5.3954$, $R^2 = 0.7757$, $p = 0.0019$. Although the relationship is highly significant, there is a great deal of scatter and it is likely that better results could be achieved in modeling local water temperatures by using local air temperatures.

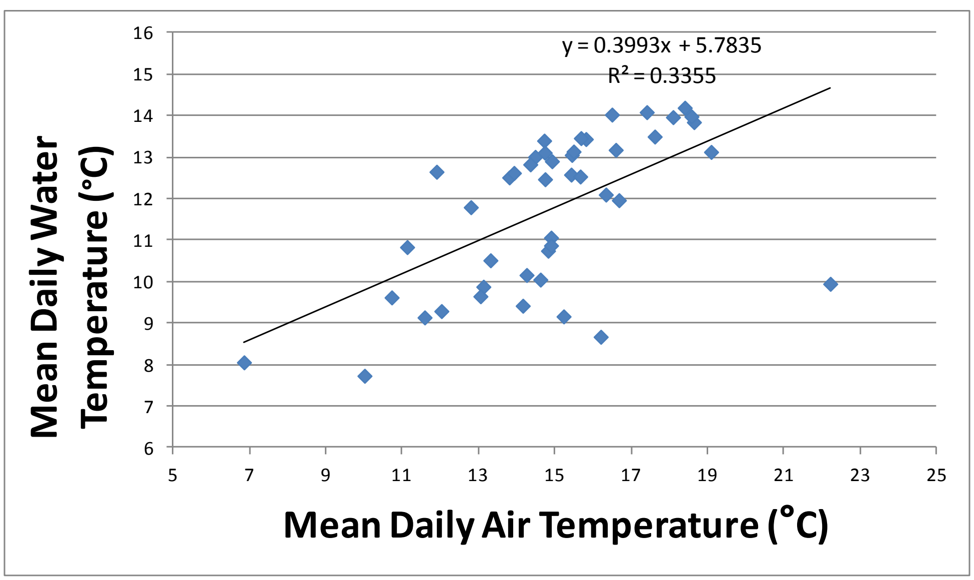
The NOAA climatic station at the La Grande airport is designated as LA GRANDE/UNION COUNTY APT (24148). It is located at elevation: 826.9 m; Latitude: 45.28333°; Longitude: -118.000°. CHaMP site dsgn4-000009 is at elevation 1413 m. The mean July air temperatures at the CHaMP site and the La Grande airport in 2012 were 15.4° and 21.0°C, respectively. Given the difference in elevation between the sites, this air temperature difference represents a lapse rate of 9.6°C/1000 m. The environmental lapse rate is the rate of decrease in temperature with altitude in a standard atmosphere, which is defined as containing no moisture (http://en.wikipedia.org/wiki/Lapse_rate). The environmental lapse rate in a standard atmosphere is considered to be 6.49°C/1000m. The dry adiabatic lapse rate is a lapse rate in air that is unsaturated with moisture and where no heat transfer occurs as the air parcel rises and cools (i.e., it does not gain heat by conduction, but its temperature decreases as the air does work by expanding when it rises). The dry adiabatic lapse rate is 9.8°C/1000 m. This rate is very close to that found by comparing the CHaMP site with the La Grande airport climatic station data.

Boyd and Kasper (2003) state: “When simulating over long distances in the Pacific Northwest, you will likely traverse variable land cover and topographic conditions that will affect the local microclimates. Further, the adiabatic lapse rate will generally reduce atmospheric pressure (affecting vapor pressures and the vapor pressure deficit), cool the air temperature as a function of increasing elevation and affect wind speed variability. This problem is only truly addressed with multiple atmospheric data measurement locations along the simulated stream network. However, such data will often be a limiting factor in model accuracy.” This information indicates that considerable value could be gained by maintaining a system of air temperature data loggers around the study basins so that more precise water temperature simulations can be conducted.



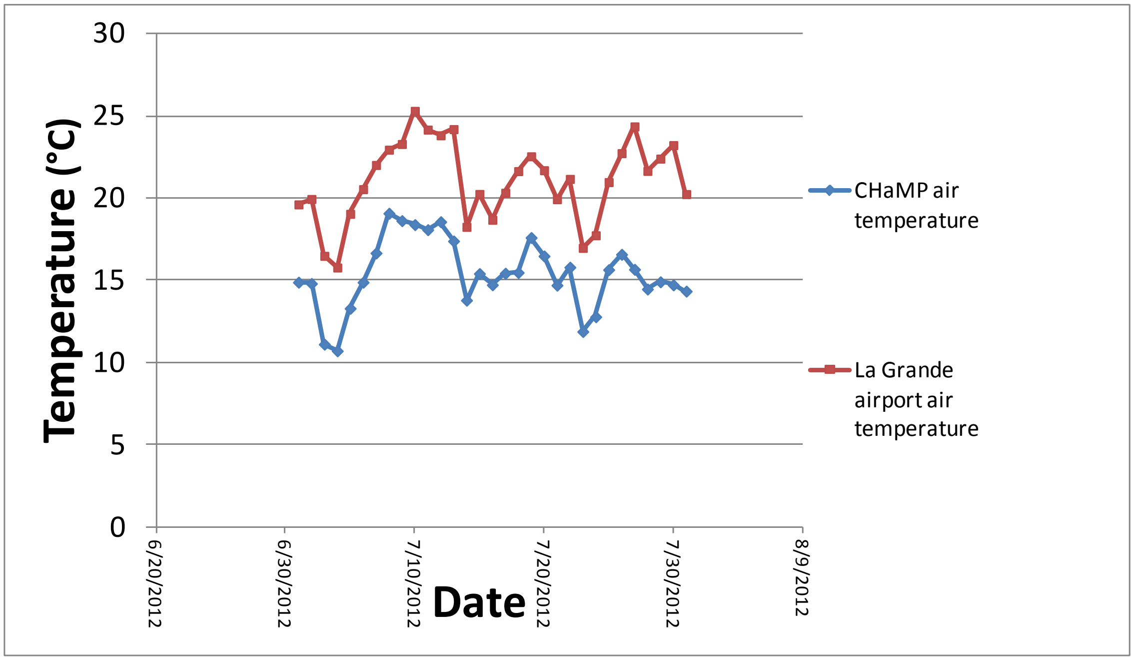
Note: see file Water vs air temperature.xlsx

Figure D - 1. CHaMP site (dsgn4-000009) on the UGR mainstem, monitored in 2012. Comparison of site mean daily air temperature and mean daily water temperature.



Note: see file Water vs air temperature.xlsx

Figure D - 2. Relationship between mean daily water temperature (°C) at CHaMP site dsgn4-000009 on the UGR mainstem above Muir Creek mouth and mean daily air temperature (°C) measured at dsgn4-000009.



Note: see file Water vs air temperature.xlsx

Figure D - 3. Mean daily air temperatures at CHaMP site (dsgn4-000009) on the UGR mainstem, monitored for July 1-31, 2012 compared to mean daily air temperature at La Grande airport..