Assessing the Status and Trends of Spring Chinook Habitat in the Upper Grande Ronde River and Catherine Creek: Annual Report 2014

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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. Critical uncertainties for fisheries managers in the Columbia Basin are whether habitat restoration actions will yield a net improvement in basin-wide habitat quality, and 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; and 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 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 streamflows. 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.

Progress and Key Findings from Individual Project Components

Juvenile salmonid abundance

- Completed fourth rotating panel schedule for snorkeling and electrofishing for juvenile fish densities at CHaMP sites in the upper Grande Ronde and Catherine Creek, and second panel of visits in the Minam River, a wilderness system (in collaboration with ODFW La Grande).

- Structural equation models linking rearing densities with local habitat conditions were updated to R software and using new data.
- Juvenile Spring Chinook rearing densities decreased over the 2011-2014 period in the upper Grande River and Catherine Creek. This pattern coincided with increasing water temperatures over the same period but the exact reason for decline is yet to be determined.
- Juvenile Spring Chinook rearing densities were generally lower in the Minam River, but constant over time.
- Updated structural equation models confirmed previous findings that large wood in the stream channel has a direct positive effect on rearing densities, and an indirect positive effect on rearing densities through the association of wood with pools.

Benthic macroinvertebrates

- Sampled benthic macroinvertebrates (BMIs), in collaboration with ODFW La Grande, at 66 sites in 2014, completing the fourth rotating panel.
- For each sample, calculated a suite of metrics including stressor indicator taxa, Grande Ronde IBI, functional feeding composition, PREDATOR model, and density and mass of individuals.
- Explored relationships between metric scores and watershed characteristics (derived from USGS StreamStats) using maximal information coefficients (MIC).
- Expanded structural equation models to evaluate relationships among local site conditions and BMIs.
- BMI indices were strongly linked to watershed characteristics, with MIC values up to 0.89 (analogous to r^2) for bivariate relationships, indicating (a) the need to control for background environmental noise when using BMIs to describe aquatic habitat quality and that (b) BMIs are sensitive to fluctuations in conditions rendering them good indicators of environmental change.
- Structural equation modeling revealed that greater canopy closure was associated with higher frequencies of large wood in the channel, which was associated with greater stonefly taxa richness.

Stream habitat conditions

- Continued collection of stream habitat condition data using the Columbia Habitat Monitoring Program (CHaMP) methodology at 25 sites in 2014 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 2011-2014 CHaMP data and assistance with revisions to CHaMP protocol.
- Preliminary analysis of key habitat metrics within distinct biologically significant reaches (BSRs), Interior Columbia Technical Recovery Team (ICTRT) populations, and valley setting classifications.
- Over the four years of CHaMP implementation, 120 unique sites have been surveyed and 225 visits have been conducted within the Chinook sample frame. This has led to a large body of data that is being used in numerous analyses to link habitat condition to juvenile populations.
- Initial summaries of seven habitat metrics highlight the diversity of streams present across the Grande Ronde River, Catherine Creek, and Minam River watersheds. The results from the valley setting analysis hold promise for using this classification system to extrapolate habitat metrics to un-sampled sections of streams.

CHaMP habitat data relative to landscape/land use metrics

- We analyzed the relationship of three important fish habitat metrics (fine sediment, large woody debris, and pool area) with landscape/land use characteristics in the Grande Ronde River basin with the objective of extrapolating site-level habitat data from CHaMP surveys to a larger spatial scale that would be more useful for life cycle modeling.
- The best fitting model for large woody debris (LWD) frequency included the explanatory variables elevation (positive effect), bankfull width (negative effect), and tree cover (positive effect), and together explained approximately 90% of the variation in LWD. The top model for percentage pool area included elevation (positive effect), valley width index (positive effect), watershed area (negative effect), slope (negative effect), and large woody debris frequency (positive effect) as explanatory variables, together explaining 88% of the variation in pools. In contrast with LWD frequency and percentage pools, the best fitting model for pool tail fines <2 mm was relatively weak ($r^2 = 0.44$). Despite statistically significant effects of elevation, valley width index, road density, and drainage density, this model was not a reliable predictor of fine sediment in pool tails.
- Spatial statistical network models showed promise for predicting LWD frequency as a function of landscape/land use characteristics and position in the watershed, but did not compare favorably with mixed-effects models for fine sediment or pool area metrics.
- Next steps will include using these mixed-effects models and/or spatial statistical network models to predict key habitat metrics at prediction points spaced every 500 m across the stream network. Prediction sites will then be rolled up using block kriging or simple averaging to calculate average habitat conditions at the scale of Biologically Significant Reaches (BSRs), the spatial unit used in our life cycle model.

Stream temperature analyses

- Continued monitoring of stream temperature at 72 sites across three watersheds. Summer temperatures recorded for 36 sites.
- Developed a temperature database to store temperature data that CRITFC collects in addition to what is collected through the CHaMP protocol. Compiled past data from 2009-2014, QA/QC, and validated the data to the same watershed standards set by CHaMP.
- Conducted analysis of peak temperatures and trends over the four year sample period.
- Compared predicted stream temperatures using the NorWeST temperature model in the upper Grande Ronde watershed with measured water temperature.
- Temperatures in 25 of the 36 sites sampled had seven day average maximum temperatures (7dAM) that exceed the thermal standards set by Oregon Department of Environmental Quality (ODEQ). Thirteen sites exceed this threshold for the entire summer sample timeframe (July 15th - Aug 31st). Extreme high temperatures in the lower Grande Ronde River are prohibitive to juvenile salmonid use.
- A four-year analysis of temperature data at three sites, which represent a wide range of stream diversity, demonstrated that 2011 was a cooler year than the following three years. Temperature extremes and record high temperatures were more common in 2013 and 2014.
- NorWeST temperature models do not perform as well when scaled down to the Grande Ronde watershed as they do on a regional and statewide scale. Temperatures at measured sites were frequently under-predicted with the NorWeST model and the model fit was not as strong compared

with the results from larger-scale areas. However, the methods produced promising results and we plan to apply the spatial stream network modeling to the Grande Ronde using temperature data collected by CRITFC and ODFW to augment and improve the NorWeST predictions.

Hydrologic analysis of low flows

- Based on multivariate relationships between watershed characteristics and low-flow metrics derived from 39 stream gages, characterized low-flow metrics for 195 ungaged locations including CHaMP sites and HUC6-Assessment Unit intersections in the upper Grande Ronde, Catherine Creek, and Minam River basins.
- Final report is in review by USGS and CRITFC staff.
- Measures of low-flow variability (Q98), timing of seasonal flows (Julian day of low-flow onset), and baseflow index (BFI) were associated with the watershed characteristics stream drainage density, average January maximum air temperature, and mean annual precipitation.
- We foresee utilizing these results to identify stream reaches vulnerable to low flows and associated high summer water temperatures.

Restoration database

- Hired a graduate student intern from Oregon State University to compile all restoration activities in the project area from multiple data sources.
- Generated a master spreadsheet of nearly 4500 restoration activities and associated GIS maps, categorized by BPA restoration action and sub-category type.
- Currently finalizing a report and beginning to evaluate alternative metrics for restoration intensity due to inconsistent reporting by data sources of restoration project metrics.

Life Cycle Model

- A life cycle model was designed and built to reconstruct the population dynamics of spring Chinook salmon and to predict potential future dynamics under uncertain spawning, juvenile rearing, mainstem, and ocean survival conditions. All populations in the Grande Ronde/Imnaha Major Population Group (MPG) of the Snake River Evolutionarily Significant Unit (ESU) were included in a multiple population abundance reconstruction and parameter estimation analysis. The Grande Ronde/Imnaha MPG consists of the Grande Ronde River, Catherine Creek, Lostine/Wallowa, Minam, Wenaha, and Imnaha. The analysis focused on empirical validation of the survival of outmigrating juveniles and returning adults. Smolts survival through the hydro system and in the ocean was modeled to explicitly mimic all routes of passage and was formulated in relation to annual fluctuations in key environmental variables. A statistical estimation of rates predicting survival through all routes of smolt passage is performed. This provides a strong empirical basis for further refinements of the life cycle model in the fresh water stages.
- Results indicate that key variables predicting smolt outmigration survival include water transit time, contact with powerhouses, the Pacific Decadal Oscillation, and an upwelling index in the ocean. The analysis indicates that survival of in-river (untransported) smolts was negatively related to powerhouse contact rate, and survival during the first year in the ocean was also negatively related to powerhouse contact (an indication of delayed mortality from contact with powerhouses). Water transit time had a

positive effect on in-river survival, the Pacific Decadal Oscillation had a negative effect on ocean survival, and upwelling a positive effect on ocean survival.

Coordination with regional agencies, tribes, and landowners (Atlas)

- Dedicated CRITFC staff time to participating in the Grande Ronde Atlas science technical advisory committee to continue prioritization of restoration activities in the project area.
- Completion of prioritization of biologically significant reaches (BSRs) in Catherine Creek, and beginning on upper Grande Ronde River.
- Continued active participation in design and implementation of CHaMP. Participation in shared information across the Columbia River basin.
- Grande Ronde-wide development of a coordinated fish database with Oregon Department of Fish and Wildlife (ODFW).
- Participation in data sharing and fish-habitat modeling with the Integrated Status and Effectiveness Monitoring Program (ISEMP).
- Continued communication with landowners for access to private property; development of methods for summarizing site-specific results for individual landowners.

Conclusions

Significant progress has been made over the last four years in collection of high quality stream habitat and biotic data as well as development of analytical tools needed to quantify status and trends in habitat conditions and fish populations and to evaluate effectiveness of aggregate restoration activities. CHaMP habitat surveys, fish snorkel surveys and benthic macroinvertebrate sampling have been conducted at 120 unique sites throughout the spring Chinook salmon distribution area in the upper Grande Ronde, Catherine Creek, and Minam River, providing highly precise and spatially referenced data for a large suite of stream habitat and biotic factors. Because fluvial and riparian processes that create fish habitat generally operate over a relatively long time frame (i.e., decades), we don't feel it would be appropriate or informative at this time to quantify long-term trends in fish habitat conditions. However, the data needed to develop important fish-habitat relationships, habitat-land use relationships, and to parameterize a life cycle model to make projections in fish response to habitat change are now available, and as demonstrated in this report, have been applied successfully to make great strides towards meeting our project objectives.

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 spring Chinook salmon populations. A critical uncertainty for fisheries managers in the Columbia Basin involves determining whether freshwater habitat restoration actions will yield a net improvement in basin-wide habitat quality such that remaining man-caused survival impairments elsewhere during the life cycle can be compensated. Bonneville Power Administration funds our project and has an interest in determining whether expected

improvements in salmon habitat and, thereby, fish production can be brought about by improvements in the quality and quantity of salmon habitat.

Habitat restoration in the Upper Grande Ronde River basin and Catherine Creek basin 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 their 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 holding and juvenile rearing, 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 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). In addition, CRITFC has funded ODFW to conduct CHaMP surveys in the Minam River in 2014 and 2015 to provide a set of monitoring sites to act as an unmanaged reference for more heavily disturbed, managed sites in the Upper Grande Ronde and Catherine Creek.

As a means to integrate habitat monitoring efforts with recovery planning, CRITFC is developing a life cycle model. The life cycle model is being designed as a tool to simulate population trends in relation to projected environmental conditions, and to examine the relative benefits of habitat improvements on population recovery potential. A prototype model was developed which includes all Chinook salmon populations in the Grande Ronde/Imnaha Major Population Group (MPG) of the Snake River Evolutionarily Significant Unit (ESU), which consists of the Grande Ronde River, Catherine Creek, Lostine/Wallowa, Minam, Wenaha, and Imnaha. Modeling analyses to date have focused on empirical validation of the survival of outmigrating juveniles and returning adults, with particular focus on the environmental and operational variables that influence survival through the hydro system and ocean. This prototype model provides a strong empirical basis for further refinements of the life cycle model to include effects of freshwater habitat conditions on productivity and abundance of rearing juvenile salmonids.

Future refinement of the life cycle model and the research needed to parameterize the model are guided by a basic conceptual model framework. 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 (Figure 1). Current and future habitat conditions can act as predictors of relative change in survival at different life history stages, and therefore affect recovery potential.

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 describing the influence of soil type, forest harvest, road density, land uses, or bare earth on sediment delivery; a fine sediment model linking survival-to-emergence to fine sediment in spawning gravel; a water temperature model that links summer water temperature metrics to summer juvenile survival; a potential natural vegetation map that will aid in estimating stream shade, LWD input rates, and terrestrial macroinvertebrate inputs that aid in estimating the food base and growth potential for drift-feeding salmonids; and a low flow model that will permit evaluation of site vulnerability to climatic variations in precipitation, snow melt timing, and air temperature variations. 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.

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.

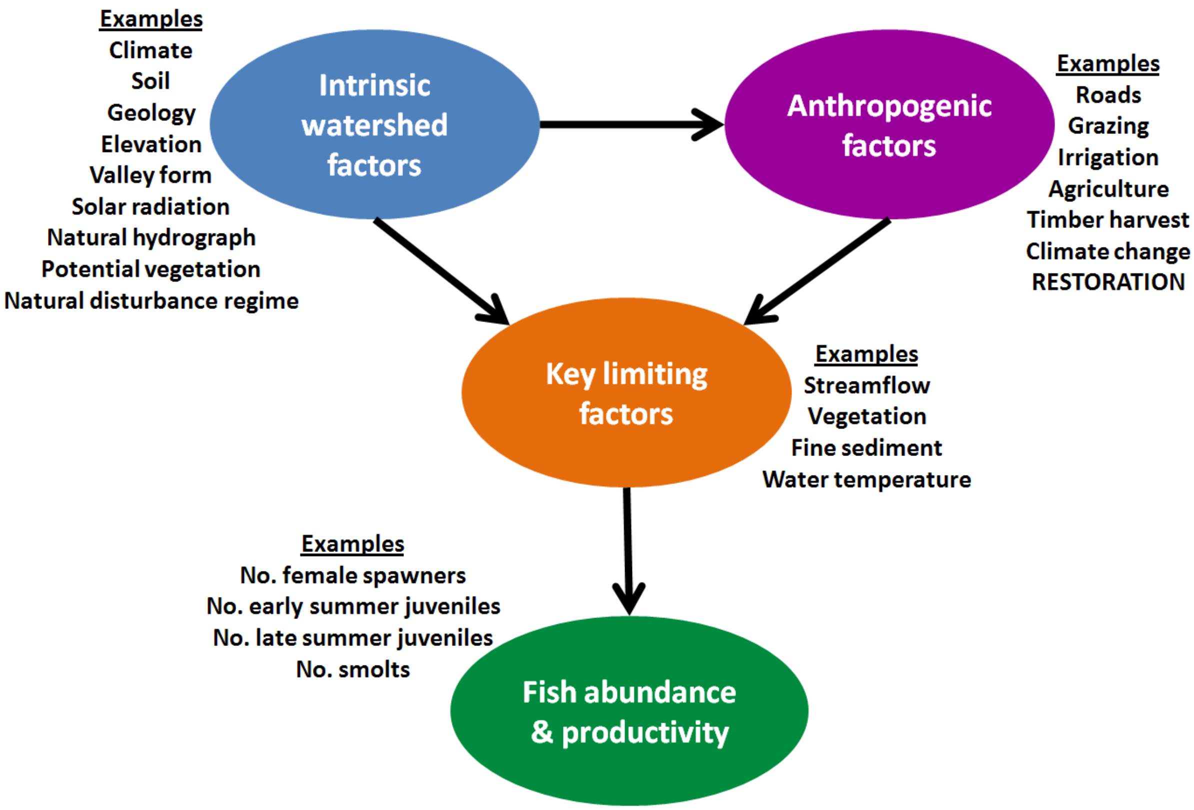

Figure 1. Conceptual framework for relating fish abundance and productivity to watershed characteristics and limiting factors. Direction of arrows indicates direction of influence.

Methods

Study Area

This study is being 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.

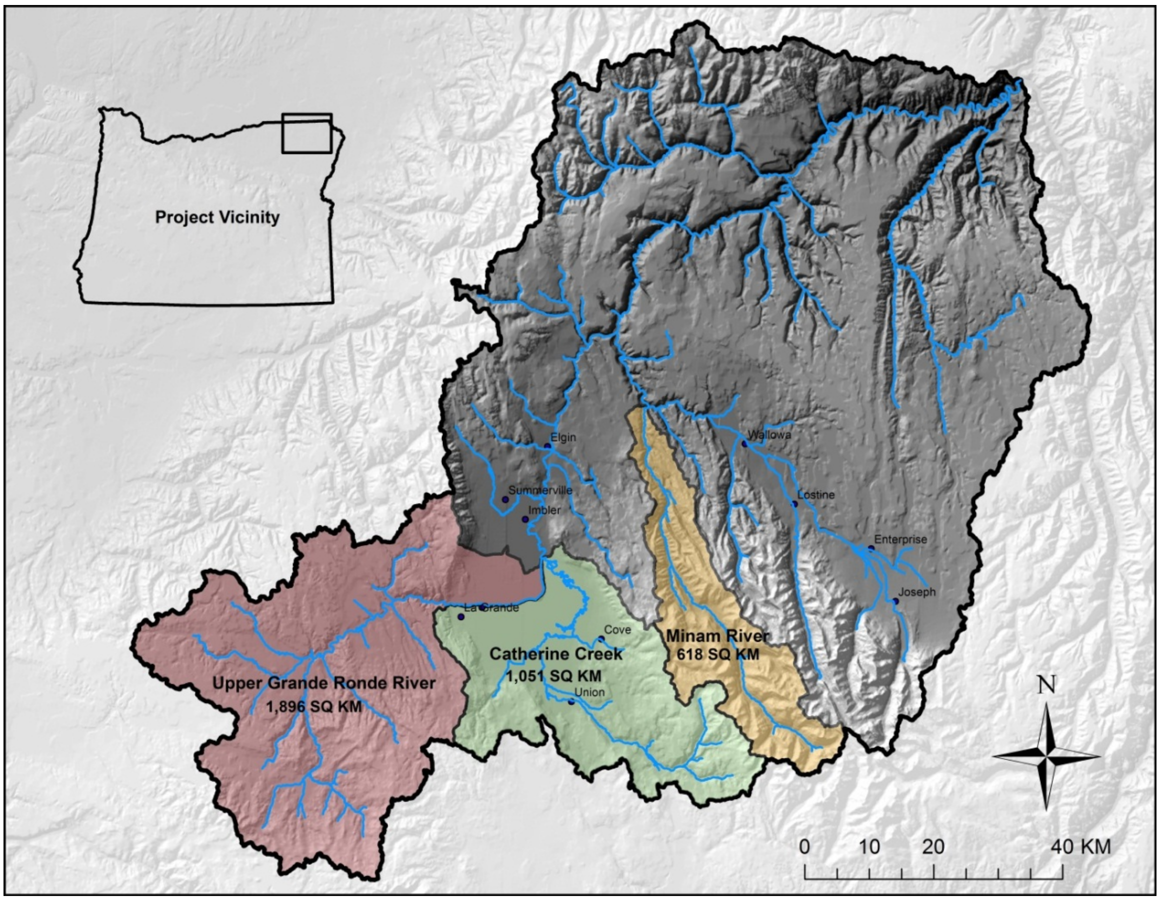

Figure 2. Study area in the Grande Ronde River basin, NE Oregon. Focal watersheds include the Upper Grande Ronde River, Catherine Creek, and Minam River. The Upper Grande Ronde and Catherine Creek are the basins with significantly damaged habitat that is undergoing restoration in various locations. The Minam River basin is the local reference basin that has far less current evidence of human impact.

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).

Stream biota

Fish Populations

We conducted snorkel surveys to quantify juvenile Chinook salmon and steelhead abundance and size in their summer rearing habitats. These data were used to inform fish assemblage structure and to assess potential fish-habitat relationships. CRITFC performed snorkel surveys at all 25 sites where CHaMP habitat data were collected in 2014. In addition to these surveys, the Oregon Department of Fish & Wildlife (ODFW) conducted 42 snorkel surveys in the Upper Grande Ronde (UGR) and Catherine Creek (CC) watersheds and 10 snorkel surveys in the Minam watershed at all CHaMP sites. The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) also conducted snorkel surveys at 2 sites in the UGR watershed. Methods for calculation of fish abundance from snorkel counts are described in Appendix A.

These three agencies have recognized the need to use a common snorkel survey protocol 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 and viability of ESA-listed fish species. To this end, we developed a snorkeling protocol, drawing heavily from the protocols of Thurow (1994) and O'Neal (2007) and integrated with the Pacific Northwest Aquatic Monitoring Program (PNAMP) methods, with the intention that this protocol will be implemented by 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). In 2014, in a further effort to increase the quality of data being collected in the watershed, a coordinated snorkel training was conducted in La Grande with the participants from local agencies along with representatives from other parts of the Columbia basin.

In addition to monitoring generalized trends in fish density over time, we have linked fish densities to local site characteristics and landscape-level variables to help understand patterns driving change. 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. Updates to previous years include migrating the analysis from proprietary SPSS-AMOS software to open source R statistical software (Lavaan and semplot packages).

Benthic Macroinvertebrates

Benthic macroinvertebrate sampling was conducted at each CHaMP visit according to procedures outlined in "Methods for the collection and analysis of benthic macroinvertebrate assemblages in wadeable streams of the Pacific Northwest" (https://www.monitoringmethods.org/Protocol/Details/44). In essence, the PNAMP protocol calls for sampling a total of 8 ft^2 from riffle or fastwater habitats throughout each reach, composited

from eight individual 1 ft^2 samples selected randomly or systematically using a rectangular dip net, Surber sampler, or Hess sampler (CRITFC and ODFW use a rectangular dip net or Hess sampler only).

While the basic methods outlined in the PNAMP protocol are recommended, we also suggest the following sampling and processing methods in order to insure consistency with existing CHaMP collaborators (e.g., CRITFC). These alternate methods include: 1) Samples should be collected during base flow only (e.g., July 15 – September 30) compared to the recommended period from July 1 – October 15 in order to control for the effects of streamflow and seasonality of macroinvertebrate communities; 2) when subsampling is used in the laboratory, the recommended number of organisms sampled is 500 compared to the suggested minimum of 300 organisms; 3) the taxonomic resolution of sampling to the "lowest practical level" should be determined by the research question or biotic index intended for use; and 3) if subsampling is used, processing should include a 10-min search for large and rare organisms, but organisms found during the search should be recorded separately from other data.

Laboratory processing for CRITFC and ODFW samples results in a large set of measures in addition to taxonomic counts (Table 1) that are useful in evaluating water quality and describing habitat quality for aquatic biota. Cole Ecological calculated a suite of benthic macroinvertebrate indices (BMIs) for each sample using R statistical software and code developed for PREDATOR models by Shannon Hubler at Oregon DEQ. These BMIs included: standard biotic condition indices (BCI), functional feeding group composition, Hilsenhoff metrics, tolerant/intolerant species based on fine sediment and temperature conditions, PREDATOR model indices, DEQ temperature and fine sediment stressor model indices, total taxa densities, and biomass per m^2.

A total of 66 sites were sampled for benthic macroinvertebrates between the CRITFC and ODFW in 2014. Benthic macroinvertebrate indices calculated for these sites are provided in Appendix B. We explored trends among 2014 benthic macroinvertebrate indices and watershed characteristics for the contributing drainage area above collection sites from StreamStats ("Welcome to StreamStats." 2015. Accessed March 11. http://water.usgs.gov/osw/streamstats/). In addition to monitoring generalized trends in BMIs over time, we have linked BMIs to local site characteristics and landscape-level variables to help understand patterns driving change using structural equation modeling (SEM) (see "Fish Population RM&E" section for details of approach).

Table 1. Taxonomic resolution for CRITFC and ODFW benthic samples, derived from taxonomic standards established by the Northwest Biological Assessment Workgroup.

1	**Ephemeroptera** – Genus level except as noted below:
	- Baetidae – species as allowed by specimen conditions and maturity
	- Ephemerellidae – species in almost all cases
	- Heptageniidae – genus only except for *Epeorus* (*albertae, longimanous, grandis*, etc.)
	- Leptophlebiidae – genus except for *Paraleptophlebia* to species
2	**Plecoptera** - genus level except as noted below and for monotypic genera:
	- Capniidae – genus where possible
	- Chloroperlidae – genus in late instars
	- Leuctridae – genus, species for monotypics
	- Nemouridae – genus, species for *Zapada* (*cinctipes, frigida* etc.) and where keys permit.
	- Peltoperlidae – genus, species for monotypics
	- Perlidae – species
	- Perlodidae – genus, except *Isoperla* to species
	- Pteronarcidae – species
	- Taeniopterygidae- genus
3	**Trichoptera** - genus level except as noted below (and species where keys permit):
	- Hydropsychidae – *Parapsyche* to species, other to genus
	- Lepidostoma- denote case type (panel, turret, sand)
	- Limnephilidae- genus, except to species where keys permit and for monotypics
	- *Rhyacophila*- to species group except to species where keys permit and as noted below:
	Betteni gr. - *R. malkini*
	Lieftinchi gr. - *R. arnaudi*
	Sibirica gr. - *R. blarina* and *R. narvae*
4	**Coleoptera** - Family level except for the following:
	- Psephenidae- genus
	- Hydrophilidae- genus
	- Haliplidae- genus
	- Dytiscidae. – genus
	- Elmidae- species where keys permit.
5	**Diptera** - genus level for all families except for:
	- Chironomidae – subfamily/tribe (can go to genus, species if preferred)
	- Ceratopogonidae - sub family, except genus where possible
	- Tabanidae, Dolichopodidae, Ephydridae, Sciomyzidae, Syrphidae – genus where keys permit
6	**Hemiptera** - genus level.
7	**Odonata** - genus level, except to species where keys permit.
8	**Lepidoptera** - genus level
9	**Megaloptera** – genus level
10	**Gastropoda** – genus level where possible
11	**Bivalva** – family level (except to genus or species where possible).
12	**Amphipoda** – genus level.
13	**OSTRACODA** – Order
14	**OLIGOCHAETA** – Class (i.e., leave at Oligochaeta)
15	**HIRUDINEA** – genus level as keys allow
16	**TURBELLARIA** – Phylum (i.e., leave at Turbellaria)
17	**Nemata and Nematomorpha** - Phylum
18	**Nemertea** – genus (Prostoma)
19	**TROMBIDIFORMES** – Order

Stream Habitat

CHaMP Habitat Surveys

In 2014 we continued to implement the Columbia Habitat Monitoring Program (CHaMP) protocol and sampled 25 sites in the upper Grande Ronde and Catherine Creeks basins. When combined with CHaMP sites surveyed

by ODFW and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), a total of 146 unique sites (269 site visits) have been surveyed in the Grande Ronde basin. 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. 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 and characterize stream responses to watershed restoration and/or management actions. A detailed description of the CHaMP protocol is provided at http://www.monitoringmethods.org/Protocol/Details/806).

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 or historic spawning and rearing areas for spring Chinook salmon (Figure 3). The spring Chinook distribution area was modified from 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 (Table 2) 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. The 2014 field season was the fourth year of implementing the protocol in the upper Grande Ronde watershed. This year's surveys were the fourth visit to annual sites and the first revisit to panel 1 sites since the start of the program in 2011.

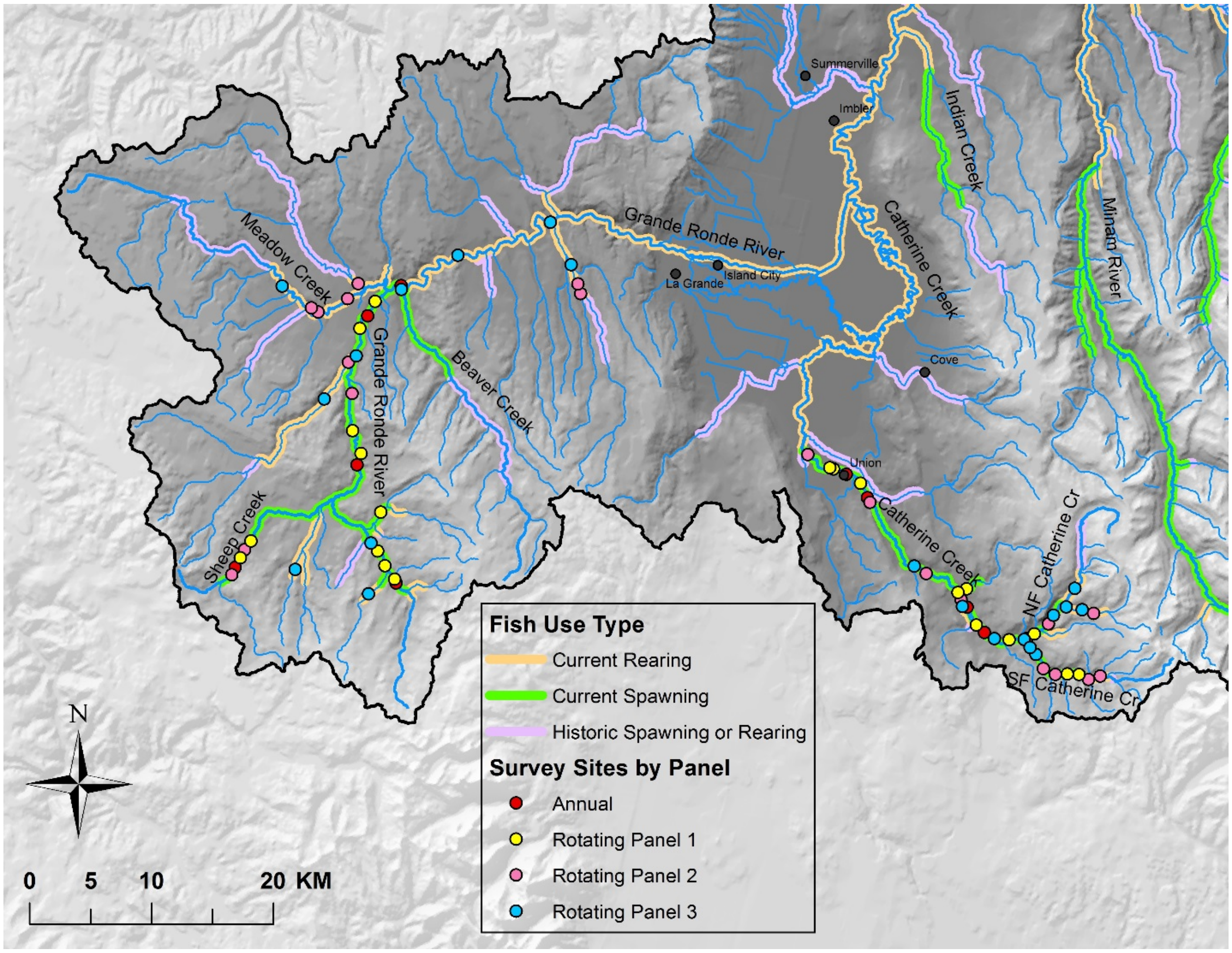

Figure 3. Sample design showing the distribution of CRITFC habitat survey sites in the upper Grande Ronde River and Catherine Creek basins.

Table 2. Rotating panel design for CHaMP sites in the Grande Ronde River and Catherine Creek watersheds. Note that 5 of the 30 sites in our survey design are sampled 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								

A large number of stream habitat variables were 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. The measurements were collected using a combination of traditional habitat data collection methods along with use of technical survey equipment (e.g., Total Stations) that allows for the development of detailed topographic maps of the stream channel. A complete list of metrics generated by CHaMP surveys is available at https://www.champmonitoring.org/.

Topographic data are composed of deliberately placed coded points and lines in the stream channel and floodplain that are used to illustrate inflection points in the channel bedform such as pools, the toes and tops of banks, and the thalweg (the location with the highest streamflow) along with important features such as the edge of water, bankfull elevations, and channel unit boundaries (Figure 4). Depending on the channel length and complexity, crews capture between 700 and 1500 points in order to accurately represent a stream reach. The raw data were imported into ArcGIS and processed to create digital elevation models (DEM), channel unit delineations, and water depth maps (Figure 4). These data were evaluated for quality control during the initial processing that occurs directly after the survey. After the field season is completed, the output products from each survey were processed through the River Bathometry Toolkit (RBT) to derive metrics that are potentially important to fish, such as residual pool depth. After the RBT metrics were created, a second round of quality control analysis is performed to ensure the accuracy of the topographic data. These data were then made available to the public on the program’s website (www.champmonitoring.org).

These detailed surveys will become increasingly powerful as the CHaMP program progresses because these surveys can be repeated and overlaid to inform topographic change over time. We have just completed the

fourth year of the nine year study design and have started the process of revisiting panel sites. At the end of the nine year period we will have a minimum of three visits at each site and will be able to quantify the degree of channel and habitat change over time at individual sites and start to look at patterns of channel erosion and aggradation across the watershed.

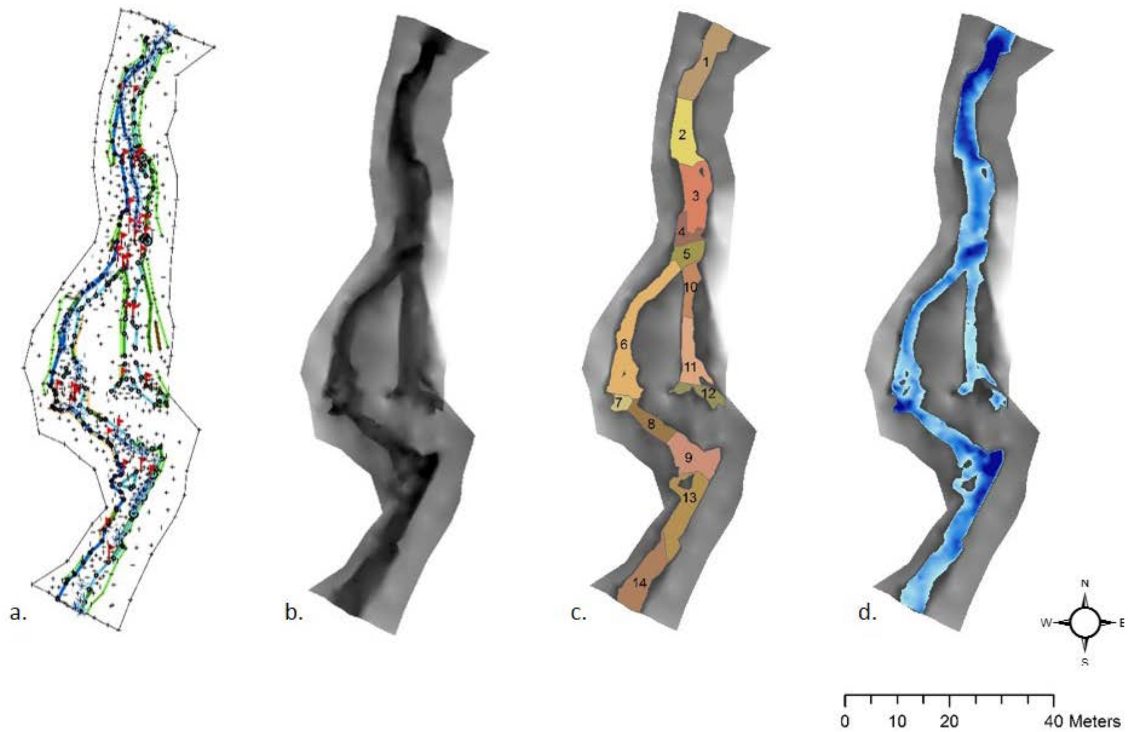

Figure 4. Example of topographic data surveyed conducted on Sheep Creek, site CBW05583-490810, in summer 2014 using the CHaMP protocol and a Total Station. The panel depict a) the raw point and line data as surveyed in the field, b) the digital elevation model (DEM), c) channel units overlaid on the DEM, and d) the water depth map produced by analysis at each CHaMP site.

Selected habitat metrics important for Chinook salmon at various life history stages (percentage pools, residual pool depth, percentage total fish cover, large woody debris frequency, percentage fine particles <2 mm, percentage cobbles, and drift biomass) were summarized for all sites across all years by Chinook population group (upper Grande Ronde, Catherine Creek, and Minam), by biologically significant reaches (BSRs), and by valley setting classification. BSR boundaries correspond approximately to the HUC6 watershed boundaries, but were aggregated or modified to better represent significant breaks in physical channel morphology (e.g., tributary junctions or major changes in valley confinement), land ownership, or fish use. BSRs were developed by local experts associated with the Federal Columbia River Power System (FCRPS) Biological Opinion expert panel and restoration implementation group (i.e., Atlas Group) for use in planning and implementing stream restoration actions. Valley setting classifications are based on the valley confinement and the bankfull width of a stream segment. Valley confinement is defined as the degree to which a stream channel abuts a valley margin and is divided into three categories, confined (against valley margin >90%), partly confined (10 - 90%),

and laterally unconfined (against valley margin <10%) (Brierley and Fryirs 2005). The bankfull width categories were separated into two categories, floodplain/constrained (>8 m) and mountain channel (<8 m) (Montgomery and Buffington 1997, Beechie *et al*. 2006). The combination of these characteristics results in six different classification levels: mountain confined (MC), mountain partly confined (MPC), mountain laterally unconfined (MLU), floodplain/constrained confined (FCC), floodplain/constrained partly confined (FCPC), and floodplain/constrained laterally unconfined (FCLU).

In future analyses we plan to extrapolate fish density estimates to include unsampled portions of the watershed by using the combination of the BSR regions and valley setting stream classification. Using GRTS we can compute population estimates based on stream classification type and then calculate BSR-wide estimates based on the proportional stream length of each classification type. We can use the classification to more accurately extrapolate population metrics to BSR reaches where we have few or no CHaMP sites based on stream type.

CHaMP Data Collection in the Minam River

In addition to our CHaMP monitoring in the Upper Grande Ronde and Catherine Creek, CHaMP data were also collected in the Minam River via a subcontract with the Oregon Department of Fish and Wildlife. A summary of this work is provided in Appendix C. The Minam River is important to our overall efforts and to those of the ODFW program in providing a reference site that represents minimally disturbed environmental conditions with which to contrast results from the two significantly disturbed watersheds.

Analysis of CHaMP Data Relative to Landscape Metrics

We analyzed the relationship of three important fish habitat metrics (fine sediment, large woody debris, and pool area) with landscape/land use characteristics in the Grande Ronde River basin with the objective of extrapolating site-level habitat data from CHaMP surveys to a larger spatial scale that would be more useful for life cycle modeling. We used both mixed-effects models and spatial statistical network models to fit relationships between CHaMP habitat metrics and landscape/land use data derived from remote sensing. Detailed methods for this analysis are provided in Appendix D.

Water Temperature

Year round temperature records were collected at all CHaMP sites in the three focal watersheds using Hobo Tidbit and Pro V2 data loggers following the Water Temperature Probe Installation Protocol (https://www.monitoringmethods.org/Method/Details/846). In 2014, temperature data were captured at 16 CHaMP sites in the Catherine Creek watershed, 23 CHaMP sites in the Upper Grand Ronde watershed, and 3 in the Minam River watershed. These sites were visited once in spring and once in fall in order to download the data and to assess the condition of the temperature loggers. In addition to the sites monitored through the CHaMP protocol, CRITFC has temperature loggers deployed at 12 other locations in the Catherine Creek and upper Grande Ronde watersheds. These loggers fill in areas where temperature data were not sufficiently captured by the CHaMP program and often are located up- and downstream of significant tributary junctions. The data validation and storage for non-CHaMP sites was conducted by CRITFC staff. This year a new database was built to house the 12 actively monitored sites in addition to records from 70 other inactive legacy locations, which were monitored at any point from 2009 - 2013. The data from the past six years (643,313

hourly records) were validated and summary statistics were calculated to match those metrics derived from the CHaMP data. This database will continue to be updated each year as more temperature data are collected in the field.

Stream temperature metrics were summarized for 36 sites sampled in 2014 in the Grande Ronde watershed, 21 in the upper Grande Ronde basin and 15 in Catherine Creek basin. These calculations were all based on the "summer period" as defined by CHaMP, which is between July 15th and Aug 31st. This timeframe is crucial due to the potentially detrimental influences of high temperatures on salmonids. For every consecutive 7-day period within this 48-day period, rolling averages of maximum temperatures were calculated (7dAM). The number of 7dAM periods where the average maximum temperature exceeds 12˚, 13˚, 16˚, 18˚, 20˚, and 22˚C was evaluated at every site. These water temperature standards were designated based on beneficial uses by various salmonid life history stages as defined by the Oregon Department of Environmental Quality (Sturdevant 2008). Additionally, the average daily temperature (Avg), maximum daily temperature (Max), and the maximum 7-day rolling average of maximum temperature (Max7dAM) are reported over the same summer time period. Stream data in the Minam were collected earlier in the field season and did not cover the summer period and therefore were not included in this report.

As part of a Pacific Northwest region wide temperature monitoring and modeling effort, NorWeST, led by the Forest Service's Air, Water, and Aquatic Environments Program, a database of temperature observations and modeled predictions was made available for the entire stream network of the upper Grande Ronde Watershed. The observed stream temperature data represent a collaborative sharing of data from eight entities from 267 unique sites over a 19-year period (1993-2011) within the basin. These observations, along with air temperature data, solar radiation estimates, and morphological characteristics were inputs to a spatial statistical stream network model (SSNM) that models average August stream temperatures at 1-kilometer intervals. The SSNM leverages inherent spatial autocorrelation (non-independence) present in stream networks and results in a strong model predicting stream temperatures. From the baseline model, two future climate projections were incorporated to predict stream temperature under 1, 2, and 3˚C changes in air temperature along with projections for 2040's and 2080's under these two scenarios.

The database itself as well as the methods used to predict temperatures are great resources for assessing temperature throughout the Columbia River basin. However, we wanted to scale down this regional effort to focus on the Grande Ronde watershed. This initial investigation determined the model's prediction accuracy within the Grande Ronde by exploring the correlation between observed average August temperatures and model-predicted values. This analysis will evaluate whether to use the "off the shelf" model in future watershed analysis or to apply the SSNM methods and build a Grande Ronde-specific temperature model to gain improved extrapolation and predictive power.

For our analysis we compared average August temperatures measured at 47 temperature sites in 2013 in the upper Grande Ronde watershed and the Minam watershed with the nearest NorWeST predicted average August 2013 temperature point located on the same stream segment. Points were required to be on the same stream segment to ensure there was not an influence of tributary temperatures on the correlation as the spatial model accounts for location along networks. All paired sites were within one kilometer of one another.

Water Chemistry

Data on alkalinity and conductivity were obtained from CHaMP surveys (2011-2014) and the Oregon Department of Environmental Quality (1960-2012; http://deq12.deq.state.or.us/lasar2/) and were plotted to explore spatial patterns in water chemistry. Water chemistry was measured during the summer field season (late June-September). Eight sites surveyed by ODEQ near landfills, sewage outfalls, industrial outfalls, or sloughs had anomalously high conductivity values between 206 and 1000 µS and were removed from our analysis because they did not represent the general downstream progression of conductivities.

Large Woody Debris (Remote Estimation)

High resolution aerial photo imagery was obtained from the Confederated Tribes of the Umatilla Indian Reservation (CTUIR, courtesy Allan Childs) that covered the mainstem Upper Grande Ronde River from approximately the mouth of Meadow Creek to the upstream boundary of La Grande. Because it was possible to see large woody debris (LWD) in the stream channel with imagery at this resolution and to easily measure lengths, an attempt was made to explore the use of aerial imagery to remotely estimate LWD frequency and volume on a spatially extensive basis.

Three CHaMP sites were selected from 2013 surveys to test this on (CBW05583-031546, dsgn4-000245, and dsgn4-000277). The polygon delineations of water extent from Total Station surveys were downloaded from champmonitoring.org and overlaid on the imagery so that LWD could be counted and measured according to what would be estimated as being wet vs. dry. Dry pieces must have a portion of the mainstem or root $\geq$ 10 cm diameter within the planar boundaries of the bankfull channel but outside the wetted channel and is wholly or partially within the bankfull prism and is either suspended by other LWD above bankfull elevation or would fall below bankfull elevation if the suspending LWD moves. The left and right bank edges are frequently possible to discern from aerial imagery, but small amounts of displacement of water extent boundaries from their true location in space can make the designation of wet vs. dry somewhat tenuous.

Lengths of LWD pieces were tabulated and volumes were estimated by making assumptions about diameters. It was assumed that pieces 3-6 m in length were 0.3 m diameter; 6-15 m length were 0.35 m diameter, and pieces >15 m length are 0.5 m diameter. Pieces that were 1-3 m in length were not tallied because it was considered that they were not visible on the imagery. Using these assumptions, it was possible to contrast the estimates made from imagery with those made from CHaMP surveys on the ground.

Riparian Vegetation

We worked with riparian plant ecologists to develop and field verify a map of riparian vegetation communities, height, and density under current and historic conditions. Integrated Terrain Unit methods developed by Alaska Biological Research, Inc. (ABR) were modified for use by the team of Aaron Wells (ABR plant ecologist) and Elizabeth Crowe (independent plant ecologist), who both had experience as specialists in the Grande Ronde basin and each developed many of the publications used in classifying vegetation communities in the region. A good understanding of the potential natural vegetation (PNV) communities that would be found in all streamside areas under a fully restored (historic) condition is critical for modeling how water temperatures will respond to riparian restoration. In addition, the riparian vegetation mapping would also support additional

ecological modeling needs, such as aiding in prediction of streambank stability under current and restored conditions, LWD input rates; and terrestrial macroinvertebrate input rates. More details about riparian mapping methods can be found at: http://www.monitoringmethods.org/Protocol/Details/805. The final report from this vegetation mapping is expected to be completed in April 2015 and will be included in our 2015 Annual Report.

Hydrology-Low Flows

A primary objective of this work was 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 developed detailed analytical protocols for each step of the analysis, and demonstrated their application for selected streams and reaches that were determined in collaboration with CRITFC. Analytical methods followed previously-published methods for calculating flow metrics, incorporating climate and landscape-scale characteristics into streamflow predictions, and using the hydrological neighborhood approach (Ribeiro-Correa *et al*. 1995). In summary, the analysis proceeded as follows: (1) identify appropriate gage stations and acquire streamflow data, (2) calculate baseflow index (BFI) and derive low flow metrics from theoretical frequency distributions 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 relationships 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, and (6) utilize data from neighborhood sites to generate theoretical regional frequency curves for target sites and derive low-flow metrics. Detailed methods for this analysis are provided in Appendix E.

Road Density

CRITFC GIS staff completed mapping of roads on the Upper Grande Ronde basin and Catherine Creek which represented a substantial improvement over existing road layers. An accurate road layer is critical for modeling land use impacts on fine sediment delivery to streams, which is known to impact salmon egg-to-fry survival. This work made use of the latest existing USFS and TIGER road layers. The complete protocol for this mapping project was reported in McCullough *et al*. (2014).

The USFS road layer included important data such as road surface material, road type, whether the road is actively used or decommissioned. TIGER roads, available from the US Census Bureau, have no road attributes other than length. Both road layers suffer from extensive missing road segments that are visible on NAIP (2012) imagery at 1:6000 scale. In addition, it was very common for roads to be poorly located in X-Y space, as evidenced by their displacement with regard to NAIP imagery. CRITFC staff examined all road segments against NAIP (2012) imagery and repositioned any road segment that was improperly located to make all roads spatially accurate to within 20 m within a 200-m buffer (each side of a river segment) and 30 m for the watershed as a whole. Unless roads are accurately located spatially, it would not be possible to calculate riparian road density meaningfully. CRITFC staff also mapped all roads visible at 1:6000 scale that were not mapped by either USFS or TIGER systems.

Any road segment mapped by both USFS and TIGER systems retained the metadata present in the USFS layer. USFS roads had a USFS designation in the AttSource (agency attributed as data source) column in the table. If

the road segment was repositioned by CRITFC, this was noted as CRITFC in the GeoSource column of the table. If no road metadata were available for either USFS or TIGER road segments, CRITFC assigned road surface type to the road attribute table. Any road segment added by CRITFC was termed either native surface or improved, received a CRITFC AttSource label, and was given a CRITFC label for the GeoSource (geospatial) column.

The new USFS_TIGER_CRITFC roads map layer, which is a complete, spatially accurate representation of all permanent and temporary roads visible on NAIP (2012) imagery at 1:6000 scale for the entire study area, was used for calculation of road density within the watershed upstream of all CHaMP monitoring sites. Road densities were also computed for riparian buffer polygons (200 m on each side of the stream) within each watershed.

Many factors other than road density are important in determining the magnitude of sediment delivered to a stream. Some of these factors include terrain slope that each road segment is on, vegetation cover adjoining each segment, and the distance to the stream from the pour point on the road. We have made considerable progress creating a complete database of all road segments attributed with the corresponding hillslope, proximate tree cover, and distance to the stream, but more work is needed.

In order to link each road segment to the corresponding hillslope, we first subdivided the USFS_TIGER_CRITFC roads layer into 100-m segments. It was assumed that road segments of 100 m length or shorter would tend to represent a relatively uniform terrain slope and, thereby, erosion potential due to the hillslope gradient that the segment occupies. The terrain slope for each 100-m road segment was calculated as the mean of the hillslope gradient for each pixel that the road segment crosses determined from a slope map created from the 30-m DEM.

The desired output would be histograms of the length of road and road density occupying various terrain slope categories. Terrain slope categories may either be arbitrary bins for terrain slope or may tier to a published erosion rating scheme with a known physical basis. In either case, it is assumed that the greater the terrain slope, the greater the potential for eroded sediment to be transported down that slope toward a stream. Eroded sediments also are typically intercepted by roadside ditches that collect the sediment and route it directly to a stream or through a road-crossing culvert and downslope to either infiltrate or to run overland to a stream channel. The USFS sediment models GRAIP (http://www.fs.fed.us/GRAIP/) (Geomorphic Road Analysis and Inventory Package) or GRAIP-lite are products of the USFS Rocky Mountain Research Station used to estimate sediment erosion and sediment delivery from roads. CRITFC has made contact with the GRAIP modeling team of the USFS and is considering use of these models to estimate sediment delivery. However, successful application of the GRAIP or GRAIP-lite models would require spending time in the field gaining a statistical sample of roadside vegetation density for representative road segments. Until this is done, we intend to apply a correlative approach to estimate sediment delivery.

Restoration Database

With the decline of endangered salmon populations in the Columbia basin and uncertainty associated with the extent that tributary restoration actions can significantly help recover populations, it is important to evaluate the influence of habitat restoration on fish habitat at appropriate spatial and temporal scales. Evaluating stream restoration projects at tributary and watershed scales, as opposed to the common practice of

evaluating restoration at individual restoration sites, can offer insights into habitat actions required to address limiting factors for freshwater salmon production. A preliminary step in evaluating restoration at tributary and watershed scales is compiling existing information on where, what type, and, to the degree possible, intensity of restoration across the entire project area. We addressed these issues by compiling restoration project information for the Upper Grande Ronde River, with the goal of providing a comprehensive understanding of restoration carried out in the area from the mid-1990s to 2014. We also addressed the topic of rating restoration intensity for a large number of projects where restoration metrics are inconsistently reported. We foresee these efforts leading to statistical analysis of restoration ratings linked to biologic responses that account for potential longitudinal (upstream to downstream) and lateral (hillslope to stream channel) effects of restoration.

Life Cycle Model

A life cycle model was developed to reconstruct the population dynamics of spring Chinook salmon and to predict potential future dynamics under uncertain spawning, juvenile rearing, mainstem, and ocean survival conditions. The focal analysis of this project is on Catherine Creek and the Upper Grande Ronde, but since these populations share common life histories with neighboring populations in the Grande Ronde/Imnaha Major Population Group (MPG) of the Snake River Evolutionarily Significant Unit (ESU)), we have expanded the life cycle analysis to include those populations in the reconstruction phase of the analysis. The Grande Ronde/Imnaha MPG consists of the Grande Ronde River (GR), Catherine Creek (CC), Lostine/Wallowa (LOS), Minam (MIN), Wenaha (WEN), and Imnaha (IMN). Those six populations are modeled as separate spawning and rearing populations that share common aspects in their life histories, and are treated as independent samples of populations surviving common conditions outside of their natal streams. By including additional populations, we strengthen our statistical power when inferring survival downstream of spawning areas.

In 2014, we focused on empirical validation of survival of outmigrating juveniles and returning adults. We estimated survival of smolts through the hydro system and in the ocean in relation to environmental variables that describe inter-annual variation. Survival was modeled such that environmental variables influence the rate of survival. The degree of variation in survival in relation to each variable was estimated statistically. Model improvement efforts in 2014 provide an empirical basis for parameterizing the complete life cycle. The statistically estimated parameters provide the rates necessary to complete the prediction of survival and maturation from the smolt stage onward, whereas the spawning and rearing component predicts the spatial and temporal variation from the adult-to-smolt stage. The contents in this 2014 annual report section focus mainly on improvements to the empirical validation of the mainstem and ocean components. Future modeling work will focus on incorporating freshwater habitat conditions into model predictions of life stage specific productivity and capacity. A detailed description of the modeling methods is provided in Appendix F.

Results

Stream Biota

Fish Populations

The 2014 field season marks the completion of four rotating panels and four consecutive visits to annual panels for CHaMP sampling, coupled with associated fish snorkeling and electrofishing to determine late summer rearing capacity. While several analyses of fish distribution and its linkages to local and landscape conditions are underway, a cursory look at juvenile Chinook salmon rearing densities at site visits in three TRT Chinook salmon populations (Catherine Creek, upper Grande Ronde, and Minam River) and by Tier I channel unit type (pools, fastwater non-turbulent, and fastwater turbulent) was instructive. We noted a trend of decreasing juvenile salmon rearing densities by channel unit type across the study period (Table 3). The typical trend was one of higher fish densities in pools, followed by fastwater non-turbulent and fastwater turbulent units in all populations. Some exceptions occurred in Catherine Creek, with fish densities occasionally higher in fastwater non-turbulent habitat than in pools. Site-level estimates indicated a decreasing trend in juvenile fish densities over time in the two Chinook populations affected by land use (Catherine Creek and upper Grande Ronde), whereas fish densities appeared low but relatively constant over the two years when data were available for that stream (2012-2013) (Figure 5).

Table 3. Density (fish/m^2) of juvenile Spring Chinook salmon by Tier I channel unit type for three TRT Chinook populations. Sample size (n) indicates number of sites having a particular channel unit type present, including all within-year repeat visits. No data were available for Minam River 2011-2012.

		Slow/Pool			Fast-NonTurbulent			Fast-Turbulent		
TRT Chinook Population	Year	Mean	StdDev	n	Mean	StdDev	n	Mean	StdDev	n
Catherine Creek	2011	0.56	0.87	17	0.58	0.86	8	0.12	0.17	17
	2012	0.44	0.50	17	0.31	0.41	9	0.10	0.19	17
	2013	0.14	0.20	20	0.36	0.95	11	0.04	0.07	20
	2014	0.27	0.26	26	0.23	0.39	18	0.05	0.06	26
Minam River	2013	0.15	0.15	9	0.08	0.10	6	0.05	0.07	10
	2014	0.14	0.12	10	0.09	0.14	5	0.04	0.03	10
Upper Grande Ronde	2011	0.29	0.29	26	0.16	0.21	24	0.09	0.13	20
	2012	0.15	0.36	23	0.08	0.20	22	0.04	0.07	19
	2013	0.13	0.45	71	0.11	0.43	74	0.04	0.13	75
	2014	0.03	0.09	61	0.04	0.13	44	0.02	0.05	49

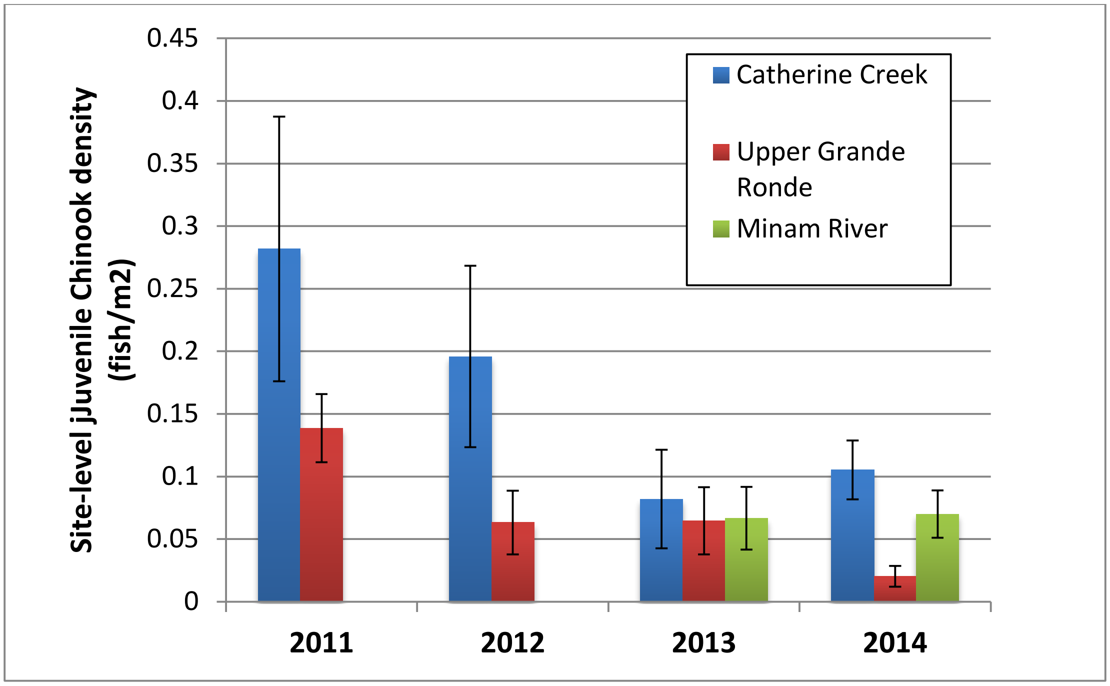

Figure 5. Site-level density (fish/m²) of juvenile Spring Chinook salmon for three TRT Chinook populations, 2011-2014. No data were available for Minam River 2011-2012. Error bars are +/- one standard error of the mean.

Structural equation modeling (SEM) results from fish densities from 2011-2013 across three TRT populations demonstrated that, after accounting for position in the watershed, large wood was associated with a direct increase in rearing fish densities, but also an indirect effect through the association between large wood and pools, with pools directly (and positively) affecting fish densities (Figure 6). The overall model containing only three predictor variables explained 71% of the variation in rearing fish densities.

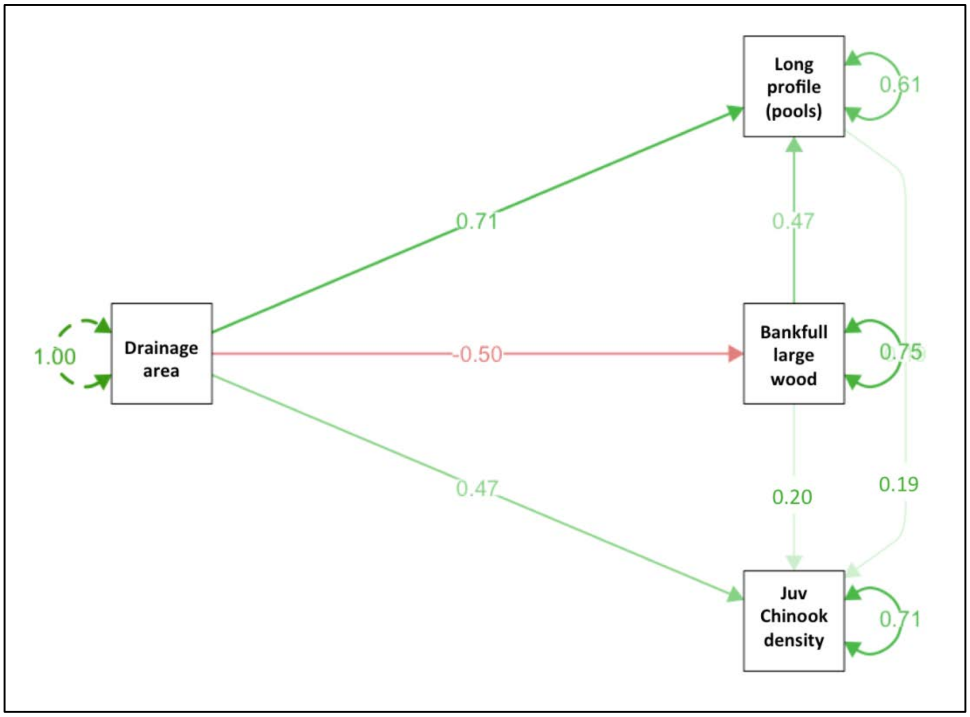

Figure 6. SEM results linking cumulative drainage area with longitudinal thalweg depth profile (a proxy for pool frequency), large wood frequency within the bankfull channel, and juvenile Chinook density (fish/m). Direction of arrows indicates the hypothesized direction of causal effect; whereas the color, shade, sign, and magnitude of the path coefficients indicate the direction and strength of the relationship (green is positive, red is negative, coefficients closer to |1| and darker shade of arrow are stronger). Values in double-headed arrows are amount of variance explained for dependent variables (analogous to r^2 in linear regression).

Benthic Macroinvertebrates

We used maximal information coefficients (MIC), a statistical tool for discovering novel and potentially non-linear relationships in large datasets (Reshef *et al*. 2011) to select the strongest relationships from within each of the five benthic macroinvertebrate (BMI) categories (stressor indicator taxa, Grande Ronde IBI, functional feeding composition, PREDATOR model, and density or mass of individuals). We found several strong relationships; the best within each BMI category are shown in Figure 7. Number of fine sediment sensitive taxa was negatively associated with average maximum air temperature, potentially due to higher fine sediment values at lower and warmer elevations of the Grande Ronde Valley. Grande Ronde IBI was positively associated with elevation. Collector-gatherers were positively associated with minimum basin elevation. PREDATOR O/E scores were negatively correlated with average January minimum temperatures. Finally, the density of individuals per m^2 was positively associated with basin relief (max-min elevation).

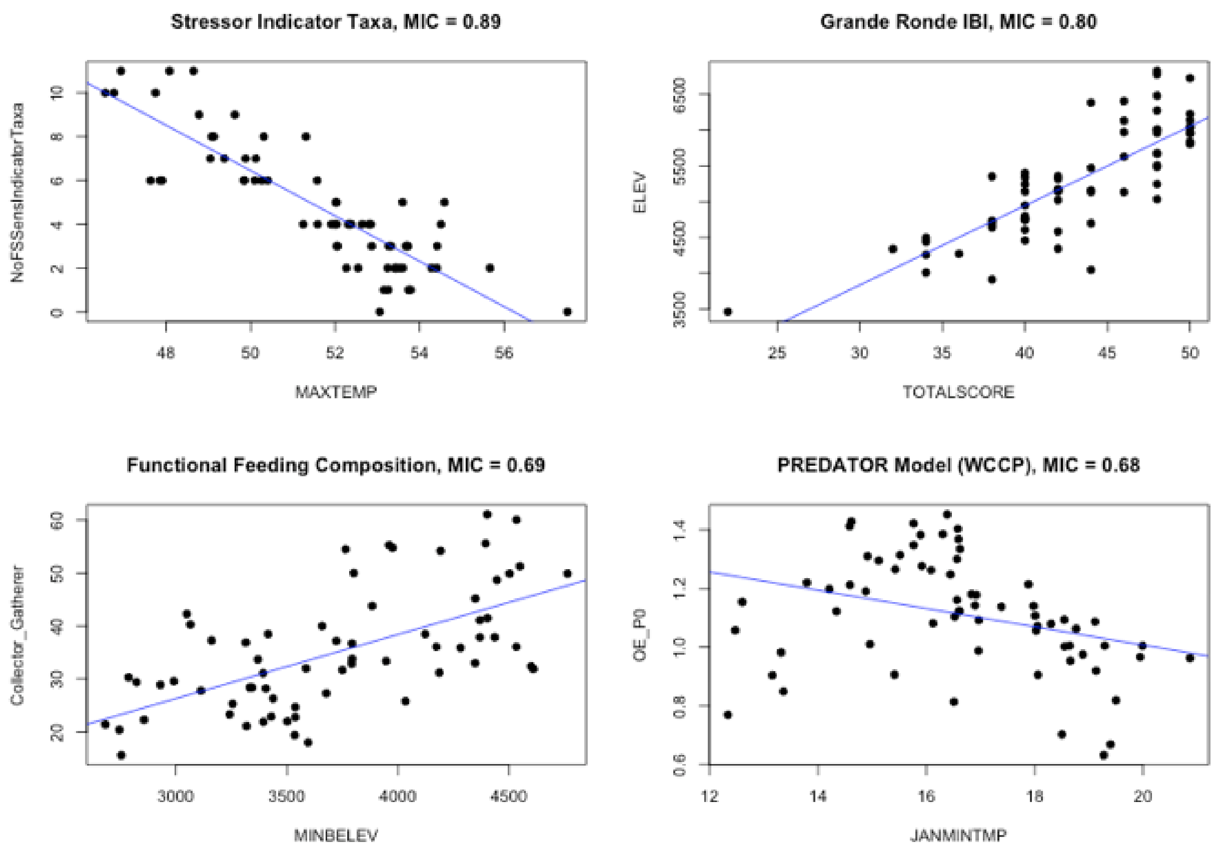

Figure 7. Best relationships between categories of 2014 benthic macroinvertebrate scores from the upper Grande Ronde River, Catherine Creek, and Minam Rivers and StreamStats watershed characteristics, based on highest maximal information coefficient (MIC) scores. See text for translation of axis abbreviations.

Structural equation modeling (SEM) results from BMIs across all three watersheds using data from 2011-2013 are shown in Figure 8. These results demonstrated that, after accounting for position in the watershed, large wood was associated with a direct increase in stonefly taxa richness, and large wood was greater in areas with more tree canopy closure, as measured by solar radiation. A large portion (69%) of variability in stonefly taxa richness was explained by the single variable of large wood frequency.

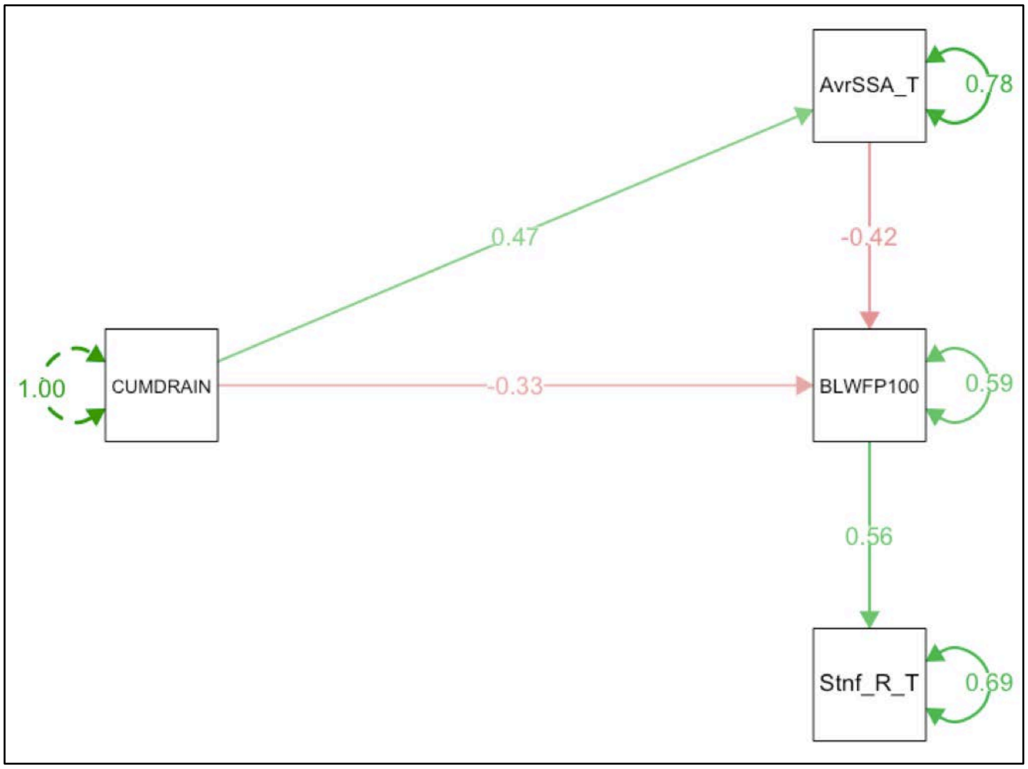

Figure 8. SEM results linking cumulative drainage area (CUMDRAIN) with solar radiation (AvrSSA_T, a proxy for tree canopy closure), large wood frequency within the bankfull channel (BLWFP100), and stonefly taxa richness (Stnf_R_T). Direction of arrows indicates the hypothesized direction of causal effect, whereas the color, shade, sign, and magnitude of the path coefficients indicate the direction and strength of the relationship (green is positive, red is negative, coefficients closer to |1| and darker shade of arrow are stronger). Values in double-headed arrows are amount of variance explained for dependent variables (analogous to r^2 in linear regression).

Stream Habitat

CHaMP Habitat Surveys

A summary of seven important CHaMP habitat metrics including percentage fines less than 2 mm, percentage cobbles, large woody debris (LWD) frequency (count/100 m), percentage total fish cover, percentage slow water, residual pool depth (m), and drift biomass (g/m^3) within each Chinook population group, valley setting classification, and Biologically Significant Reaches (BSR) is provided (Table 4). This data includes sites sampled by both CRITFC and ODFW within the Chinook habitat extent, which encompasses 120 unique sites (n) and 225 visits. Data at each site were averaged across all years, 2011-2014, and then average values and standard deviations were summarized across the various spatial units.

The habitat values within the three ICTRT population regions were similar overall with a few variables that stood out as distinctive. Catherine Creek had the highest mean values in five of the seven variables, percentage fines, percentage cobbles, LWD frequency, percentage fish cover, and drift biomass. The average drift biomass values for Catherine Creek, 0.000545 g/m^3, and for the upper Grande Ronde, 0.000447 g/m^3, both greatly exceed the average biomass observed in the Minam River, 0.000151 g/m^3. The Minam River had the lowest average percentage fines, 5.95%, while fines in Catherine Creek and the Grande Ronde were 12.48% and 11.03% respectively. The Minam also had the lowest percentage fish cover (9.41%) and the highest residual pool depth (0.45 m) amongst the three watersheds. The Grande Ronde population sites had the lowest average percentage cobbles (31.66%), LWD frequency (9.46/100 m), and residual pool depth (0.31 m).

The six valley setting classes showed characteristics that were separated most notably by the mountain and floodplain/constrained channel characteristic, especially with Floodplain/Constrained Confined (FCC) and Floodplain/Constrained Partly Confined (FCPC) classes having average values distinct from the other classes. The largest deviations from the other four valley classes were observed in percentage fines, percentage fish cover, and percentage slow water, where the FCC and FCPC valley setting classes had average values lower than those seen in the mountain valley setting classes and the Floodplain/Constrained Laterally Unconfined (FCLU). The floodplain/constrained valley setting group as a whole had higher residual pool depths and lower large wood frequency than the mountain valley classes. There were also some notable distinctions based on valley confinement. Average values of percentage cobbles reflected confinement differences rather than valley setting, where the largest percentage cobbles were observed in the confined valley setting classes, followed by the partly confined, and then the unconfined classes.

The summary data presented by BSR demonstrate how variable the number of survey locations can be within different BSRs. There are seventeen BSRs that cover the three watersheds. The greatest number of survey sites found within a single BSR is 23 in the UGR13 BSR, the Meadow Creek drainage. Conversely, there are two BSRs within the upper Grande Ronde that have only a single survey site, UGR10-Five Points Creek and UGR18-Limber Jim Creek. Roughly half of the BSRs have five or fewer sites. This uneven distribution of sites within different BSRs supports the potential use of the valley setting classification in the future summarization and extrapolation of metrics. Using the valley setting classification to assess habitat variables demonstrates a more evenly spaced sampling effort when compared to the BSRs. The least sampled valley setting classification is the floodplain/constrained laterally unconfined (FCLU, n=8) and the most heavily sampled type was the floodplain/constrained partly confined (FCPC, n=43).

In future modeling efforts we plan to use GRTS to summarize data by valley setting classes and then use distinct river segments in each BSR to roll up metrics based on the proportion of each class in a BSR. This will allow us to downscale our GRTS estimates from the whole watershed scale to a finer resolution (e.g., BSR) while leveraging knowledge of habitat data in specific river types. We hope to explore how this method may improve our estimates and extrapolation of habitat variables and fish populations.

Table 4. Summary statistics for seven habitat variables measured at all CHaMP sites across the Upper Grande Ronde River, Catherine Creek, and the Minam River. Values for each site were averaged over all survey years, 2011-2014 and then summarized based on three different spatial extents: Interior Columbia Technical Recovery Team (ICTRT) populations, valley confinement classification, and biologically significant reaches (BSR). For each habitat variable, mean, standard deviation (SD), and the number of sites that had data values (n) are recorded.

Spatial Extent	% Fines <2 mm			% Cobbles			LWD Frequency (count/100 m)			% Total Fish Cover			% Slow Water			Residual Pool Depth (m)			Drift Biomass (g/m^3)		
ICTRT Populations	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*
Catherine Creek	12.48	13.88	37	36.6	13.14	36	12.53	11.34	36	12.05	8.76	35	21.64	12.77	36	0.39	0.16	36	0.000545	0.002237	40
Minam River	5.95	7.40	14	34.39	9.81	15	10.17	8.99	15	9.41	4.11	15	23.97	15.51	15	0.45	0.24	15	0.00015	0.000098	6
Upper Grande Ronde River	11.03	12.01	62	31.66	12.37	48	9.46	12.06	48	11.81	9.44	48	26.06	16.96	48	0.31	0.14	48	0.000447	0.000565	53
Valley Setting Classification	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*
FCC	7.79	7.29	26	37.29	10.02	25	9.53	10.54	25	9.68	5.02	24	18.49	11.38	25	0.37	0.17	25	0.000069	0.000282	24
FCPC	7.66	7.66	43	35.91	11.54	37	7.07	6.66	37	8.64	4.72	37	8.64	4.72	37	0.38	0.17	37	0.000344	0.000475	32
FCLU	19.80	21.47	7	23.28	17.87	8	9.91	10.64	8	15.61	9.79	8	37.09	20.70	8	0.52	0.23	8	0.000715	0.001023	8
MC	11.37	6.81	15	36.25	10.93	10	20.64	17.58	10	14.75	2.49	10	24.33	12.26	10	0.32	0.10	10	0.001143	0.003643	15
MPC	19.72	17.14	9	29.72	16.71	7	17.22	13.83	7	19.24	19.6	7	28.19	15.32	7	0.23	0.17	7	0.000347	0.000362	9
MLU	16.15	20.44	13	27.75	9.42	12	12.66	12.89	12	14.22	11.94	12	36.39	19.31	12	0.29	0.10	12	0.000236	0.000278	11
Biologically Significant Reach	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*
CC2A	51.20	69.01	2	19.00	26.87	2	1.57	2.22	2	23.85	12.24	2	20.79	29.41	2	0.09	0.13	2	0.00728	0.009916	2
CC3A	22.57	16.07	3	29.02	14.94	4	9.07	11.41	4	7.52	7.86	3	31.36	7.36	4	0.50	0.25	4	0.000143	0.000105	4
CC3B1	5.01	3.73	7	41.47	11.57	8	6.62	4.35	8	9.48	4.13	8	20.14	10.35	8	0.48	0.13	8	0.000169	0.000153	8
CC3B2	6.42	5.26	7	47.24	7.53	7	14.07	7.18	7	8.06	5.55	7	25.68	17.16	7	0.43	0.08	7	0.00021	0.000182	7
CC4	40.45	29.03	3	22.53	5.75	3	22.40	9.04	3	27.86	17.12	3	28.43	7.45	3	0.19	0.10	3	0.000083	0.000098	3
CC5	11.88	8.48	16	36.12	8.93	12	16.09	14.99	12	11.32	4.08	12	15.48	9.30	12	0.36	0.08	12	0.000215	0.00024	17
MRC3	8.78	7.97	9	33.50	10.45	10	9.20	9.08	10	8.30	4.28	10	28.33	16.11	10	0.48	0.28	10	0.000157	0.000107	5

MRC4	0.86	0.78	5	36.17	9.21	5	12.12	9.49	5	11.62	2.93	5	14.94	10.44	5	0.40	0.18	5	0.000111	NA	1
UGR10	3.33	NA	1	31.48	NA	1	0.85	NA	1	5.65	NA	1	17.67	NA	1	0.28	NA	1	0.000339	NA	1
UGR11	5.19	1.96	5	38.66	5.39	4	0.37	0.37	4	6.57	5.61	4	17.68	16.67	4	0.40	0.12	4	0.000426	0.000299	5
UGR12	5.28	2.93	7	38.78	9.86	5	1.54	0.97	5	8.30	6.13	5	16.02	9.36	5	0.27	0.14	5	0.000619	0.000849	7
UGR13	10.13	12.60	23	27.44	10.13	20	6.93	10.91	20	11.87	5.95	20	27.37	16.62	20	0.30	0.13	20	0.000536	0.000695	14
UGR15	10.38	9.88	8	36.60	14.59	6	7.03	3.96	6	9.97	7.70	6	17.94	13.10	6	0.33	0.20	6	0.000538	0.000703	8
UGR16	6.63	6.46	4	52.45	6.24	2	4.30	2.09	2	6.06	1.33	2	18.27	3.74	2	0.32	0.07	2	0.000261	0.000151	4
UGR18	10.50	NA	1	26.92	NA	1	37.68	NA	1	12.65	NA	1	51.56	NA	1	0.35	NA	1	0.000074	NA	1
UGR19	22.05	19.86	7	27.76	18.91	5	18.81	9.26	5	24.09	21.39	5	40.70	24.50	5	0.22	0.12	5	0.000222	0.000149	8
UGR20	18.33	8.23	6	25.15	7.05	4	30.74	7.53	4	12.71	5.43	4	33.92	12.01	4	0.40	0.13	4	0.000438	0.00046	5

Analysis of CHaMP Data Relative to Landscape Metrics

Linear mixed-effects modeling indicated that key CHaMP habitat metrics (large woody debris, percentage pool area, and to a lesser extent, pool tail fine sediment), were significantly correlated with GIS-derived landscape characteristics. The best fitting model for large woody debris (LWD) frequency included the explanatory variables elevation (positive effect), bankfull width (negative effect), and tree cover (positive effect), and together explained approximately 90% of the variation in LWD. The top model for percentage pool area included elevation (positive effect), valley width index (positive effect), watershed area (negative effect), slope (negative effect), and large woody debris frequency (positive effect) as explanatory variables, together explaining 88% of the variation in pools. In contrast with LWD frequency and percentage pools, the best fitting model for pool tail fines <2 mm was relatively weak ($R^2 = 0.44$). Despite statistically significant effects of elevation, valley width index, road density, and drainage density, this model was not a reliable predictor of fine sediment in pool tails.

Spatial statistical network models showed promise for predicting LWD frequency as a function of landscape/land use characteristics and position in the watershed, but did not compare favorably with mixed-effects models for fine sediment or pool area metrics. These models will be used to predict habitat conditions at unsampled prediction points spaced every 500 m across the stream network. Prediction sites will then be rolled up using block kriging or simple averaging to calculate average habitat conditions at the scale of Biologically Significant Reaches (BSRs), the spatial unit used in our life cycle model. Detailed results from this analysis are provided in Appendix D.

Water Temperature

Overall, the upper Grande Ronde basin had warmer stream temperatures than Catherine Creek. Of the 21 sites sampled in the Grande Ronde basin, 17 had 7dAM temperatures that exceeded the DEQ temperature standard of 18˚C set for juvenile salmon and trout rearing during the summer period (Table 5). Of those 17, 11 sites exceeded that threshold during the entire summer. In the Catherine Creek basin, 8 of the 15 sites had 7dAM temperatures that exceeded the 18˚C threshold (Table 6). Three out of the 4 sites lowest in the watershed exceeded the 18˚C threshold all summer. In both basins, the segments of streams that met the water temperature standards were located in the headwater regions.

Average temperature in the upper Grand Ronde basin ranged from 12.1˚C to 21.2˚C (mean 16.1 ˚C). Maximum temperatures in the basin reached upwards of 30.1˚C in the lower reaches of the mainstem Grande Ronde. Average temperatures in Catherine Creek ranged from 11.0˚C to 17.9˚C (mean 14.5˚C). The highest temperature recorded in the basin was 21.7˚C. All sites in the Catherine Creek basin that maintain lower temperatures were upstream of the North Fork and South Fork Catherine Creek confluence.

The downstream temperature increases were very pronounced in the two basins. We plotted summer temperatures at five sites in the watershed to demonstrate the steady rise of temperatures as both Catherine Creek and the Grande Ronde River travel down through their basin (Figure 9). In the figure, the blue lines denote the three sites in the upper Grande Ronde basin above the city of La Grande starting from high in the basin (Grande Ronde River-mine tailings), to a mid-basin site (Grande Ronde

River-below Vey Meadows), to the lowest site (Grande Ronde River-above Five Points Creek). The red lines show two temperature records from the Catherine Creek basin, the North Fork Catherine Creek site above Middle Fork Catherine Creek, which is high in the watershed, and Catherine Creek in the city of Union, one of the lowest sites in the basin. The North Fork Catherine Creek site and the Grande Ronde River-mine tailings site are examples of headwater locations with average daily stream temperatures that are optimal for salmonids (i.e., rarely exceeding 15°C). The Grande Ronde River-below Vey Meadows and the Catherine Creek-Union sites have a similar temperature regime, where average temperatures exceed 18˚C regularly in July and August. Temperatures in this range are stressful for salmonids. The lowest Grande Ronde River site, above Five Points Creek, has average temperatures that exceed 20˚C for almost the entire survey timeframe. Reaches at these extreme temperatures are not suitable for juvenile salmonids for most of the summer. The high water temperatures in both watersheds in the middle to lower portions of the basins pose a serious threat to juvenile salmonids and severely limit the extent of streams that fish can utilize during the summer months.

We now have four years of temperature data and can start to look at variability and trends at different sites. Comparing temperatures at three sites starts to highlight patterns across the basin (Table 7). The sites selected for this comparison included South Fork Catherine Creek at the mouth, Sheep Creek (a headwater tributary of the Grande Ronde River), and the Grande Ronde River above Beaver Creek. These three sites were compared in last year's Annual Report (McCullough *et al*. 2014) and this analysis builds on those records. Sheep Creek and South Fork Catherine have similar temperature regimes, with almost identical averages and maximum 7-day rolling average of average temperature (Max7dAA), but Sheep Creek maintains roughly 1˚C higher maximum and Max7dAM temperatures. These higher temperatures are enough to result in Sheep Creek exceeding the DEQ 18˚C 7dAM temperature standard at times during the summer period, while South Fork Catherine never exceeds that threshold. The Grande Ronde River site is lower in the Grande Ronde basin and has 7dAM values that exceed the 18˚C temperature standard for the entire summer period.

Overall temperature patterns across the four years are similar at all three sites though there were some variations between the two basins. The highest 7dAM (Max7dAM) in the Grande Ronde Basin was recorded in 2013 along with the most 7-day periods where the 7dAM were highest. The highest 7dAM temperatures was not recorded in the Catherine Creek basin in 2013; however, this value was very similar for 2012, 2013, and 2014 at the South Fork Catherine Creek site. All three sites had highest average temperatures in 2013. The record for the highest maximum temperature was set in 2014 for all three sites as well as the highest 7-day average temperature. Annual patterns showed that 2011 was the coolest year across the sites while 2013 and 2014 both set records for having the highest temperatures in different metrics. Overall variability within sites was low with most metrics varying by less than 2˚C over the four-year period. The maximum and Max7dAM at the Grande Ronde River site varied the greatest amount, approximately 2.5˚C.

Continuing to sample temperature at sites across the basin will provide observations with which we can calibrate and test model predication accuracy. We have developed the Heat Source model with which we can test potential vegetation restoration scenarios and assess the influence of vegetation alterations on stream temperatures. Additionally, the combination of CHaMP and CRITFC temperature sites provide

a wide distribution of monitoring locations across the basin while targeting dynamic locations such as tributary junctions. These sites will continue to be useful in our attempts to extrapolate temperature predications across the watershed.

Table 5. Summary of summer temperatures (˚C) observed at CHaMP and CRITFC sites in the upper Grande Ronde basin between July 15th and August 31st, 2014. Daily metrics included were average (Avg) and maximum (Max) stream temperatures. Rolling average maximum weekly temperatures (7dAM) were calculated and reported as the maximum 7dAM recorded (Max7DAM) and the number of 7dAM periods that exceed specific thresholds (12, 13, 16, 18, 20, 22˚C). There were 42 7-day periods over the reported timeframe and all sites included 1152 hourly records. Values where the ODEQ temperature standard for juvenile rearing (18˚C) was exceeded are highlighted in gray.

Stream	Site	Avg	Max	Max7dAM	12˚C	13˚C	16˚C	18˚C	20˚C	22˚C
Grande Ronde Basin										
Limber Jim Creek	CBW05583-108010	12.14	17.11	16.13	42	41	7	0	0	0
Grande Ronde River	dsgn4-000009	12.66	17.89	16.97	42	42	22	0	0	0
Grande Ronde River	CBW05583-280042	12.63	17.94	17.02	42	42	22	0	0	0
Clear Creek	Clear_Cr_mouth	12.82	17.96	17.06	42	38	18	0	0	0
Grande Ronde River	CBW05583-148970	13.20	19.32	18.13	42	42	33	1	0	0
Sheep Creek	CBW05583-228666	13.19	19.15	18.39	42	42	27	6	0	0
Grande Ronde River	CBW05583-206314	13.75	20.13	19.01	42	42	34	18	0	0
Sheep Creek	CBW05583-490810	14.36	21.51	20.57	42	42	39	28	13	0
Sheep Creek	CBW05583-138554	15.57	23.50	22.47	42	42	42	36	24	5
Five Points Creek	Five_Points_Cr_mouth	17.23	23.45	22.73	42	42	42	42	29	6
Sheep Creek	Sheep_Cr_below_5160_Rd	15.67	24.07	22.77	42	42	42	38	26	13
Grande Ronde River	CBW05583-235322	17.56	25.21	23.60	42	42	42	42	34	19
Grande Ronde River	dsgn4-000277	17.57	25.70	24.16	42	42	42	42	40	24
Grande Ronde River	CBW05583-321338	17.59	25.65	24.21	42	42	42	42	40	25
Grande Ronde River	GR_below_Vey	17.79	26.01	24.61	42	42	42	42	42	29
Grande Ronde River	CBW05583-457530	18.03	27.06	24.78	42	42	42	42	39	26
Grande Ronde River	CBW05583-269114	18.08	26.52	25.12	42	42	42	42	42	28
Meadow Creek	Meadow_Cr_mouth	19.04	27.92	25.73	42	42	42	42	42	33
Grande Ronde River	dsgn4-000202	18.48	27.88	26.20	42	42	42	42	42	38
Grande Ronde River	dsgn4-000245	19.13	28.25	26.85	42	42	42	42	42	38
Grande Ronde River	GR_above_Five_Points_Cr	21.19	30.70	28.28	42	42	42	42	42	42
Average		16.08	23.47	22.13	42	42	36	28	24	16
Maximum		21.19	30.70	28.28	42	42	42	42	42	38

Table 6. Summary of summer temperatures (˚C) observed at CHaMP and CRITFC sites in the Catherine Creek basin between July 15th and August 31st, 2014. Daily metrics included were average (Avg) and maximum (Max) stream temperatures. Rolling average maximum weekly temperatures (7dAM) were calculated and reported as the maximum 7dAM recorded (Max7DAM) and the number of 7dAM periods that exceed specific thresholds (12, 13, 16, 18, 20, 22˚C). There were 42 7-day periods over the reported timeframe and all sites included 1152 hourly records. Values where the ODEQ temperature standard for juvenile rearing (18˚C) was exceeded are highlighted in gray.

Stream	Site	Avg	Max	Max7dAM	12˚C	13˚C	16˚C	18˚C	20˚C	22˚C
Catherine Creek Basin										
Middle Fork Catherine Creek	MF_CC_mouth	10.97	14.07	13.47	33	10	0	0	0	0
North Fork Catherine Creek	NF_CC_above_MF_CC	11.45	15.75	14.77	42	34	0	0	0	0
South Fork Catherine Creek	CBW05583-512938	11.36	15.84	15.02	35	33	0	0	0	0
North Fork Catherine Creek	CBW05583-138666	12.52	17.61	16.64	42	42	12	0	0	0
South Fork Catherine Creek	SF_CC_mouth	13.44	18.36	17.23	42	42	21	0	0	0
North Fork Catherine Creek	NF_CC_mouth	12.77	18.06	17.27	42	42	26	0	0	0
Catherine Creek	CBW05583-368042	13.35	18.84	17.67	42	42	33	0	0	0
Little Catherine Creek	CBW05583-155818	14.76	19.01	18.26	42	42	34	4	0	0
Catherine Creek	CBW05583-456106	14.18	19.34	18.32	42	42	34	9	0	0
Catherine Creek	dsgn4-000010	15.48	20.20	19.82	42	42	42	36	0	0
Catherine Creek	CC_HWY_203	16.19	22.44	21.08	42	42	42	40	23	0
Catherine Creek	CBW05583-430250	16.94	21.46	21.21	42	42	42	34	11	0
Catherine Creek	CBW05583-217258	17.89	22.66	21.59	42	42	42	42	34	0
Catherine Creek	CBW05583-405674	17.57	23.35	21.72	42	42	42	42	34	0
Catherine Creek	dsgn4-000204	17.86	23.71	21.99	42	42	42	42	34	0
Average		14.45	19.38	18.40	41	39	27	17	9	0
Maximum		17.89	23.71	21.99	42	42	42	42	34	0

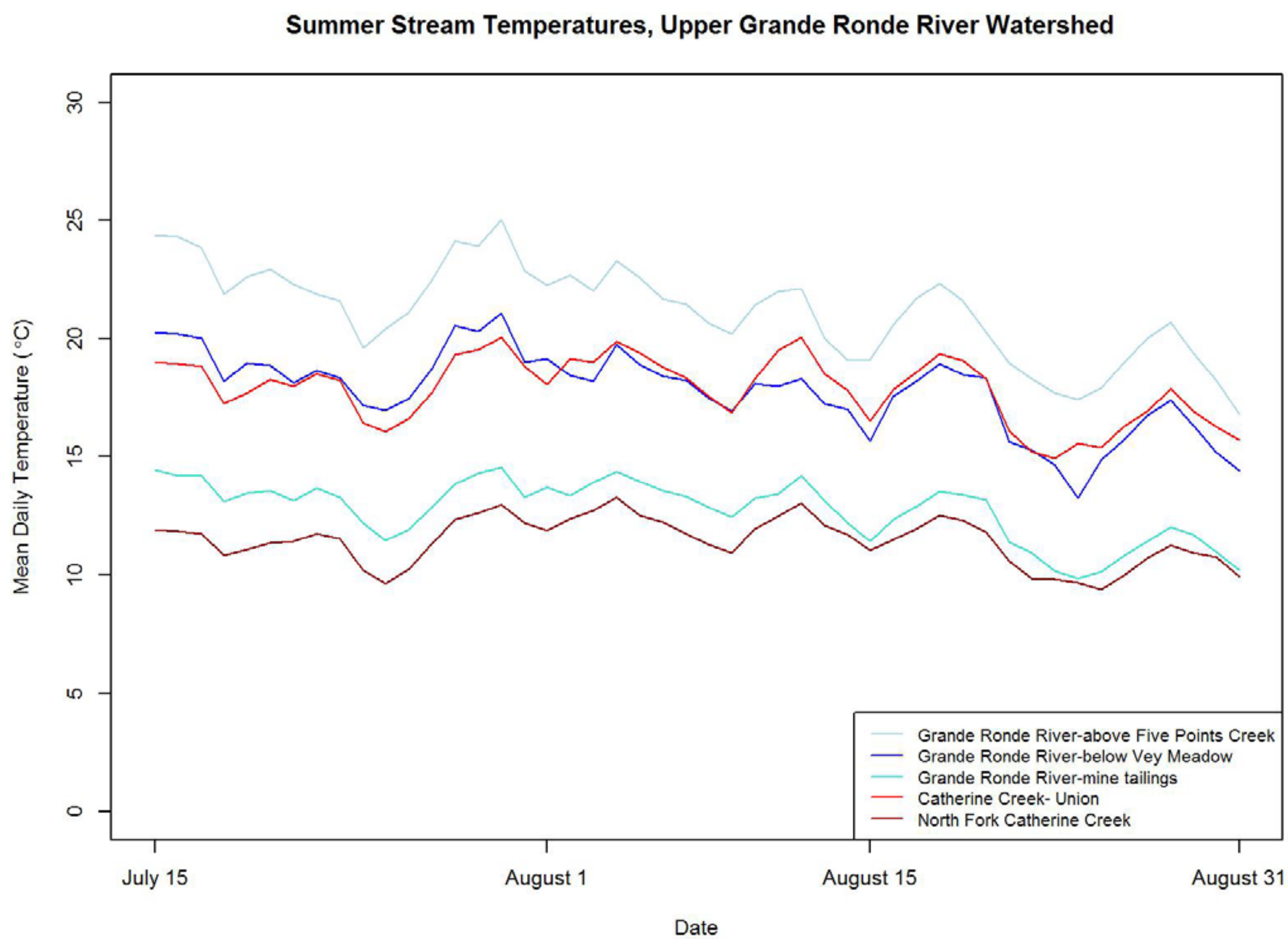

Figure 9. Plot of average daily temperature records from five sites across the upper Grande Ronde River watershed during the summer period (July 15th-August 31st) in 2014. Three sites are along the mainstem Grande Ronde River— Grande Ronde River- above Five Points Creek (the lowest site in the basin), Grande Ronde River- below Vey Meadows, and Grande Ronde River-mine tailings (dsgn4-000009) near the headwaters of the river. Two sites are in the Catherine Creek Basin: Catherine Creek in the city of Union (dsgn4-000204) and the North Fork Catherine Creek above the Middle Fork Catherine Creek.

Table 7. Annual comparison of temperature metrics (˚C) in three streams across the upper Grande Ronde basin—South Fork Catherine Creek at its mouth, Sheep Creek (a tributary to the Grande Ronde), and the Grande Ronde River. Daily metrics included were average (Avg), minimum (Min), and maximum (Max) stream temperatures. A 7-day rolling average of the average weekly temperature (7dAA) was calculated and the highest 7dAA (Max7dAA) temperature was reported. Rolling average maximum weekly temperatures (7dAM) were calculated and reported as the highest 7dAM recorded (Max7DAM) as well as the number of 7dAM periods that exceed specific thresholds (12, 13, 16, 18, 20, 22˚C). There were 42 7-day periods over the reported timeframe and all sites included 1152 hourly records.

South Fork Catherine Creek Mouth	Avg	Min	Max	Max7dAA	Max7dAM	12˚C	13˚C	16˚C	18˚C	20˚C	22˚C
2011	11.75	6.68	16.15	13.55	15.51	40	34	0	0	0	0
2012	13.38	6.99	18.34	14.64	17.23	42	40	29	0	0	0
2013	13.71	9.16	17.89	14.4	17.22	42	42	26	0	0	0
2014	13.44	7.99	18.36	14.88	17.22	42	42	21	0	0	0
Sheep Creek (CBW05583-22866)	Avg	Min	Max	Max7dAA	Max7dAM	12˚C	13˚C	16˚C	18˚C	20˚C	22˚C
2011	11.93	7.57	17.32	13.18	16.72	42	42	10	0	0	0
2012	13.11	6.41	18.86	14.17	17.96	42	42	34	0	0	0
2013	13.38	8.49	18.98	14.11	18.69	42	42	35	9	0	0
2014	13.32	6.86	19.39	15.07	18.39	42	42	27	6	0	0
Grande Ronde River above Beaver Creek (dsgn4-000245)	Avg	Min	Max	Max7dAA	Max7dAM	12˚C	13˚C	16˚C	18˚C	20˚C	22˚C
2011	17.98	10.83	26.11	19.66	25.04	42	42	42	42	41	37
2012	19.17	9.36	27.41	20.43	26.5	42	42	42	42	42	39
2013	19.48	11.44	27.97	20.73	27.57	42	42	42	42	42	42
2014	19.34	11.29	28.54	21.39	26.85	42	42	42	42	42	38

For Oregon as a whole, the NorWeST model (Isaak *et al*. 2014) performed well (r^2 = 0.90, RMSE = 1.0˚C), and was even stronger when looking at the Middle Columbia Region which includes the Grande Ronde basin (r^2 = 0.94, RMSE = 0.91˚C). Our comparison within the Grande Ronde basin however suggests that the NorWeST model within the Grande Ronde is performing well, but not as strongly as the regional and statewide models (Figure 10). We isolated the upper Grande Ronde watershed into four different sections for this analysis: the Grande Ronde River above the city of La Grande (n=10), the Grande Ronde watershed above the city of La Grande (n=28), Catherine Creek watershed (n= 14), and the entire upper Grande Ronde watershed (n=47). The Grande Ronde River (Figure 10 a) correlation was the strongest, though universally the model under-predicted temperatures (r^2 = 0.9895, RMSE = 0.65). In Figure 10 b, tributary sites that were above the city of La Grande were added to the sites on the Grande Ronde River; the resultant correlation is not as strong (r^2 = 0.8401, RMSE = 0.97), suggesting that there was more variability in the accuracy of the tributary predictions. The Catherine Creek watershed (Figure 10 c) showed a strong correlation with one significant outlier (r^2 = 0.8857, RMSE = 1.14, with the outlier; r^2 = 0.9867, RMSE = 1.08, without the outlier). At all sites within the watershed, except for the outlier site, temperatures were under-predicted by the NorWeST model, even more so than in the Grande Ronde River. The observed temperatures at the outlier site were much lower than the predicted temperatures and may be due to the water discharged from the Union City waste water treatment plant or because the NorWeST model does not adequately account for water withdrawals in the city of Union. The correlation for all sites in the upper Grande Ronde watershed (Figure 10 d) showed a further decrease in the model's prediction strength (r^2= 0.8198, RMSE = 1.09).

These results are promising. However, the Grande Ronde watershed models are not as strong as the regional or statewide models. The correlation was strongest on the larger rivers, Grande Ronde River and Catherine Creek, but was weaker when the basin as a whole was evaluated. Data collected by CHaMP and CRITFC could be leveraged to improve the SSNM and its ability to predict temperatures locally. We could add information from upwards of 157 sites, which would fill in some of the areas where the NorWeST data has gaps, and hopefully be able to predict temperatures on the tributaries with better accuracy. Likewise, with a Grande Ronde focused model we would hope to avoid under-prediction of temperatures as observed with the NorWeST model, and would in turn improve our confidence in future climate scenario predictions.

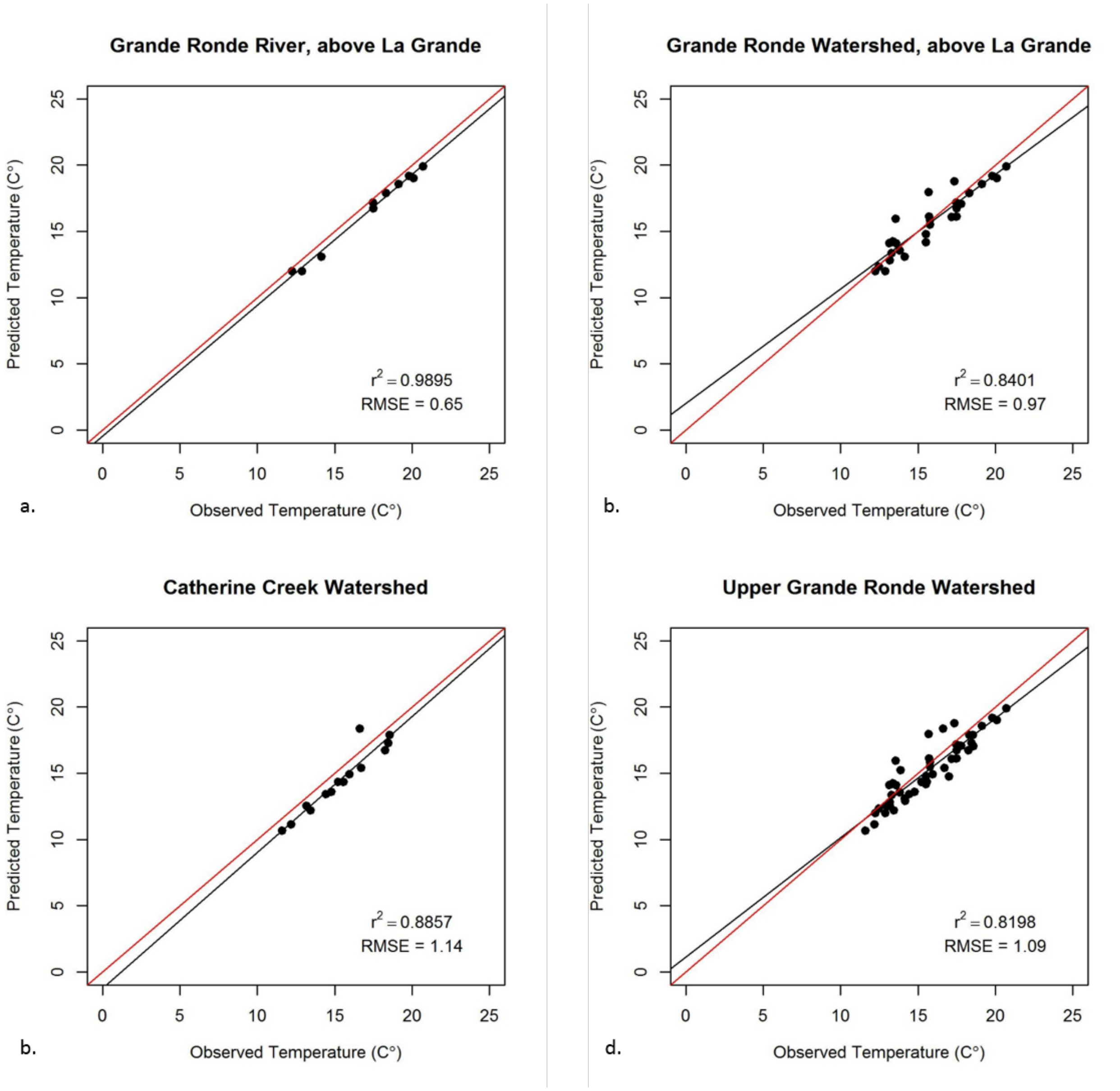

Figure 10. Observed vs. NorWeST predicted temperatures for 2013 in the upper Grande Ronde watershed. Panels show a) sites on the Grande Ronde River above the city of La Grande (n=10), b) sites in the entire Grande Ronde basin above La Grande including tributary sites (n=28), c) sites in the Catherine Creek watershed (n=14), and d) all sites in the Upper Grande Ronde watershed (n=47). The red line is the 1:1 line and the black line is the observed vs. predicted regression line.

Water Chemistry

Alkalinity data from CHaMP surveys were similar to that collected by ODEQ, so the two data sets were merged and plotted using ArcMap. Total alkalinity data ranged from 20-40 mg/l in the headwaters of the upper Grande Ronde mainstem (Figure 11). Similar results were found in the headwaters of Sheep Creek, Limber Jim Creek, Beaver Creek, Lookout Creek (Fly Creek tributary), Dark Canyon, Five Points, and McCoy Creek. Meadow Creek had generally higher alkalinity values, ranging from 40-60 in the

headwaters to 60-100 mg/l in the lower reaches. The mainstem Grande Ronde from the confluence of Sheep Creek and the upper Grande Ronde, downstream to Five Points Creek, and beyond throughout the State Ditch, tended to be 40-60 mg/l. Many of the high values observed (100-200 mg/l) were attributable to landfills and sewage plant releases. The headwaters of the NF Catherine Creek and the SF Catherine Creek downstream through Hall Ranch (near mouth of Milk Creek) were generally 20-40 mg/l. From the mouth of Milk Creek on the mainstem Catherine Creek to the confluence with Ladd Creek, alkalinities ranged from 20-60 mg/l. A high value of 157.5 occurred at the Union Sewage Treatment outfall. A value of 105 mg/l occurred at the mount of Middle Fork Catherine Creek in a CHaMP survey. This value may represent a spurious measurement because this is a relatively natural area and has a value of 20-40 upstream by 2.3 km.

Conductivity in the headwaters of the upper Grande Ronde mainstem ranged from 33.6-52.2 µS for the summer period (Figure 12). Chicken and West Chicken ranged from 53-71 µS. Sheep Creek ranged from 53 to 145 mS. Meadow/McCoy/Dark Canyon/Burnt Corral Creek values measured by CHaMP partners ranged from 69 to 152 µS (n=26). Meadow/McCoy/Dark Canyon Creek values measured by ODEQ ranged from 106 to 125 µS. The mainstem Grande Ronde from Meadow Creek mouth to Five Points Creek ranged from 70 to 99 µS, except for a single value of 22, which was probably spurious. Values recorded by ODEQ for the mainstem Grande Ronde from Five Points Creek downstream to below Phillips Creek were 72 to 160 µS, except for sewage outfalls and landfill outfalls, which ranged from 324 to 503 µS, and an industrial plant outfall of 1000 µS. NF and SF Catherine Creeks had conductivities ranging from 38.6 to 63.9 µS. Catherine Creek mainstem from the forks downstream to Pyles Creek mouth had conductivities ranging from 55 to 77.1 µS. Conductivity in Milk Creek ranged from 103 to 150.8 µS. Milk Creek, a lowland tributary that flows across a broad floodplain adjacent to Hall Ranch, had both high alkalinity and conductivity. Lower Catherine Creek, measured by ODEQ, ranged from 124 to 211.5 µS. It is clear that Catherine Creek headwaters are low in conductivity, and slightly higher than the Grande Ronde headwaters measured. As Catherine Creek passes into its lowlands, conductivities nearly quadruple. A similar tripling to quadrupling of conductivities during summer from the Grande Ronde headwaters measured to the lower reaches, extending to below Phillips Creek were observed. The lowlands of both upper Grande Ronde and Catherine Creeks were approximately in the same range (120-160 µS).

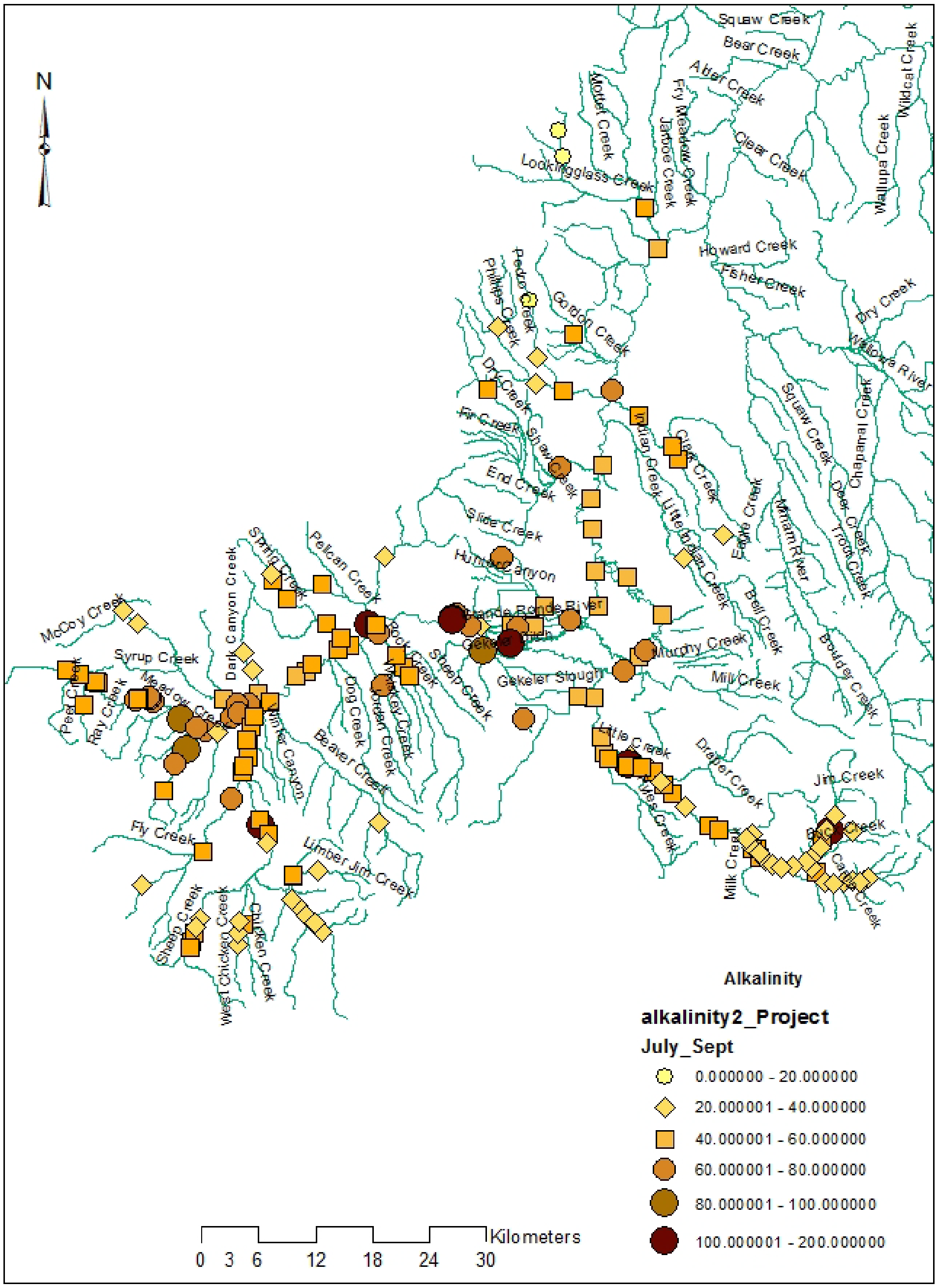

Figure 11. Alkalinity data for the summer field season (late June-September) from individual water samples collected by CHaMP crews (CRITFC and ODFW) in 2011-2014 and July-September by ODEQ from 1960-2012.

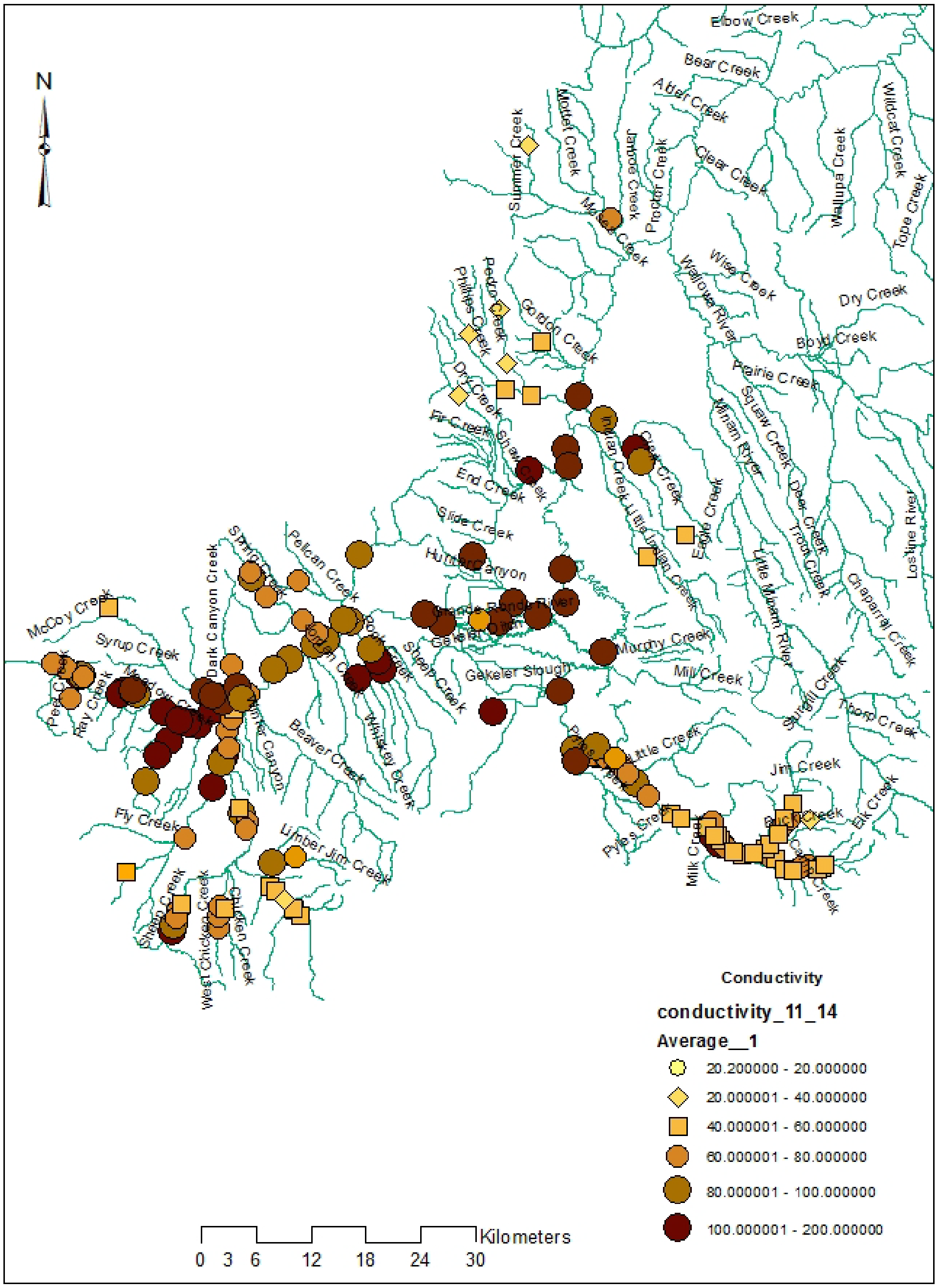

Figure 12. Conductivity data for the summer field season (late June-September) from individual water samples collected by CHaMP crews (CRITFC and ODFW) in 2011-2014 and July-September by ODEQ from 1960-2012. Centered on headwaters of upper Grande Ronde River.

Large Woody Debris (Remote Estimation)

A preliminary evaluation of the potential use of aerial imagery to quantify the frequency and volume of large woody debris indicated that when larger pieces of LWD (>3 m) are not obscured by shadows or canopy cover, it is feasible to measure their length using aerial imagery (Figure 13). Assumptions about

diameter based on length are probably not extremely far from the truth because there are few very large trees that might be broken in two and have exceptionally large diameters, thereby producing a significant deviation in the length-width relationship. One site of the three examined (dsgn4-000277) had a good correspondence between estimated and measured volume and frequency (pieces/100 m) (Table 8). It appeared that shadows and overhanging tree canopy created conditions making estimation of LWD from aerial imagery difficult. It is possible that some movement of individual pieces could have taken place from 2012 to 2013, but for the larger pieces this seems unlikely based on experience in this stream. Despite the inability to draw precise relationships between remote sensing and field-based measurements, the remote sensing technique could probably be relied upon to provide a measure of LWD > 6 m within stream reaches that have full visibility (i.e., no canopy and minimal shade). Conditions found in the lower extent of the Upper Grande Ronde make this a possible site where this method could be employed. The significance of large pieces of LWD in such a large channel width to set up debris jams makes this a viable method to address LWD better at a large spatial scale. Further, it might prove important to have a more directed high resolution aerial photo survey done to gather this information without such interference with long shadows.

Table 8. Comparison of large woody debris frequency and volume measured in the field and estimated from aerial imagery at three sites in the Upper Grande Ronde River.

	LWD volume and frequency measured in field in 2013		
Site	**Site bankfull LWD (m3)**	**Freq/100 m**	**Site length (wetted)**
CBW05583-031546	100.3	8.79	357.3
CBW05583-000245	15	3.97	613.3
CBW05583-000277	21.3	10.5	362.7
	LWD volume and frequency measured from high resolution aerial photos (2012)		
CBW05583-031546	19.18	4.2	
CBW05583-000245	4.3	0.33	
CBW05583-000277	22.84	4.69	

Figure 13. Contrast of Google Earth and higher resolution imagery on CBW05583-013546 for quantifying LWD.

Riparian Vegetation

Significant progress has been made in mapping of current and potential natural vegetation in the Upper Grande Ronde and Catherine Creek. The final vegetation map and summary report are expected to be completed during April of 2015. Of considerable interest is the potential recovery endpoint possible for Vey Meadows (Figure 14). This extensive, degraded spawning area holds the key to recovery of the Upper Grande Ronde population. If it were restored, this low gradient, potentially high quality spawning area could significantly increase the spawning and rearing potential of the Upper Grande Ronde River. Potential vegetation communities for this area include lodgepole pine moist meadow, herbland, and tall willow shrublands. While these vegetation communities would not provide the shade that apparently

was assumed as PNV in past modeling with Heat Source of thermal recovery of the Upper Grande Ronde, it would provide significant thermal recovery, which would likely result from the combination of improved shading, bank stability, and channel narrowing.

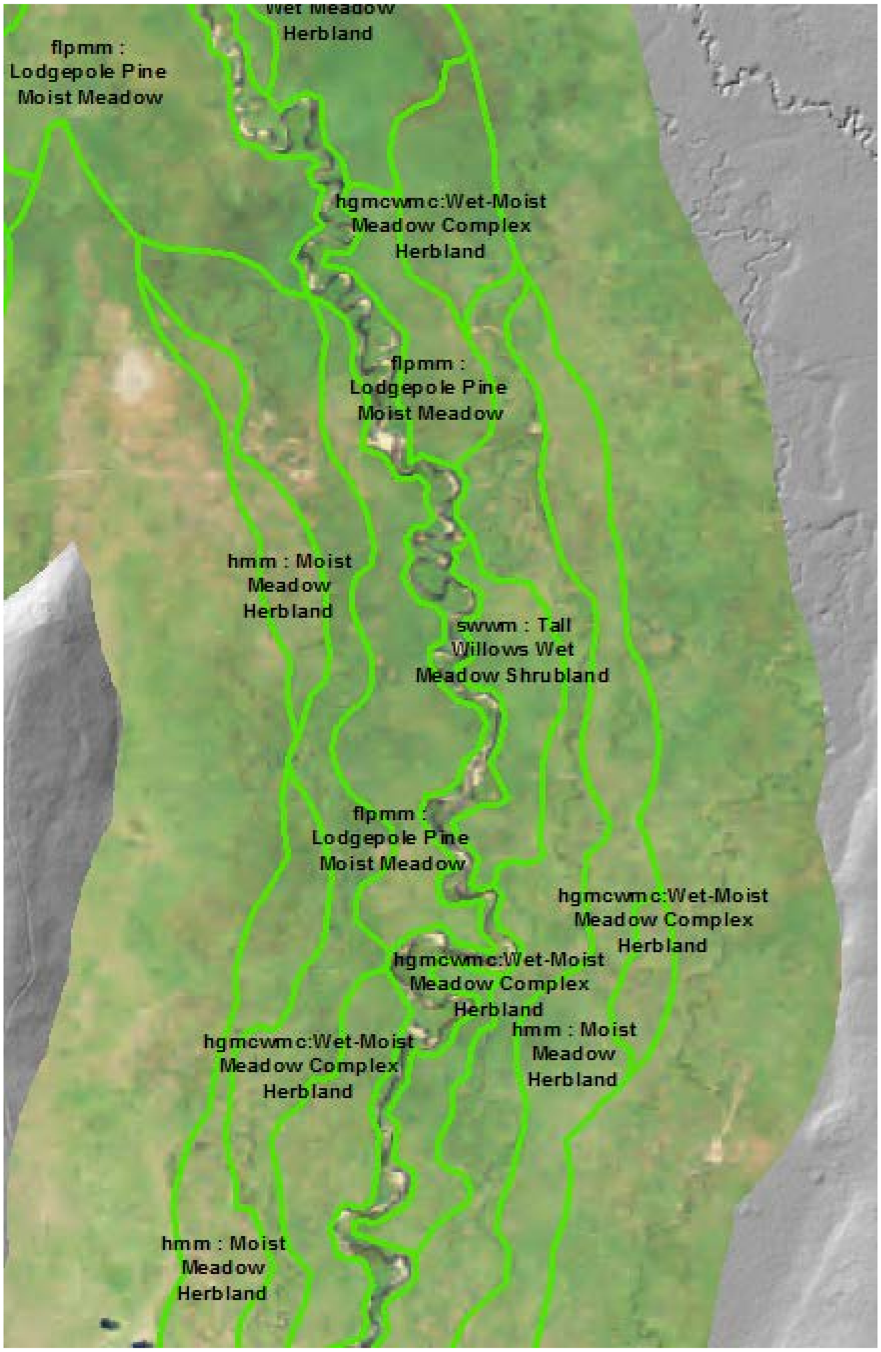

Figure 14. Section of Vey Meadows showing potential veg types over 2012 NAIP

Hydrology-Low Flows

Work on this project is now complete, with the exception of USGS and CRITFC final review of the report (see Appendix E) and subsequent use of the data for other analyses. A significant task in 2014 was deriving revised watershed characteristics for ungaged sites due to errors detected using the publically available USGS StreamStats tool ("Welcome to StreamStats." 2015. Accessed March 11. http://water.usgs.gov/osw/streamstats/). The necessity of re-calculating metrics allowed for the opportunity of incorporating estimates at CHaMP sites newly added to the project in 2014. The strongest patterns in streamflow were measures of low-flow variability (Q98), timing of seasonal low-flows (Julian day) and baseflow index (BFI) based on the watershed characteristics stream drainage density, average January maximum air temperature, and mean annual precipitation. Low-flow estimates were generated for 195 ungaged locations, which include all CHaMP sites current to 2014 and all HUC6-Assessment Unit intersections in the upper Grande Ronde, Catherine Creek, and Minam River. We foresee utilizing these results to identify stream reaches vulnerable to low flows and associated high summer water temperatures.

Road Density

Of 172 watersheds analyzed for road density, ranging in drainage area from 4.5 to 3405.45 km^2 (mean 245.28 km^2), road density varied from 0.01 to 6.5 km/km^2 (mean 3.28 km^2). Road density calculated from the USFS system was 0.0% to 89.4% (mean 60%) of that calculated from the combination of USFS, TIGER, and CRITFC layers. Given that the mean road density for these 172 watersheds was 3.28 km/km^2, an average of only 60.0% of the actual road density being accounted for by the USFS system indicates that serious errors in modeling road-derived sediment would result from using this road layer alone.

Road density was also calculated for a riparian buffer (200 m on each side of the stream) for the mainstem Upper Grande Ronde or Catherine Creek and their major tributaries. Among the example watersheds analyzed, road density in riparian buffers was often similar to the watershed as a whole, but differed substantially for one watershed (CBW05583-138554) where riparian road density was 6.18 km/km^2 compared with 4.94 km/km^2 in the total watershed.

Restoration Database

Restoration project data were compiled into a comprehensive spreadsheet for our target watersheds. Nearly 4500 project sites were listed as separate records (i.e., rows in the spreadsheet), displaying available project information per site (i.e., columns) available from data sources. Additionally, we attributed each project location with presence/absence information for each subcategory type (Table 9). Project activities were categorized into actions and sub-categories, signifying each type of restoration for each project site. Actions and sub-categories were modified from BPA's AEM program, which accounts for most types of restoration currently taking place. The project spreadsheet was imported into ArcGIS 10.2.1 for spatial visualization and analysis. A mapped display of restoration projects creates the opportunity for processing data spatially (e.g., Figure 15 and Figure 16), and in relation to other landscape features such as ecoregions, topography, and landowner type.

Table 9. Restoration action types in the upper Grande Ronde and Catherine Creek basins, number of projects by sub-category, and metrics reported by data sources in CRITFC database.

Action	Sub-category (number of projects)	Reported metric	Instances metric reported
Fish Passage	Diversion screening (17)	Cubic feet per second diverted	15
		Number of passage improvements	3
	Removal of barriers (83)	Miles unblocked stream	42
		Number of passage improvements	73
Instream Structures	Large woody debris additions (157)	Miles large woody debris	125
		Log weirs (# installed)	9
		Acres large woody debris	11
		Number logs pieces	29
		Number logjam structures	36
	Bank stabilization (96)	Miles stream bank stabilization	73
		Acres stream bank stabilization	9
		Jetties, barbs (number of)	15
		Rock weirs, cross veins (number of)	16
	Boulder addition (45)	Miles boulders	33
		Acres boulders	3
		Number boulder structures	8
		Boulders (number of)	10
	Beaver activity (1)		0
	Engineered pools (9)	Number pools created	4
	Modification/removal of bank armoring (0)		
	Nutrient addition (2)		0
Off-Channel/Floodplain	Levee set-back or removal (12)	Acres riparian habitat created	1
		Miles of dike removal or modification riparian	1
	Floodplain reconnection or creation (33)	Miles floodplain restored	11
		Acres floodplain restored	12

Action	Sub-category (number of projects)	Reported metric	Instances metric reported
	Remeandering (38)	Acres channel reconfiguration	3
		Miles channel reconfiguration	20
		Miles main channel created	12
	Side-channel/alcove construction (19)	Acres side channel created	1
Off-Channel/Floodplain (continued)		Miles side channel created	11
		Backwater alcoves in feet	3
		New spring/tributary channels in feet	2
	Thermal refugia (1)		0
	Wetland restoration (24)	Acres wetland habitat restored	14
Riparian Improvement	Installed fencing (232)	Stream miles fenced	177
		Planting miles fenced	6
		Upland miles fenced	10
		Average buffer width fencing	5
		Riparian acres protected by fencing	159
		Upland acres protected by fencing	23
		Acres wetland habitat protected by fencing	2
		X-fencing (number of)	20
	Planting (217)	Number plants planted	22
		Riparian miles planted and/or seeded	147
		Acres riparian planted and/or seeded	106
		Upland miles planted and/or seeded	5
		Acres upland planted and/or seeded	18
		Wetland acres planted and seeded	4
		Seeding in pounds	19
		Sedge/rush mats in feet	4
	Invasive plant removal (3761)	Miles upland invasive control	0
		Miles riparian invasive control	3756

Action	Sub-category (number of projects)	Reported metric	Instances metric reported
		Acres riparian invasive control	3755
		Acres upland invasive control	3753
Sediment Reduction/Addition	Road decommissioning (72)	Feet average buffer width road obliteration	3
		Miles of trail/road recontoured/removed	65
		Miles trail/road recontoured/removed upland	3
		Acres road obliterated	8
Sediment Reduction/Addition (continued)	Improving agricultural/forestry practices (107)	Acres improved agriculture	82
	Spawning gravel addition (4)	Miles treated spawning gravel	2
Acquisition & Protection	Land acquisition, lease, or easement (59)	Acres of acquisition, lease, or easement	30
		Stream miles of acquisition, lease, or easement	31
		Years out acquisition, lease, or easement	1
Flow Augmentation	Water lease or purchase (28)	Cfs purchased or leased	10
		Acres of acquisition, lease, or easement pertaining to water lease or purchase	9
		Instream dates	9
	Irrigation improvement (14)	Acres improved irrigation	1
	Mitigate point source impacts (5)	Miles toxic cleanup	1
		Acres toxic cleanup	1
Total Projects	Total projects (4448)	Site length (miles)	4206
		Site area (acres)	4123

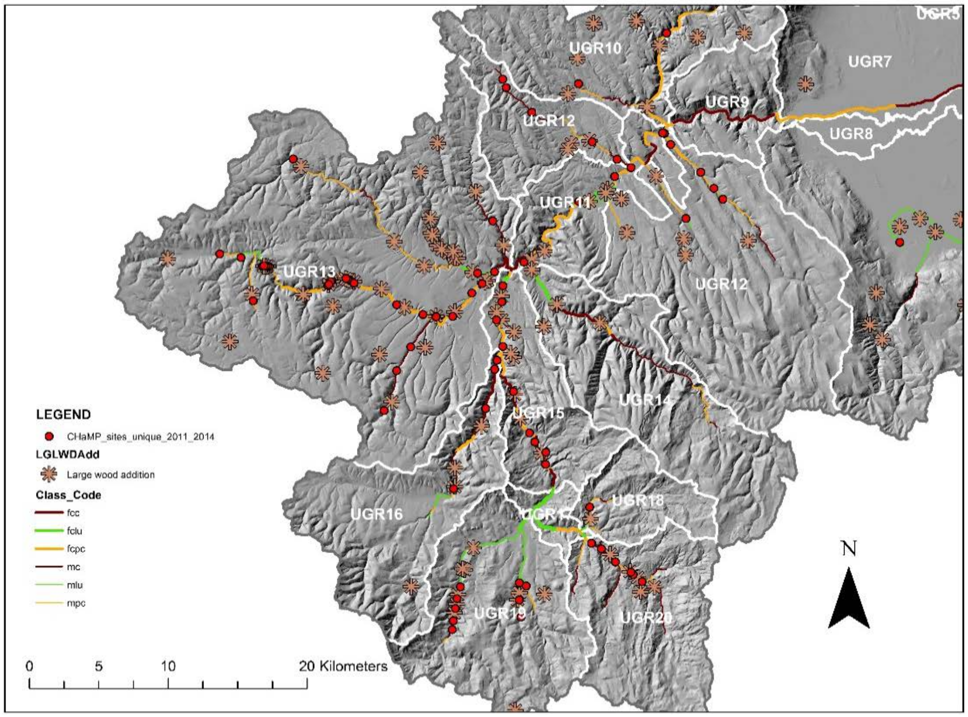

Figure 15. Large woody debris additions in relation to CHaMP sites in the upper Grande Ronde basin.

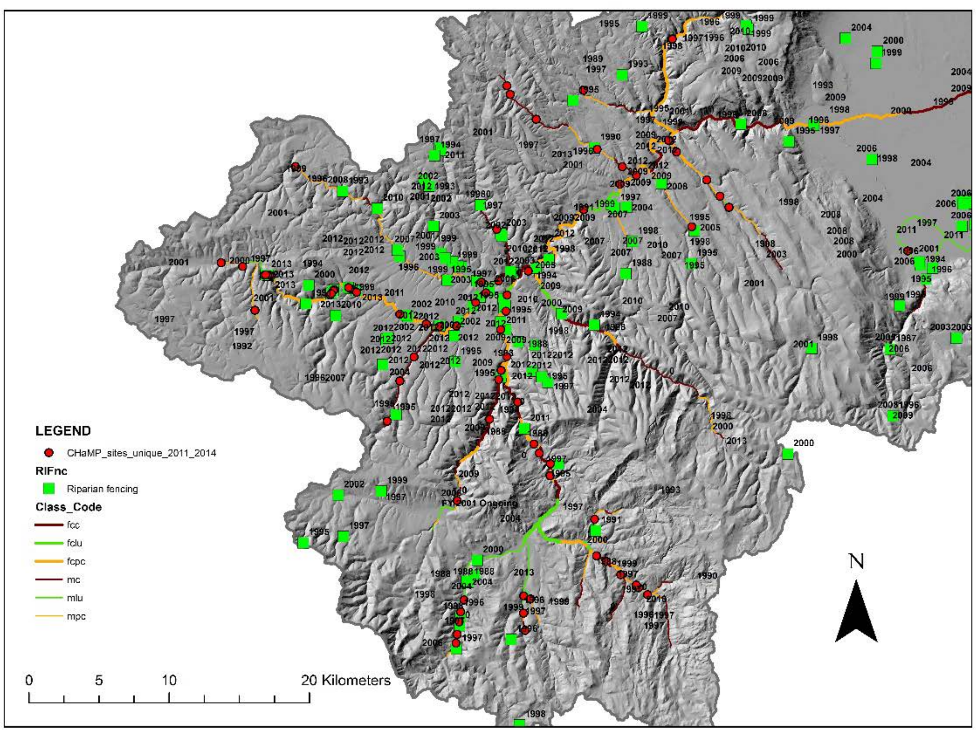

Figure 16. Riparian fencing projects, and year project was completed, in relation to CHaMP sites in the upper Grande Ronde basin.

Life Cycle Model

The maximum likelihood estimates of smolt productivities (Beverton Holt α parameters) for Catherine Creek and the Upper Grande Ronde were 166 and 1096 smolts per spawner at the origin when we assumed constant values of the productivity parameter. The value for the Upper Grande Ronde was very high when productivities were assumed to be constant, but when the deviation model was used, the rate averaged 156 smolts per spawner at the origin. The Catherine Creek deviation model productivity averaged 138 smolts per spawner at the origin. The maximum likelihood capacity estimates were 8,776 and 5,169 respectively for Catherine Creek and the Upper Grande Ronde.

The estimated in-river survival, ocean survival of transported fish, and ocean survival of in-river migrants are shown in Figure 17. We can see that ocean survival of transported migrants is lower than the ocean survival of in-river migrants, but the in-river migrants survive at a lower rate (~20-50%) than transported fish (98%) before they enter the ocean. The time series trend in Smolt-to-Adult rate is also shown along with the empirical data derived from PIT tag data. The estimated parameters for the prediction of in-river and transported fish are shown in Table 10. The two positive effects are water transit time (WTT) and ocean upwelling (UPW), and are roughly the same magnitude. An empirical reconstruction of the spill-adjusted powerhouse contact value from PIT tag detections (PITPH) is estimated to be approximately as much of a negative effect on the in-river survival rate as it is on the survival rate in the ocean at approximately -0.8 to -0.88. Pacific Decadal Oscillation (PDO) has a negative influence on survival in the ocean for both in-river migrants and transported migrants.

Detailed results from the life cycle model are provided in Appendix F.

Table 10. Estimated parameters for the prediction of the survival of in-river and transported migrants.

Parameter	Estimate
α_R in river	-0.77
α_{PH} in river	-0.8
α_{WTT} in river	0.3
β_T ocean survival of transported migrant	-2.89
β_R ocean survival of in river migrant	-1.65
β_{PDO} ocean survival both	-0.26
β_{UPW} ocean survival both	0.26
β_{PH} ocean survival in river migrant	-0.88

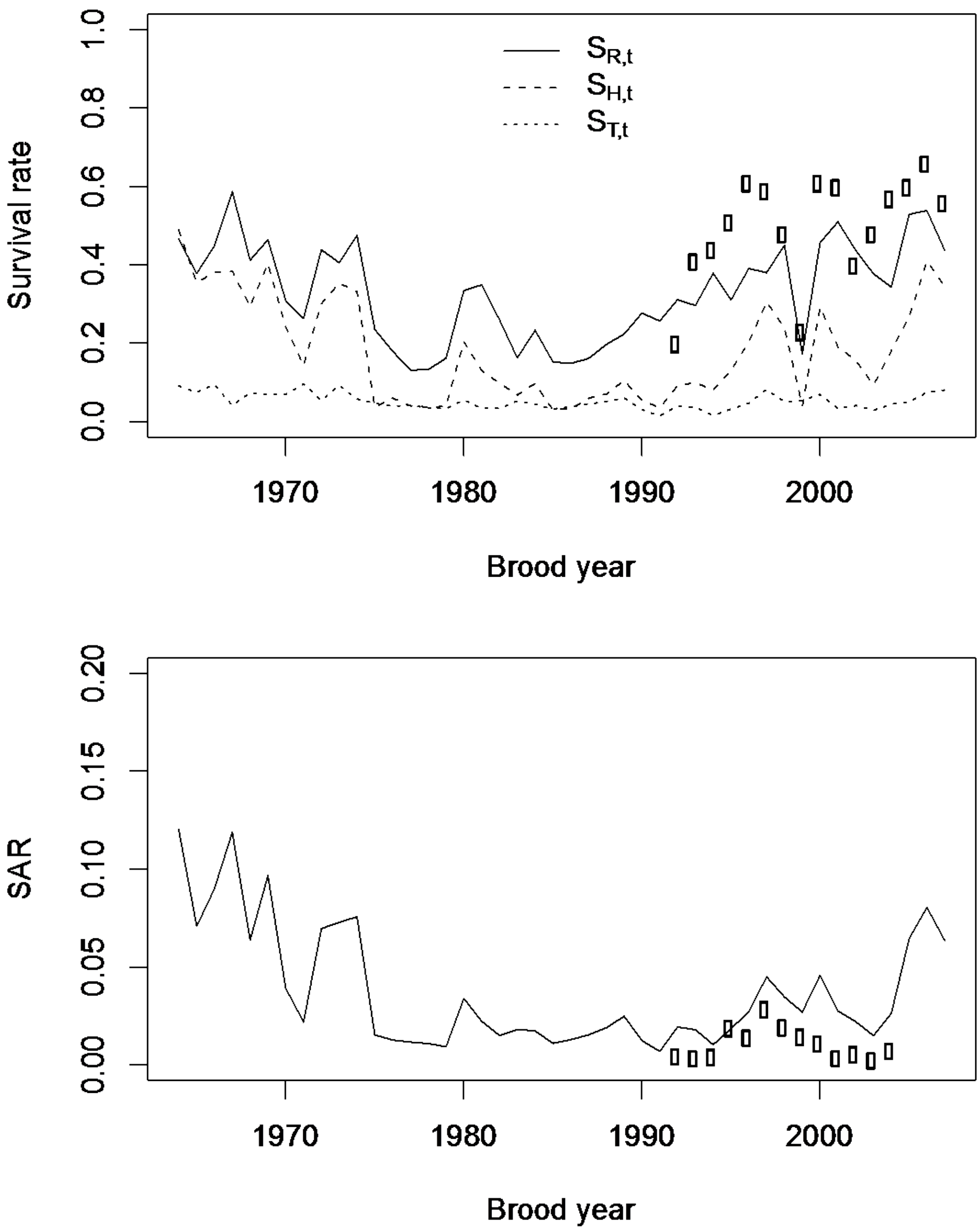

Figure 17. Upper panel shows observed in-river survival (circles) and predicted in-river and transported survival rates.

Coordination and Data Management

Fish Database Development

In order to improve inter-basin communication of fish data, ODFW and CRITFC merged juvenile fish abundance data into one joint database. This decision built from years of partnered data collection efforts, including calibrations of snorkel abundances with mark-recapture data and a shared snorkel survey protocol. The construction of the databases was led by ODFW staff with input from CRITFC scientists. Raw fish counts and site information are inputs to the database and abundance estimates were calculated from previously defined relationships based on Tier 1 unit type (Fast or Slow-water units), see Appendix A for calibration equations. Salmonid abundance, linear density, and areal density were reported at the channel unit and site level. Fish community metrics were also reported at a site level. This database will be maintained by ODFW and will continue to be updated on an annual basis.

CRITFC GIS Database

New hardware was acquired to create a new disc drive with up to 10 terabytes of storage space for the spatial datasets and geodatabases already collected or created for the project, and for future collection of large raster or vector spatial datasets collected from other agencies, tribes, or partners to model the spatial relationship between habitat and salmonids.

Upload Data to CHaMP Website

Data collected through the Columbia Habitat Monitoring Program (CHaMP) were compiled on the CHaMP programs' website (www.champmonitoring.org). As habitat data are collected in the field, data are uploaded to the CHaMP website on a daily basis where it is stored and maintained by Sitka Technology Group. This website interface allows for quality control analysis post field season of habitat and topographic measurements along with the resulting calculated metrics. After the data are endorsed by watershed analysts and program managers, the data are released to the public and are available for download.

Development of Road Layer in the Upper Grande Ronde Basin

Phase II was started and completed at the end of 2014 /early 2015 to add to the previous work to create a more accurate spatial dataset of roads in the study watersheds. Phase II used the same procedures and protocols as work reported in the 2013 annual report (McCullough *et al*. 2014), and covered all watersheds of the Grande Ronde basin between Lookingglass Creek and Catherine Creek. With the addition of this area of the Grande Ronde, all watersheds with CHaMP sites are now covered by the detailed roads layer.

GIS Tool for extraction of landscape data from riparian buffers and watershed polygons

We developed a GIS tool for extraction of raster or vector data from riparian buffers and watersheds of various dimensions. This tool was used to calculate land use or landscape-related data for each riparian

buffer or watershed such as forest cover and road density. Creation of this tool involved three steps: 1) Develop a "routed" stream network for the Upper Grande Ronde/Minam area that met the project requirements; 2) Develop procedures and code that can be used to locate sites on this network, input an upstream distance parameter, return branched stream segments above each site, and then buffer these with various width parameters; 3) Develop ArcGIS tools that can be used to overlay the buffered segments with various types of GIS data to return landscape characteristics within the buffered areas.

The UGR/Minam routed stream layer was developed as a hybrid of the StreamNet and NHD stream layers, using a method discussed with Seth and Casey, by selecting all streams with steelhead distribution, and then extending these streams upstream to their limit, or the second stream order change, whichever came first. For example, if a site was on a stream with a stream order of 3, the evaluation stream would extend upstream through stream order 2, but end where the stream order switched to 1. The stream order was derived from the Strahler stream order designations from the NHD, which were transferred to the StreamNet routed layer. Once the stream network was complete, the CHaMP sites were linked to produce stream network events (like an address) for them. QA/QC was completed to make sure that each site was assigned to the correct stream.

Upstream segments were completed with buffers for the CHaMP sites using a set of site length and buffer dimensions chosen based upon review of stream ecology literature. Specifically, buffers consisted of upstream lengths of 1, 2, and 5 km, and a fourth category to include all stream segments upstream ("EL" for entire length). The buffer widths produced for each were 30, 100, 200, and 500 meters (on each side of the stream.

The tools to overlay the buffered areas with landscape GIS data iterate through the buffer polygons for each site individually, because in many cases (at least for CHaMP sites) they overlap, so they won't work as a single overlay. Tables are written out for each overlay, containing the results for each site. Various functionality of this tool includes: 1) UGR Buffer Polygon Intersect: For intersections with polygon (vector) GIS data (for example, Whittier Landscape Classifications; 2) UGR Buffer Raster Tabulate Area: For intersections with classified raster GIS data (for example, soil class data in a raster format); and 3) UGR Buffer Raster Zonal Statistics: For overlays with numeric raster GIS data (for example, a digital elevation model).

Coordination with regional agencies, tribes, and landowners

We have continued to work closely with staff from the Natural Resources department at the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), which included coordination of field activities and sharing of data and knowledge related to our respective monitoring and restoration programs in the Grande Ronde Basin. CTUIR are now participating in the CHaMP program, which will allow for more direct sharing and compatibility of data collected. We have recognized the need for closer coordination and collaboration with other CRITFC member tribes. To this end, we are currently planning to meet with research staff from the Nez Perce tribe to discuss our respective research programs and learn how we might be of better service to the tribes. A similar meeting is planned with the Yakama Nation staff. Casey Justice with CRITFC recently gave a presentation at the Native American

Fish and Wildlife Society Pacific Regional conference in Worley, Idaho to spread the word with other tribal organizations about the work we are doing at CRITFC.

Ongoing participation in the FCPRS BiOp Grande Ronde Atlas Restoration Prioritization working group yielded significant progress. Grande Ronde Atlas is a BPA-guided process that incorporates multiple agencies and tribal staff (CTUIR and Nez Perce) to prioritize restoration activities in the sub-basin, based on current and historic life use by salmonids, geomorphic potential for change, proximity to current population core areas, and other factors. Prioritization for restoration work in Catherine Creek was completed in 2014 and the working group began prioritization of the upper Grande basin. CRITFC staff contribute vital information including water temperature data and Heat Source modeling results, spatial distribution of Chinook salmon redds, summarization of habitat conditions measured in CHaMP and other habitat programs, GIS layers of geomorphic potential for change in river conditions, and fish rearing densities derived from snorkeling and electrofishing in collaboration with ODFW La Grande. The spatial resolution of Grande Ronde Atlas prioritization is the biologically significant reach (BSRs); CRITFC's Accords project uses the same BSRs as one of several hierarchical scales in fish-habitat modeling efforts and in life cycle modeling in order to deliver relevant results to the Atlas group. In 2014, we participated in several Science Technical Advisory Committee meetings in La Grande, as well several small workgroup meetings with BPA staff in Portland to further develop and refine the Atlas process.

We have continued to maintain a strong collaborative working relationship with staff from Columbia Habitat Monitoring Program (CHaMP). We participated actively in critique and refinement of the CHaMP protocol, shared data, began co-development of a new rapid habitat assessment protocol, and presented findings from our project at a session of the Native American Fish and Wildlife Society conference which focused on the CHaMP program. We view the CHaMP program as filling a critical need in the Columbia Basin in that it provides standardized habitat data that can be used to assess status and trends in fish habitat conditions across a wide range of spatial scales, including watersheds that span the ceded lands of all four of our member tribes. We feel that our involvement in the program since its inception has been important in helping to shape and refine the program to make the most of the data collected.

On October 29, 2014 and November 18, 2014 CRITFC Habitat Team (McCullough, Justice, White, Blanchard, Lessard, and Benge) gave presentations to Rob Lothrop (Manager, Public Policy, CRITFC) and Paul Lumley (Executive Director CRITFC) on our Accords habitat monitoring program in the Grande Ronde basin. This presentation was titled "What will we be able to conclude from 10 years of habitat monitoring under the combination of our CRITFC and CHaMP Programs?" These presentations were given in an effort to more fully make CRITFC leaders aware of the scope and utility of our habitat work and the potential for using this work as a model that could be used by all member tribes in gaining a more solid understanding of the trends in spring Chinook habitat evaluated on a watershed-wide basis.

Each year CRITFC Habitat staff has contacted private landowners to gain access to their property to conduct habitat surveys. In the process, some landowners express particular interest in the data being collected. Landowner support and involvement in this work is critical to the success of restoration in

general and understanding of the results of our efforts. In order to satisfy the requests for information, we have sent individual landowners reports detailing the basic findings arising from studying the stream flowing through their property.

On May 18-23, 2014 the Joint Aquatic Sciences Meeting (JASM) was held in Portland, Oregon. The conference title was “Bridging genes to ecosystems: aquatic science at a time of rapid change.” This historic joint meeting was sponsored by the Society for Freshwater Science (SFS), Association for the Sciences of Limnology and Oceanography (ASLO), Phycological Society of America (PSA), and Society of Wetland Scientists (SWS). The intent was to explore means to enhance collaboration among scientists affiliated with these various resource organizations.

As part of the JASM meeting, CRITFC offered to lead a tour of the Columbia River Gorge as far upstream as Hood River. Dale McCullough, Seth White, and Blaine Parker from CRITFC led the tour. The objective of the tour was to present the 25 participants who signed up and represented several countries from around the globe with a broad perspective of the history and natural resources of the Columbia River. This tour included the native American history in the region, their use of the salmon resource and reliance on good habitat and water quality, the history of Columbia River exploration with the Lewis and Clark expedition, an example of collecting macroinvertebrates from Eagle Creek to examine habitat quality, wildlife reserves on the Washington side of the river, Bonneville Dam and the facilities for passing fish. We imparted to this international group a sense of the scope and complexity of the challenges in managing the fish and aquatic resources in the face of the many demands on the river. We provided examples from our work in the upper Grande Ronde of the breadth of management impacts on salmon in freshwater.

Dissemination of Project Findings

Presentations

Benge, G., S. White, D. McCullough, C. Justice, D. Kelsey, and E. Sedell. 2015. A landscape perspective of restoration effects: Case study in the upper Grande Ronde River and Catherine Creek, Northeast Oregon. Poster presentation to the River Restoration Northwest meeting, Skamania, WA.

Abstract: The Columbia River Inter-Tribal Fish Commission (CRITFC) is conducting habitat monitoring in the Upper Grande Ronde and Catherine Creek basins to evaluate the status and trends of spring Chinook salmon habitat. Most habitat restoration activities, conducted by several agencies, are directed at recovering ESA-listed salmon populations residing in the watersheds. The spatial representation and cataloging of stream restoration activities are critical in assessing watershed function in relation to salmonid population monitoring and recovery of listed species. We address two problems in the field of restoration monitoring and assessment. First, restoration projects are typically implemented with little or no habitat or fish response monitoring done after project completion. Second, restoration projects are typically evaluated on a site-by-site basis, whereas we hypothesize that habitat restoration acts at tributary and watershed scales and therefore should be evaluated at that scale. Spatial data and stream restoration metrics were collected from all known major implementers of restoration projects in the study basins. These data were acquired and

spatially represented in GIS, which is correlated with a comprehensive attributes table of collected project metrics. Habitat projects were categorized according to a standardized list of common restoration activities types, based on the Bonneville Power Administration's (BPA) action effectiveness monitoring (AEM) program. Using the activities types from each project accomplishments we created a common numerical measurement for rating the intensity of restoration projects. The understanding of what metrics are available for restoration projects and the attempt at rating them in a meaningful way at tributary and watershed scales will provide better predictive ability on the response of spring Chinook salmon to stream restoration.

Blanchard, M. 2014. Network scale modeling and the use of stream classification systems to explain fish distributions Oral presentation to the Joint Aquatic Science Meeting, Portland, OR.

Abstract: Fish distributions in streams are driven by habitat variables at a range of spatial extents. Efforts to describe fish distribution have generally been derived from site level habitat surveys, with sites distributed throughout the landscape. However, extrapolating distributions across a watershed from site level information can be problematic owing to spatial variation of habitat characteristics. Yet watershed scale distributions are necessary to prescribe appropriate management strategies for target species. In an attempt to understand network-wide distributions linking physical habitat factors to juvenile steelhead populations, we used a process-based, hierarchical river classification scheme, River Styles, in conjunction with biological and temperature variables. Data from 197 reaches, covering 31 kilometers, were used to develop fish-habitat relationships across the Middle Fork John Day watershed, Oregon. Initial model fitting and predictor variable refinement was completed using boosted regression trees. Spatially explicit, network models were then used to incorporate spatial autocorrelation in describing distribution patterns. Landscape, habitat, and water quality metrics all significantly influenced distribution of fish across the network. Continuous processed based watershed models can be useful in describing fish distributions.

Justice, C. July 2014. Modeling riparian vegetation restoration impacts on water temperature in the Grande Ronde River using Heat Source. Presentation to the USDA Forest Service, Pacific Northwest Research Station. La Grande, Oregon.

Justice, C. October 2014. Assessing status and trends in habitat conditions for spring Chinook salmon in the Upper Grande Ronde River. Presentation to Native American Fish and Wildlife Society Pacific Region Conference. Worley, Idaho. White, S.M. 2014. Fish habitat modeling to support life cycle models in the upper Grande Ronde basin. Presentation to FCRPS BiOp Adaptive Management Implementation Plan workgroup, Seattle, WA.

Smith, T., S. White, D. Kelsey, and D. McCullough. 2014. Watershed history revealed through General Land Office Surveys: Detecting over a century of change in the Columbia River Basin. Poster presentation to the Joint Aquatic Science Meeting, Portland, OR.

Abstract: Land use history can have a notable influence on the present landscape and should be accounted for when designing conservation strategies for threatened and endangered Pacific salmon and steelhead. We described research and the synthesis of environmental history of three

watersheds within the Grande Ronde sub-basin of the Columbia River. The primary data for reconstructing stream and riparian conditions were the General Land Office (GLO) township survey notes and maps from the 19th century. The GLO survey data provided useful information about historic riparian vegetation and its relationship to spatial factors such as ecoregion, comparison of past and present sinuosity/stream complexity, altered channel widths from forestry practices such as splash damming, and anecdotal environmental history of the region. We also highlighted caveats in using GLO data for the benefit of others wishing to use the survey data. We concluded that land use legacies leave an important footprint on the present landscape and should be accounted for when studying or managing rivers.

White, S.M. 2014. Update on upper Grande Ronde River, Catherine Creek, and Minam River Chinook habitat program. Presentation to FCRPS BiOp Adaptive Management Implementation Plan workgroup, Welches, OR.

White, S.M. 2014. Informing recovery options for spring Chinook salmon in the upper Grande Ronde River. Presentation at CHaMP State of the Science symposium, Portland, OR.

White, S.M. 2014. Determining the influence of land use on stream habitat: Lessons learned (and not learned) from the Catherine Creek studies, 1995-1998. Presentation at annual CHaMP training, Cove, OR.

White, S.M. 2014. Updates to Heat Source model & distribution of Chinook spawning in assessment units. Presentation to the Grande Ronde Atlas group, La Grande, OR.

White, S., C. Justice, D. McCullough, K. See, and E. Sedell. 2014. Guiding restoration for Columbia River salmonids using interconnected, holistic measures of ecosystem process. Oral presentation to the Joint Aquatic Science Meeting, Portland, OR.

Abstract: Complex relationships between biota and their environment can hinder effective prioritization of restoration. We describe results from a monitoring program designed to evaluate whether aggregate restoration can positively affect threatened Pacific salmon and steelhead in sub-basins of the Columbia River. Fish-habitat models typically suffer from two fundamental problems. First, response variables are overly-simplistic measures of standing crop (e.g., fish abundance). Second, models assume variables are not causally connected, whereas many examples demonstrate the contrary. We solve the first problem by including holistic metrics integrating ecosystem processes: biotic indices of river health, temporal change in stream geomorphology, and ecological network properties. We solve the second problem by using a riverscape perspective and structured models (boosted regression trees and structural equations) to explore and test hypotheses about the interconnected links between biota and their environment. Like the jewels of Indra’s net in Hindu and Buddhist traditions, each node reflects the properties of all others. Our findings have implications for guiding the location and type of restoration for salmon and their ecosystem.

Publications

White, S., G. Giannico, and H. Li. 2014. A 'behaviorscape' perspective on stream fish ecology and conservation: Linking fish behavior to riverscapes. *WIREs: Water* 1:385-400.

Abstract: Landscape ecology (and its application to rivers and streams: riverine landscapes or riverscapes) provides an expansive depiction of patterns of physical and biological phenomena, yet mechanisms driving those patterns are rarely identified. Behavioral ecology aims to elucidate mechanisms of organisms' response to their environment, but often lacks the context of natural conditions and the surrounding landscape or riverscape. Bringing together the relative strengths of these two fields—context in the case of riverscapes and mechanism in the case of behavioral ecology—can provide fisheries managers and conservation biologists with improved predictions of fish response to anthropogenic impacts such as habitat degradation, landscape fragmentation, and climate change. Existing research on fish behavior incorporating a riverscape perspective includes the study of fish migration and dispersal, habitat selection, and reproduction and life history strategies. The merging of these disciplines is termed 'behaviorscapes' and a program of research would adhere to four principles: (1) study fish populations or communities in a natural setting, (2) account for landscape and riverscape context, (3) incorporate a refined understanding of fish behavior, and (4) forge linkages between individual behavior and population or community demographics. Several potential directions for future research exist, including developing or improving technologies to map internal heterogeneity of rivers; making explicit links between that heterogeneity and fish behavior through observations or experiments; and employing an iterative approach to using ecological knowledge, a priori hypotheses, and precise spatial analysis to bridge the pattern-process divide.

Draft journal article based on CHaMP data

Title: Modeling relationships between key fish habitat metrics and landscape characteristics in the Upper Grande Ronde River basin.
Author: Casey Justice

Abstract: We analyzed the relationship of three important fish habitat metrics (fine sediment, large woody debris, and pool area) with landscape/land use characteristics in the Grande Ronde River basin with the objective of extrapolating site-level habitat data from CHaMP surveys to a larger spatial scale that would be more useful for life cycle modeling. We used both mixed-effects models and spatial statistical network models to fit relationships between CHaMP habitat metrics and landscape/land use data derived from remote sensing. The best fitting mixed-effects model for large woody debris (LWD) frequency included the explanatory variables elevation (positive effect), bankfull width (negative effect), and tree cover (positive effect), and together explained approximately 90% of the variation in LWD. The top model for percentage pool area included elevation (positive effect), valley width index (positive effect), watershed area (negative effect), slope (negative effect), and large woody debris frequency (positive effect) as explanatory variables, together explaining 88% of the variation in pools. In contrast with LWD frequency and percentage pools, the best fitting model for pool tail fines <2 mm was relatively weak ($r^2 = 0.44$). Despite statistically significant effects of elevation, valley width index, road density, and

drainage density, this model was not a reliable predictor of fine sediment in pool tails. Spatial statistical network models showed promise for predicting LWD frequency as a function of landscape/land use characteristics and position in the watershed, but did not compare favorably with mixed-effects models for fine sediment or pool area metrics. These models will be used to predict habitat conditions at unsampled prediction points spaced every 500 m across the stream network. Prediction sites will then be rolled up using block kriging or simple averaging to calculate average habitat conditions at the scale of Biologically Significant Reaches (BSRs), the spatial unit used in our life cycle model.

The current state of this draft journal article is provided in Appendix D.

Discussion/Conclusions

CHaMP Habitat Surveys

This year marks the completion of four years of habitat data collection using the CHaMP protocol. Use of this protocol has not only provided repeatable and region-wide coordinated methods for habitat surveying, but has also strengthened CRITFC's communication and participation with groups around the Columbia River basin. Summaries of selected CHaMP metrics from 2011-2014 revealed substantial variability in habitat conditions across the three subbasins, Grande Ronde River, Catherine Creek, and Minam River, as well as across Biologically Significant Reach (BSR) boundaries. Our data summary also indicated a wide range in the number of sites present within each BSR. This uneven distribution of sites across BSRs has motivated the use of a valley setting classification to extrapolate habitat metrics based on the proportion of valley settings classes in each BSR. These classes, based on both stream confinement and bankfull width, demonstrated distinct differences in many of the metrics summarized and were particularly different when comparing floodplain/constrained classes (bankfull width > 8 m) to mountain classes (bankfull width < 8 m). Large woody debris frequency and residual pool depth were two variables that were clearly split by the stream size distinctions of floodplain/constrained and mountain, with the floodplain/constrained valley classes having higher residual pool depths and lower large wood frequency than the mountain valley classes. There were also some notable distinctions based on valley confinement. For example, the largest percentage cobbles were observed in the confined valley setting classes, followed by the partly confined, and then the unconfined classes. These distinctions in valley setting classifications along with higher numbers of sites surveyed in each class will provide a framework with which we can improve our habitat extrapolation. This classification system will allow us to more accurately estimate average habitat conditions within each BSR, which will provide a useful spatial unit to concentrate life cycle modeling and restoration and management planning. As surveying continues over the next five years of the study, we will build on our ability to use CHaMP data in modeling efforts. CRITFC analyses, including landscape/land use metric modeling, structural equation modeling, and life cycle modeling, all depend heavily on CHaMP habitat metrics as important inputs to the assessment of habitat status and trends across the three basins.

Strong statistical relationships between key CHaMP habitat metrics (large woody debris and pool area) and GIS-derived landscape characteristics demonstrated the potential utility of mixed-effects models and spatial statistical stream network models for extrapolating CHaMP metrics to unsampled areas in the basin. In addition, these models can provide a robust means of predicting how stream habitat conditions might change in response to changes in land use (e.g., deforestation, road building, and habitat restoration). The best fitting mixed-effects model for large woody debris (LWD) frequency included the explanatory variables elevation (positive effect), bankfull width (negative effect), and tree cover (positive effect) ($r^2 = 0.90$). The top model for percentage pool area included elevation (positive effect), valley width index (positive effect), watershed area (negative effect), slope (negative effect), and large woody debris frequency (positive effect) as explanatory variables ($r^2 = 0.88$). The direction and magnitude of these effects generally agreed with our *a priori* assumptions and with the current body of literature.

Water Temperature

Observed stream temperatures from 2014 monitoring efforts throughout the upper Grande Ronde basin revealed that summer temperatures in 25 of 36 locations exceeded the temperature criteria set for juvenile Chinook salmon beneficial use of 18˚C 7-day average maximum temperature (Sturdevant 2008). Nineteen locations also exceeded the migration corridor threshold of 20˚C 7-day average maximum temperature for adult passage. Analysis of the data collected over the past four years at three sites revealed that the temperatures observed in 2014 were similar to those recorded in 2013 and 2012, all of which were higher than temperatures in 2011. These trends suggest that in the upper Grande Ronde basin it is typical that extreme temperatures reached in the lower sections of both Catherine Creek and the Grande Ronde River occur and are unsuitable for multiple life stages of Chinook salmon. Temperatures at these levels restrict access to large segments of the basin and result in high stress conditions for Chinook, affecting both survival and growth. These observations support the need for future restoration and modeling efforts to maximize improvements in temperature regimes across the lower reaches of both subbasins.

Fish Populations

We are attempting to link the above information about physical habitat in the study watersheds to biological response—namely juvenile Chinook salmon rearing densities and various benthic macroinvertebrate indices (BMIs). Snorkeling and electrofishing (in collaboration with ODFW) revealed that, as expected, juvenile Chinook densities were typically greater in pool habitat than fast-non-turbulent (runs) and fast-turbulent habitats (riffles), with the exception of Catherine Creek where rearing densities were often higher in runs (Table 3). More importantly, we noted a decrease throughout the years of the study period in rearing densities for the Chinook populations most impacted by anthropogenic land use—Catherine Creek and upper Grande Ronde (Figure 5). These declines appear to correspond to increasing water temperatures throughout the study area over time; however, the pattern could alternatively (or additionally) be explained by declining spawner abundance due to out-of-basin factors, such as ocean or mainstem conditions. Our work in assigning likely causal factors for the declines is in the preliminary stages. In the Minam River, a wilderness area with land use impacts nearly

absent, fish densities were typically lower but maintained a consistent level in the two years for which data were available (2013-2014). Less impacted streams such as wilderness areas or roadless areas have previously been shown to provide a refuge for salmonid populations during droughts even though productivity can be lower overall due to watershed characteristics intrinsic to those areas (higher elevation, simpler riparian communities, colder water temperature, etc.) (White and Rahel 2008).

Structural equation modeling confirmed previous results demonstrating the direct and indirect effect of large woody debris on Chinook rearing densities (Figure 6). Although the overriding variable influencing fish densities was drainage area above the site (which likely rolled up several other factors such as water temperature and stream size), we found that large wood provided refuge habitat for rearing fish and that large wood was implicated in creating pool habitat, which also provided rearing habitat for fish. Future modeling work will include exploring the role of water temperature, other CHaMP-derived habitat metrics, food availability, and landscape variables including anthropogenic impacts.

Benthic Macroinvertebrates

Strong correlations between benthic macroinvertebrate indices (BMIs) and watershed characteristics (Figure 7) indicate first the need to control for background environmental noise when using BMIs to describe aquatic habitat quality, and second that BMIs are sensitive to fluctuations in conditions rendering them good indicators of environmental change. The strongest overall relationship was a negative association between the number of fine sediment-sensitive taxa and average maximum air temperature. This is likely the result of warmer air temperatures lower in the basins (nearer to the Grande Ronde valley) where fine substrates are transported to depositional areas or fine sediment from the Pleistocene lakebed dominates the substrate. Structural equation modeling revealed that richness of stonefly taxa was strongly related to a single habitat variable, with nearly 70% of the variation explained by the frequency of large woody debris in the bankfull channel (Figure 8). BMIs are known to be quick responders to restoration activities (e.g., Miller et al. 2010). Although BMIs provide only indirect knowledge of how habitat change can affect fish productivity, they can provide an early warning signal that positive or negative activities (e.g., restoration or land use) applied to stream habitats will have relevant biological effects.

Hydrology-Low Flows

Our results from modeling relationships among watershed characteristics and summertime low-flow statistics were useful in characterizing low-flow metrics at ungaged sites (Appendix E). Our method allows characterization of low-flows at stream sites without gages using information about variables easily derived from publically-available datasets: (1) stream drainage density, (2) average January maximum air temperature, and (2) mean annual precipitation. Because streamflow has the potential to be a strong limiting factor for salmonids through various pathways (e.g., space limitation, correspondence with high water temperatures, food limitation, etc.) we envision this product will be useful in developing indices of vulnerability to low-flow events in stream reaches across the project area, especially as it relates to coincidence with periods of warm stream temperatures. Additionally, we expect that benthic macroinvertebrate communities respond rapidly to streamflow regimes (as per Blackburn and Mazzacano 2012) because of their highly specialized life history traits. This presents a

future research direction of assessing impact of low-flow regime predictions on benthic macroinvertebrates, which not only provide indices of watershed health but also the most common food resource for salmonids.

Restoration Database

Compiling information on restoration completed in the project area from the mid-1990s to present revealed a large number of restoration projects—over 4,000—and a diversity of different project types (Table 9). These projects represent a significant impact on the landscape and on stream habitat quality, yet are typically ignored during stream assessments or when attempting to designate “control” (unrestored) sites in action effectiveness studies. There is potential use of our restoration project’s GIS shapefile to acquire project information based on proximity to CHaMP monitoring reaches. A project’s map presents opportunities for selecting sites by location, by project attribute, or by identifying title. Restoration project sites can also be displayed by specific attributes, such as sub-category, or project size. Next steps include developing restoration effectiveness metrics based on literature-derived information on how particular restoration types affect fish habitat or stream function (e.g., Beechie et al. 2010), and linking these metrics through models to local site conditions measured in CHaMP surveys. We expect that the large number of existing and ongoing restoration activities in the basin (e.g., see Figure 15 and Figure 16) affect current and future habitat conditions, and need to be accounted for when attempting to link management scenarios to local habitat conditions for fish.

Life Cycle Model

Life cycle model development in 2014 focused mainly on providing an empirical basis for parameterizing mainstem and early ocean survival to vary in relation to environmental conditions for all migration routes through the hydro system. We found that Catherine Creek and the Upper Grande Ronde likely had higher than average freshwater production during the early period of the model fitting timeframe, and spawning or rearing productivity in those natal streams likely degraded over the course of approximately 10-15 years relative to the other four populations. The next step in model development will involve formulating similar mechanisms for predicting freshwater rearing dynamics in relation to changes in environmental conditions as the mechanisms used in downstream survival dynamics. On-going efforts to measure freshwater habitat conditions will be used to characterize a relationship between productivities and capacities, and conditions measured and monitored in natal streams. The ultimate goal of the life cycle modeling continues to be focused on building a relationship between habitat and freshwater spawning and rearing productivity and capacity for the purpose of monitoring and evaluating the effects of changes in habitat conditions.

Conclusions

Significant progress has been made over the last four years in collection of high quality stream habitat and biotic data as well as development of analytical tools needed to quantify status and trends in habitat conditions and fish populations and to evaluate effectiveness of aggregate restoration activities. CHaMP habitat surveys, fish snorkel surveys and benthic macroinvertebrate sampling have been conducted at 120 unique sites throughout the spring Chinook salmon distribution area in the upper

Grande Ronde River, Catherine Creek, and Minam River, providing highly precise and spatially referenced data for a large suite of stream habitat and biotic factors. Because fluvial and riparian processes that create fish habitat generally operate over a relatively long time frame (i.e., decades), we do not feel it would be appropriate or informative at this time to quantify long-term trends in fish habitat conditions. However, the data needed to develop important fish-habitat relationships, habitat-land use relationships, and to parameterize a life cycle model to make projections in fish response to habitat change are now available, and as demonstrated in this report, have been applied successfully to make great strides towards meeting our project objectives.

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Appendix A Fish Snorkel Calculations

Reporting CRITFC & ODFW fish abundance & density for channel units and sites

Channel unit-level calculations

At the tier I channel unit level (and for off-channel units at the tier II level) (Figure 18), report by species and size class the projected fish abundance (no. fish), linear fish density (no. fish/m) and areal fish density (no. fish/m^2) for each channel unit where snorkeling was conducted. Values for channel unit length and area come from CHaMP-derived estimates. Projected fish abundance is derived from equations relating no. fish observed while snorkeling (*N*) to a population estimate based on mark-recapture (*N-hat*) (Sedell & Horn, unpublished data[1]):

Eq.1. For slow water (sw) channel units: $\widehat{N}_{Sw} = (-0.0505 + (1.439 \times \sqrt{N_{Sw}}))^2$, and

Eq. 2. For fastwater (fw) channel units: $\widehat{N}_{Fw} = (-0.1321 + (1.676 \times \sqrt{N_{Fw}}))^2$, and

Eq. 3. If $N = 0$, then $\widehat{N} = 0$.

For small stream that were electrofished, abundance is estimated from equations relating single-pass electrofishing catch to mark-recapture population estimates (Sedell & Horn, unpublished data). Estimates are made at the tier I and tier II levels similar to snorkeling.

Eq. 4. For 1-pass electrofishing (all unit types): $\widehat{N}_{efish} = 1.7507 \times N_{efish}$

Accounting for unsampled areas in channel units: In some cases, individual channel units are subsampled due to extreme length or obstructions (e.g., dense wood jams) which make it impossible to snorkel the entire length or width of the unit. If so, the channel unit area recorded as a subsample on the data form is to be used to derive a fish density estimate based in the number of fish observed (*n*) and the area actually snorkeled (*a*), and then extrapolated up to the CHaMP-derived channel unit area (*A*):

Eq. 5. $N = \frac{n}{a} \cdot A$

Calculating channel unit-level fish density estimates: The above value (*N*) provides the input for calculating estimated fish abundance (*N-hat*) based on the first two equations. Fish density estimates are computed using CHaMP-derived channel unit areas as:

Eq. 6. $Areial\ fish\ density = \frac{\widehat{N}}{A}$, where A is the CHaMP derived channel unit area, and

[1] A new study relating fish observed snorkeling to mark-recapture population estimates planned for 2015 will yield new equations for 2015 and beyond. The current equations should be used for 2011-2014 data.

Eq. 7. $Linear\ fish\ density = \frac{\hat{N}}{L}$, where *L* is the CHaMP-derived channel unit length.

Site-level calculations
For each CHaMP site, report the projected fish abundance (no. fish), linear fish density (no. fish/m) and aerial fish density (no. fish/m^2) by tier I and off-channel unit types by scaling up from estimates at the channel unit scale. Site-level estimates of fish density are calculated according to equations 6 & 7, but using entire reach lengths and areas.

Accounting for unsampled channel units: CRITFC snorkels 25% (by count) of the fastwater turbulent channel units. Therefore, an adjustment needs to be made to account for subsampling:

Eq. 8. $\hat{N}_{Ft} = \frac{\hat{n}_{Ft}}{a_{Ft}} \times A_{Ft}$, for area, and

Eq. 9. $\hat{N}_{Ft} = \frac{\hat{n}_{Ft}}{l_{Ft}} \times L_{Ft}$, for length, where

$\hat{N}_{Ft}$ and $\hat{n}_{Ft}$ are the projected fish abundance for the entire site and in the subsampled portions for fastwater turbulent channel units, respectively; A_{Ft} and a_{Ft} are the CHaMP-derived and subsamped area of the reach, respectively; and L_{Ft} and l_{Ft} are the CHaMP-derived and subsamped area of the reach, respectively.

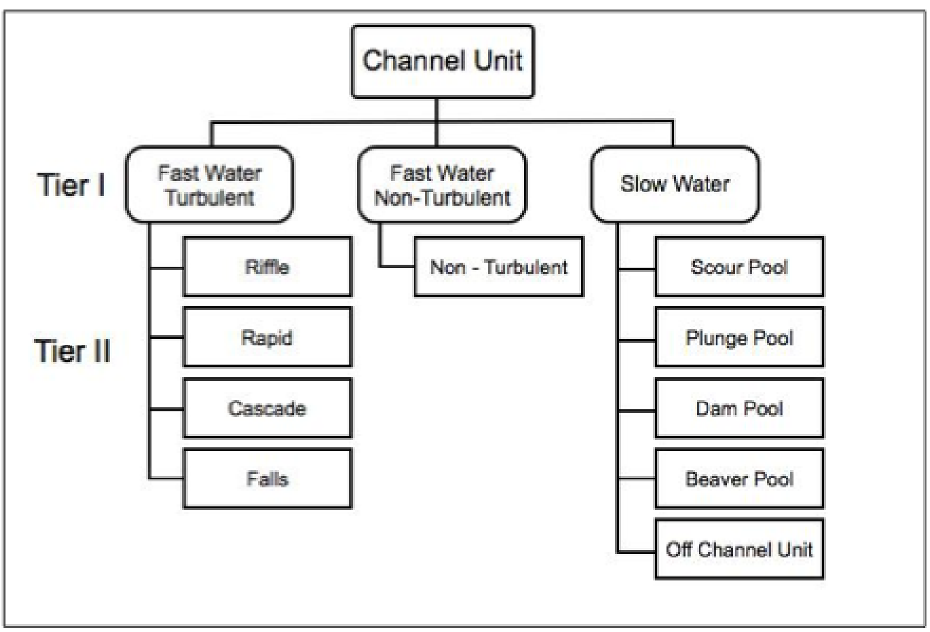

Figure 18. Hierarchical channel unit classification in CHaMP.

Site level reporting of metrics

Code[2]	**Description**
Site information	
ID_short	Site ID suffix only
Strm_grp	Integer grouping the stream names
Obs_mthd	Observation method for fish estimates, report as "snorkel" or "efish"
SiLgth	Site length (m)
SiArea	Site area (m^2)
SwLgth	Tier I slow water length (m)
FnLgth	Tier I fastwater non-turbulent length (m)
FtLgth	Tier I fastwater turbulent length (m)
OcLgth	Length (m) of tier II off channel unit
SwAr	Tier I slow water area (m^2)
FnAr	Tier I fastwater non-turbulent area (m^2)
FtAr	Tier I fastwater turbulent area (m^2)
OcAr	Area (m^2) of tier II off channel unit
Salmonid site summary	
ChAbSi	Abundance of juvenile Chinook in the site
ChDlSi	Linear density (counts/m) of juvenile Chinook in the site
ChDaSi	Aerial density (counts/m^2) of juvenile Chinook in the site
ChDlsiCV	CV of juvenile Chinook linear density among channel units in the site
ChAbAdlt	Abundance of adult Chinook in the site
StAbSi	Abundance of steelhead in the site
StDlSi	Linear density (counts/m) of steelhead in the site
StDaSi	Aerial density (counts/m^2) of steelhead in the site
StDlSiCV	CV of steelhead linear density among channel units in the site
Salmonids by channel unit type	
ChAbSw	Abundance of juvenile Chinook in all tier I slow water types
ChDaSw	Aerial density (counts/m^2) of juvenile Chinook in all tier I slow water types
ChAbSwCV	CV of juvenile Chinook abundance in tier I slow water
ChDaSwCV	CV of juvenile Chinook aerial density in tier I slow water
StAbSw	Abundance of steelhead in all tier I slow water types
StDaSw	Aerial density (counts/m^2) of steelhead in all tier I slow water types
StAbSwCV	CV of steelhead abundance in tier I slow water
StDaSwCV	CV of steelhead aerial density in tier I slow water
ChAbFn	Abundance of juvenile Chinook in tier I fastwater non-turbulent
ChDaFn	Aerial density (counts/m^2) of juvenile Chinook in tier I fastwater non-turbulent
ChAbFnCV	CV of juvenile Chinook abundance in tier I fastwater non-turbulent
ChDaFnCV	CV of juvenile Chinook aerial density in tier I fastwater non-turbulent

[2] Codes for metrics must be ≤ 8 characters to conform to PC-ORD software requirements.

StAbFn	Abundance of steelhead in tier I fastwater non-turbulent
StDaFn	Aerial density (counts/m^2) of steelhead in tier I fastwater non-turbulent
StAbFnCV	CV of steelhead abundance in tier I fastwater non-turbulent
StDaFnCV	CV of steelhead aerial density in tier I fastwater non-turbulent
ChAbFt	Abundance of juvenile Chinook in tier I fastwater turbulent
ChDaFt	Aerial density (counts/m^2) of juvenile Chinook in tier I fastwater turbulent
ChAbFtCV	CV of juvenile Chinook abundance in tier I fastwater turbulent
ChDaFtCV	CV of juvenile Chinook aerial density in tier I fastwater turbulent
StAbFt	Abundance of steelhead in tier I fastwater turbulent
StDaFt	Aerial density (counts/m^2) of steelhead in tier I fastwater turbulent
StAbFtCV	CV of steelhead abundance in tier I fastwater turbulent
StDaFtCV	CV of steelhead aerial density in tier I fastwater turbulent
ChAbOc	Abundance of juvenile Chinook in tier II off channel unit
ChDaOc	Aerial density (counts/m^2) of juvenile Chinook in tier II off channel unit
ChAbOcCV	CV of juvenile Chinook abundance in tier II off channel unit
ChDaOcCV	CV of juvenile Chinook aerial density in tier II off channel unit
StAbOc	Abundance of steelhead in tier II off channel unit
StDaOc	Aerial density (counts/m^2) of steelhead in tier II off channel unit
StAbOcCV	CV of steelhead abundance in tier II off channel unit
StDaOcCV	CV of steelhead aerial density in tier II off channel unit
ChDlSw	Linear density (counts/m) of juvenile Chinook in all tier I slow water types
ChDlSwCV	CV of juvenile Chinook linear density in tier I slow water
StDlSw	Linear density (counts/m) of steelhead in all tier I slow water types
StDlSwCV	CV of steelhead linear density in tier I slow water
ChDlFn	Linear density (counts/m) of juvenile Chinook in tier I fastwater non-turbulent
ChDlFnCV	CV of juvenile Chinook linear density in tier I fastwater non-turbulent
StDlFn	Linear density (counts/m) of steelhead in tier I fastwater non-turbulent
StDlFnCV	CV of steelhead linear density in tier I fastwater non-turbulent
ChDlFt	Linear density (counts/m) of juvenile Chinook in tier I fastwater turbulent
ChDlFtCV	CV of juvenile Chinook linear density in tier I fastwater turbulent
StDlFt	Linear density (counts/m) of steelhead in tier I fastwater turbulent
StDlFtCV	CV of steelhead linear density in tier I fastwater turbulent
ChDlOc	Linear density (counts/m) of juvenile Chinook in tier II off channel unit
ChDlOcCV	CV of juvenile Chinook linear density in tier II off channel unit
StDlOc	Linear density (counts/m) of steelhead in tier II off channel unit
StDlOcCV	CV of steelhead linear density in tier II off channel unit

Fish community

Fish_S	Number of fish species in reach
Fish_H	Shannon diversity of fish species in reach
Fish_dom	Dominant fish species in reach (2012 and later)
Ther_dom	Thermal class of fish taxa dominant in reach (see Zaroban 1999) (2012 and later)
Age_FIBI	Age class IBI metric (sum of presence/absence = 1/0 for each of four age classes of salmonids)

XX_PA	Presence (1) or absence (0) of each fish taxa in the reach including salmonids and non-salmonids, where XX is the two- or three-letter code for the fish taxa (e.g., "RS_PA" for redside shiner presence-absence or "dace_PA" for dace spp. presence-absence. This output can be its own table called the "community matrix".

Appendix B Benthic Macroinvertebrate Indices

Appendix B, Table 11. Values of selected metrics calculated from 2014 benthic macroinvertebrate samples from upper Grande River, Catherine Creek, and Minam River. Table sorted by stream name.

		Grand Ronde IBI	Functional Feeding Composition	Density	PREDATOR	Stressor Indicator Taxa
Stream Name	CHaMP ID	Total Score	Collector-Gatherer	Individuals/m^2	O/E P>0.0	No. fine sediment taxa
Burnt Corral Creek	CBW05583-382778	40	55.3	1231	0.70	1
California Gulch	CBW05583-531546	34	22.9	895	0.82	4
Catherine Creek	CBW05583-456106	48	31.1	7362	1.27	7
Catherine Creek	CBW05583-368042	50	32.0	4790	1.30	9
Catherine Creek	CBW05583-430250	46	20.4	2889	1.12	3
Catherine Creek	CBW05583-217258	44	15.6	2242	1.12	3
Catherine Creek	CBW05583-405674	42	22.3	3200	1.16	4
Catherine Creek	dsgn4-000204	40	30.3	3736	1.37	5
Catherine Creek	dsgn4-000010	46	36.9	7118	1.31	6
Catherine Creek	CBW05583-090282	42	23.3	363	1.26	4
Catherine Creek	CBW05583-527786	48	26.3	2709	0.91	6
Catherine Creek	CBW05583-446634	42	29.4	1739	1.40	5
Clark Creek	CBW05583-142490	40	37.3	699	1.07	4
Dark Canyon Creek	CBW05583-149594	42	22.8	799	1.09	1
Fly Creek	dsgn4-000094	42	35.9	1173	1.14	2
Fly Creek	CBW05583-092986	40	24.7	796	1.14	2
Gordon Creek	CBW05583-135615	44	28.9	740	1.06	5
Grande Ronde River	dsgn4-000245	40	25.3	2172	1.21	2
Grande Ronde River	CBW05583-269114	42	21.1	2674	1.09	3
Grande Ronde River	dsgn4-000202	44	28.4	4584	0.99	4
Grande Ronde River	CBW05583-457530	42	21.9	5694	1.18	4
Grande Ronde River	CBW05583-235322	42	33.8	2918	1.33	4
Grande Ronde River	dsgn4-000009	50	31.9	2151	1.35	6
Grande Ronde River	CBW05583-280042	46	32.4	4408	1.42	6
Grande Ronde River	CBW05583-148970	48	36.1	1307	1.38	8
Grande Ronde River	CBW05583-206314	46	55.6	1108	1.28	6
Grande Ronde River	dsgn4-000277	38	33.4	7292	1.10	4
Grande Ronde River	CBW05583-321338	40	43.8	1830	1.30	4
Grande Ronde River	CBW05583-420954	38	42.3	3518	1.06	3
Grande Ronde River	dsgn4-000205	40	40.3	2964	1.11	3
Limber Jim Creek	CBW05583-108010	48	45.2	5247	1.18	6
Little Catherine Creek	CBW05583-155818	48	28.2	3217	1.08	8
Little Indian Creek	CBW05583-288410	48	37.9	206	1.08	4
Little Minam River	MNM00001-000197	50	38.5	2634	1.31	7
Little Minam River	MNM00001-000081	50	36.7	3130	1.12	7
Little Minam River	MNM00001-000445	48	40.0	2131	1.21	7
McCoy Creek	CBW05583-095642	40	54.8	1574	0.97	3
Meadow Creek	CBW05583-252730	34	33.7	740	0.95	2
Meadow Creek	dsgn4-000213	32	28.4	753	0.98	2

Stream Name	CHaMP ID	Grand Ronde IBI Total Score	Functional Feeding Composition Collector-Gatherer	Density Individuals/m^2	PREDATOR O/E P>0.0	Stressor Indicator Taxa No. fine sediment taxa
Meadow Creek	orw03446-101560	38	25.8	1624	1.01	1
Meadow Creek	CBW05583-275866	38	36.1	131	0.67	2
Meadow Creek	Stky-P2-Cntrl	42	37.2	1096	1.09	2
Meadow Creek	orw03446-125832	40	32.9	1025	1.00	3
Minam River	MNM00001-000096	48	61.1	3532	1.06	10
Minam River	MNM00001-000444	50	54.2	2739	1.15	11
Minam River	CBW05583-425130	48	60.1	3787	0.77	10
Minam River	MNM00001-000229	46	19.4	942	0.98	6
Minam River	MNM00001-M53240	48	18.0	3105	0.90	6
Minam River	MNM00001-000009	44	22.0	2837	0.85	6
NF Catherine Creek	dsgn4-000001	50	27.3	3579	1.43	8
NF Catherine Creek	dsgn4-000168	50	31.2	1349	1.22	11
North Fork Catherine Creek	CBW05583-138666	50	31.7	5409	1.41	8
Peet Creek	CBW05583-013882	44	41.5	734	1.14	2
Rock Creek	CBW05583-240730	34	29.6	846	0.92	3
SF Catherine Creek	dsgn4-000161	48	49.9	938	1.20	10
SF Catherine Creek	CBW05583-316330	48	37.9	1184	1.01	9
Sheep Creek	CBW05583-138554	40	41.1	10656	1.39	2
Sheep Creek	CBW05583-490810	44	48.7	3539	1.45	4
Sheep Creek	CBW05583-228666	48	49.9	7414	1.25	4
South Fork Catherine Creek	CBW05583-512938	50	51.3	4996	1.19	11
Spring Creek	CBW05583-489882	34	54.5	222	0.63	3
Spring Creek	dsgn4-000092	38	27.8	801	1.00	2
Spring Creek	CBW05583-514458	36	50.0	431	1.01	5
Waucup Creek	CBW05583-480666	38	38.5	468	0.91	1
West Chicken Creek	dsgn4-000006	40	33.0	293	0.81	0
Willow Creek	CBW05583-384154	22	21.4	806	0.96	0

Appendix C Chinook Population Habitat Status in Minam River, Northeast Oregon

Chinook Population Habitat Status in Minam River, Northeast Oregon

Project: 2100.13.038542

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INTRODUCTION

Spring/summer Chinook salmon *Oncorhynchus tshawytscha* and summer steelhead *O. mykiss* populations in the Grand Ronde River, a tributary to the Lower Snake River, have been depressed for decades. Snake River spring/summer Chinook were listed as threatened under the Endangered Species Act (ESA) in 1992 and summer steelhead were listed in 1997. Freshwater habitat alteration has been identified as a contributing factor to population declines, but the specific relationships between habitat and salmon/steelhead survival are not fully understood (NOAA 2008). Thus, it was recommended that a region-wide habitat monitoring program be developed for key threatened/endangered salmonids in the Columbia River basin (FCRPS Action Agencies, 2010).

The Columbia Habitat Monitoring Program (CHaMP) was developed to undertake the recommended habitat monitoring. The goal of CHaMP is to generate and implement a standard set of fish habitat monitoring (status and trend) methods in watersheds across the Columbia River basin. The watersheds have been chosen to maximize the contrast in current habitat conditions and also represent a temporal gradient of expected change in condition through planned habitat actions. Surveys are conducted in watersheds with identified large freshwater life-stage survival gaps resulting from habitat impairments or in some cases watersheds that are home to existing high quality fish monitoring programs

CHaMP is built around a set of standardized habitat monitoring protocols with a program-wide approach to data collection and management. The protocol is fish-centric, i.e., it measures habitat relevant to salmonids of interest under the BiOp. This protocol is structured around a general understanding of the link between habitat attributes and specific life history requirements of salmonids managed under the 2008 BiOp. These fish are likely not only responding to watershed and reach conditions, but also to the conditions of individual channel units within reaches. Accordingly, the CHaMP protocol has been developed to capture habitat features that drive fish population performance.

Within the Grande Ronde River watershed, the Upper Grande Ronde/Catherine Creek sub-watershed was selected for CHaMP monitoring. Monitoring began in 2011, and continues annually. This sub-watershed has undergone significant habitat alteration in the form of timber harvest, road building, cattle grazing, mining, fish passage barriers, and substantial irrigation withdrawal. With the myriad of human influences impacting stream habitats there is little unaltered habitat remaining where baseline/reference condition data can be gathered. In attempt to better understand the linkages between habitat characteristics in NE Oregon streams and anadromous salmonid populations, we chose to look to neighboring watersheds for reference conditions.

In addition to reference conditions, we wanted to capitalize on two opportunities to monitor restoration effectiveness in Catherine Creek. A post restoration site was re-surveyed, and two pre-restoration sites were added to our 2013 sampling regime (details in following section). In conjunction with other programs, the goals of this project are to:

- Establish long-term monitoring of habitat restoration actions in Catherine Creek
- Establish monitoring sites in the Minam River watershed to serve as habitat reference reaches for current and future habitat conditions in Catherine Creek and the Upper Grande Ronde River

- Assess status and trends of Grande Ronde spring Chinook and summer steelhead populations and their habitats
- Identify key limiting factors, quantify responses to management actions and provide guidance for implementation of future management actions (an overall program goal larger than the scope of this report)

STUDY AREA

Catherine Creek is a tributary to the Grande Ronde River, which originates in the Blue Mountains in northeast Oregon. Catherine Creek flows 89 kilometers from the junction of South Fork and North Fork Catherine Creeks to its (current) confluence with the State Ditch (Figure A 1). The creek flows out of the North and South Fork of Catherine Creek, which is underlain by Grande Ronde and Imnaha basalt lithology (Walker 1990). Most of Catherine Creek flows through alluvial deposits that form the valley bottom. The lower reaches are deep, meandering sections of stream with little definition or structure, with remnant, cut-off oxbows. The surrounding landscape consists primarily of agriculture fields. The middle reaches of Catherine Creek have more distinct habitats, flow through an urban area (the town of Union), and has a mix of landscape influences. The upper reaches below and into North and South Fork Catherine creeks are mostly on state or federal land, have an increased gradient, and have more opportunities for off-channel habitat formation.

We chose three sites within Catherine Creek to capture habitat changes associated with stream restoration. A restoration project was completed in summer 2012 at site CBW05583-086186. We captured pre-treatment conditions in summer 2012, but were not slated to capture post-treatment conditions until 2015. We used NFWF funds/crew to capture the habitat conditions one year post-treatment at this location. Additionally, a large, multi-year restoration project covering approximately 6 km of stream began in 2013. We added two additional pre-restoration surveys in this 6 km reach at sites CBW05583-147626 and -278698, with plans to monitor them post-restoration as part of other projects.

We selected the Minam River as a reference watershed based on its history of less-intense land use, close genetic relationship between Minam River and Catherine Creek spring Chinook salmon (ICTRT 2003), near proximity to the focal watersheds, and readily available information about spring Chinook salmon from ODFW monitoring (long term adult abundance, juvenile abundance, life stage specific survival, and habitat surveys, etc.). The Minam River flows through the Wallowa-Whitman National Forest and Eagle Cap Wilderness Area. The Eagle Cap was established as primitive area in 1930, designated as wilderness in 1940, and registered in the National Wilderness Preservation System in 1964 (www.fs.fed.us). In 1988, the Minam River was registered as a Wild and Scenic River from its headwaters at Minam Lake, 62.8 rkm downstream to Cougar Creek (www.rivers.gov). The protected status of the Minam River provides a stark contrast to the current and historical agricultural, grazing, and logging use in the upper Grande Ronde and Catherine Creek basins, and therefore in one sense is an ideal reference condition.

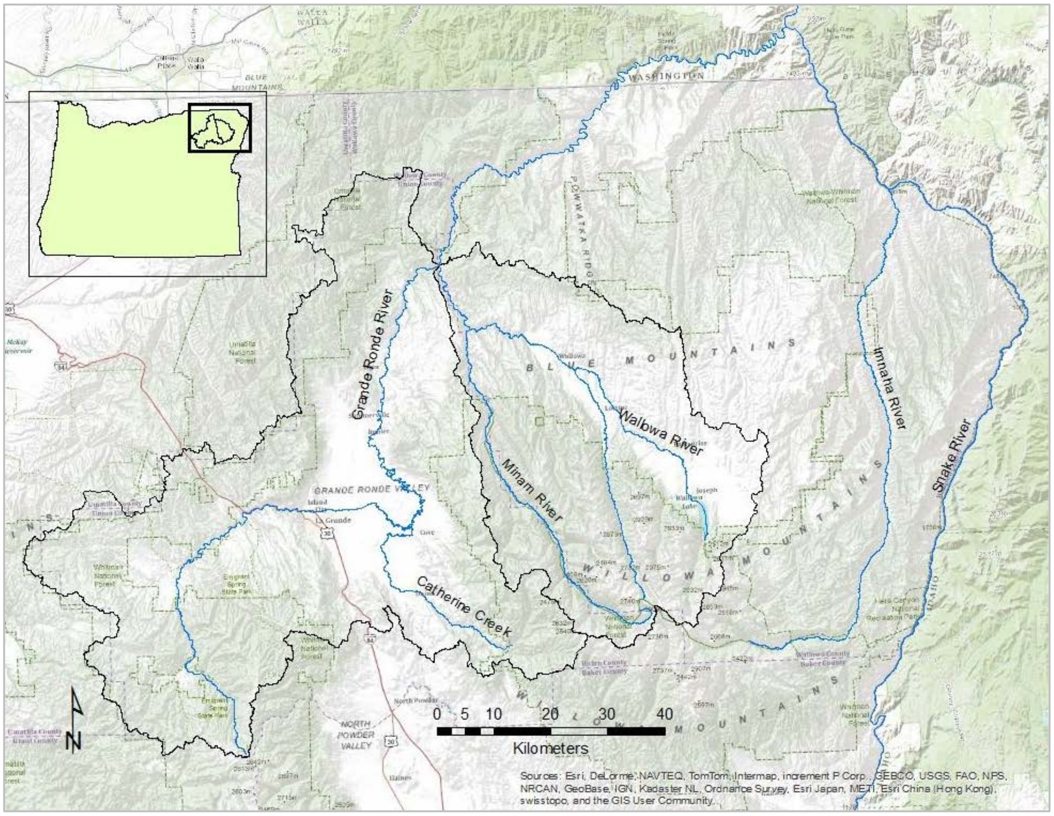

Figure A 1. NE Oregon Rivers that fall within the lower Snake River Basin. Sub-basins are outlined for Upper Grande Ronde/Catherine Creek and Wallowa/Minam Rivers.

METHODS

Study Design

Minam River sample design mimics that of a typical CHaMP watershed, with annual samples and three rotating panels, totaling 20 (or more) sites over a 3-year period (Table A 1). Researchers from the Columbia River Inter-Tribal Fish Commission (CRITFC) conducted a study evaluating reaches in the Minam River and upper Grande Ronde-Catherine Creek shared similar geomorphic and climatic conditions; these reaches with shared geoclimatic conditions are termed "reference areas." ODFW also samples Minam River non-reference reaches to represent the broader area where spring Chinook salmon are known to spawn.

There are five annual sites: two in the Little Minam River, two in the Minam River reference area between North Minam and Elk Creek, and one non-reference legacy CRITFC site in the large alluvial valley adjacent to the airstrip at Red's Horse Ranch (Table A 2, Figure A 2). The target weighting for rotating panel sites in reference/non-reference areas is 60/40. However in 2013, only one non-annual site in the non-reference area was sampled (the canyon site just upstream of the annual site at Red's

Horse Ranch), whereas in 2014-2015 we will allocate 3 sites to the reference area and 2 sites to the non-reference area.

Table A 1. Split panel design to be used in the Minam River where status and trend evaluations need to be balanced.

	Number of CHaMP sites		
Panel ID	**2013**	**2014**	**2015**
Annual	5	5	5
Panel 1	5		
Panel 2		5+	
Panel 3			5+

Table A 2. Basic descriptors and locations of Minam River CHaMP survey sites and Catherine Creek restoration sites sampled in 2013.

Site ID	Stream	Easting	Northing	Mean BF	Site Length(m)	Site Type
CBW05583-113834	Minam River	458223	5012245	18.3	400	Reference
CBW05583-344746	Minam River	460713	5006507	17.7	360	Reference
MNM00001-M53240	Minam River	451282	5021495	22.0	440	Reference
MNM00001-M53247	Minam River	452715	5021094	21.1	440	Reference
MNM00001-000369	Little Minam River	447944	5023573	16.4	360	Reference
MNM00001-000209	Little Minam River	447308	5025368	14.9	320	Reference
MNM00001-000236	Minam River	459138	5007699	19.2	400	Reference
MNM00001-000197	Little Minam River	447256	5027581	14.4	320	Reference
MNM00001-000081	Little Minam River	448877	5021927	11.9	240	Reference
MNM00001-000096	Minam River	458396	5010082	13.3	280	Reference
CBW05583-086186	Catherine Creek	428505	5007537	13	380	Post-restoration
CBW05583-147626	Catherine Creek	436695	5002449	22.5	480	Pre-restoration
CBW05583-278698	Catherine Creek	435188	5003951	14.6	320	Pre-restoration

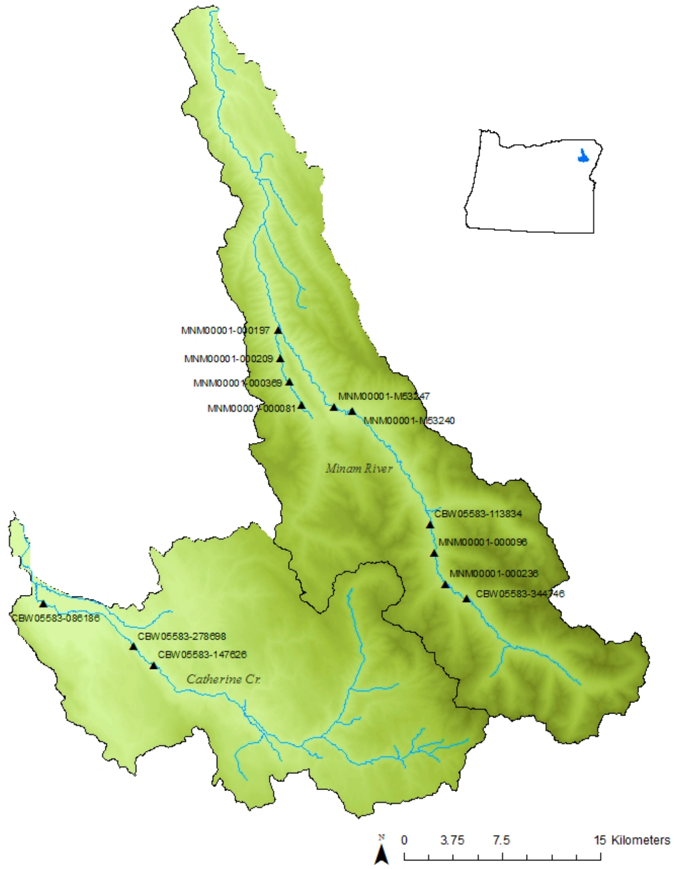

Figure A 2. Survey sites in the Minam and Little Minam Rivers, summer 2013. Dark green indicates high elevations, light green low elevations.

Habitat Surveys

Stream habitat surveys were conducted using the CHaMP protocol (CHaMP 2013). This protocol measures habitat relevant to salmonids of interest under the FCRPS BiOp and is structured around a general understanding of the link between habitat attributes and specific life history requirements of salmonids. Accordingly, the CHaMP protocol has been developed to capture habitat features that drive fish population performance.

Methods in the CHaMP protocol draw from many existing protocols (i.e. AREMP, PIBO, and ODFW's Oregon Plan) and incorporate novel approaches to collecting and analyzing channel geomorphological data. The protocol is designed to maintain the rapid nature of existing stream habitat protocols, and to collect data within a geomorphological hierarchy spanning multiple spatial scales, i.e., within-channel unit, channel unit, geomorphic reach, watershed and subbasin scales. The protocol employs spatially continuous sampling strategies to conduct precise topographic surveys of a stream and it's floodplain from which digital elevation models (DEM) are produced. These topographic surveys are augmented with other data (e.g., channel classification, fish cover, substrate composition, distribution and

embeddedness, large woody debris, solar input and water temperature, stream discharge, water chemistry, and riparian structure) that help to characterize aspects of channel units that influence site-scale fish production potential. List of commonly used metrics and indicators are found in Table A 3. Full CHaMP protocol details are found at: https://www.monitoringmethods.org/Protocol/Details/806.

Table A 3. Subset of measurements and metrics calculated from CHaMP surveys. Over 100 metrics are calculated in total.

Alkalinity	Sand and Fines
Bankfull Area	Site Bankfull Area
Bankfull Large Wood	Site Sinuosity
Cobble Embeddedness	Solar Input/Shading
Conductivity	Stream Temperature (year-round)
Digital Elevation Model	Substrate Composition (% boulders, cobbles, etc.)
Drift Biomass Density	Substrate Size: D16, D50 and D84
Fish Cover Composition	Thalweg Depth Profile
Macroinvertebrate Composition	Total Undercut Area
Pool Area	Volume of Deposition and Erosion (multiple years)
Pool Frequency	Wetted Area
Pool Tail Fines	Wetted Large Wood
Riparian Composition & Cover	Width to Depth Ratio

Juvenile Salmonid Surveys

Snorkel surveys are conducted to document fish assemblage structure and relative abundance and distribution of juvenile salmonids at the habitat unit and reach scales and are intended to supplement data collected at CHaMP monitoring sites. CRITFC, Confederated Tribes of the Umatilla Indian Reservation (CTUIR), and ODFW 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. The key assumption of this protocol is that snorkeling provides a consistent measure of relative fish abundance and assemblage structure.

Briefly, one snorkeler begins the survey at the bottom of site and attempts to identify, enumerate and estimate size class of all Chinook salmon and steelhead observed while moving upstream. Size classes are set to reflect length-at-ages for each species (Chinook salmon: <80 mm = Age 0, 100+mm = Age 1+; steelhead: <70 mm = Age 0, 70 – 130 mm = Age 1, 130 – 200 mm = Age 2, 200 – 250 mm = Age 3, 250+mm = Age 4+). No attempt is made to differentiate resident from anadromous O. mykiss, and all

are classified as steelhead. Also, the relative abundance of all fish taxa observed is estimated as dominant (>50% of all fish observed), common (10 – 49%) or rare (<10%). Fish data are collected by habitat unit number and type, which is determined during the CHaMP habitat surveys (CHaMP 2013). Wetted channel area of each unit is determined during habitat surveys as well. Full protocol details are in White *et al*. 2012, found at https://www.monitoringmethods.org/Protocol/Details/499.

Salmonid counts from snorkel surveys were adjusted to estimate abundance within each habitat unit and each survey reach. In 2012 ODFW and CRITFC implemented a study to correlate snorkel counts with mark-recapture population estimates at 43 sites within the UGRR basin. This study resulted in "correction factors" that allow us to expand single-pass snorkel counts to an abundance estimate for each type of habitat unit (Horn and Sedell 2013). Salmonid counts in riffles, rapids and runs are multiplied by ~2.5 to estimate actual abundance, while salmonid counts in pools are multiplied by ~2. Using these correction factors allows us to sample fish quickly and efficiently, while still obtaining a statistically defensible population estimate for each reach.

Metrics calculated for snorkel surveys include: total count of Chinook and steelhead, fish abundance for the whole site, fish density per unit area (total and by size/age class). Mean densities are calculated for each site, both for steelhead and Chinook, and compared by habitat unit type and treatment using Kruskal-Wallis Rank Sum ANOVA and Tukey's tests (alpha=0.05).

RESULTS

Minam River surveys were completed late July – early September, 2013. Ten total sites were surveyed for habitat and juvenile fish abundance. Of the ten sites, four were in Little Minam River, four in upper Minam River (mainstem) and two were in the middle Minam River (mainstem) (Figure 2). Sites were surveyed for habitat first (CHaMP) and then snorkeled afterward. Due to logistic constraints of working in wilderness, sites could not be snorkeled the same day as habitat surveys, and the delay from CHaMP survey completion to snorkel survey ranged 1 – 29 days (Table A 4).

Catherine Creek surveys occurred in late August/early September, 2013. Snorkeling occurred within two weeks of the habitat surveys.

Table A 4. Sampling dates for Minam River and Catherine Creek sites.

Site ID	*Stream*	*CHaMP Date*	*Snorkel Date*	*Days Difference*
MNM00001-000081	Little Minam River	7/26/2013	7/27/2013	1
MNM00001-000197	Little Minam River	7/28/2013	7/30/2013	2
MNM00001-000209	Little Minam River	7/24/2013	7/26/2013	2
MNM00001-000369	Little Minam River	7/25/2013	7/29/2013	3
MNM00001-000096	Minam River	8/9/2013	9/7/2013	29
MNM00001-000236	Minam River	8/6/2013	8/11/2013	4
CBW05583-113834	Minam River	8/10/2013	9/7/2013	28
CBW05583-344746	Minam River	8/8/2013	8/11/2013	3
MNM00001-M53240	Minam River	9/7/2013	9/8/2013	1
MNM00001-M53247	Minam River	9/5/2013	9/8/2013	3
CBW05583-086186	Catherine Creek	9/9/2013	9/16/2013	7
CBW05583-147626	Catherine Creek	8/27/2013	9/9/2013	13
CBW05583-278698	Catherine Creek	9/3/2013	9/16/2013	13

Habitat Surveys

Minam River and Catherine Creek sites were generally similar in size, with bankfull widths of 12 – 24 m and site lengths from 240 – 480 m. Gradient was generally lower in Catherine Creek than Minam River. Pre-restoration Catherine Creek sites also had higher width:depth ratios, less large woody debris and shallower channels than reference sites in the Minam. However, the restored reach on Catherine Creek had the highest wood counts and lowest width:depth ratio of all the sites sampled (Table A 5).

Substrates were generally larger in the Minam and Little Minam Rivers than Catherine Creek, reflecting the higher gradients and stream power in the Minam. Boulders and cobbles were more abundant in the Minam sites, while gravel, sand and fines were more common in Catherine Creek (Table A 6). Of note were the high fines and embeddedness in the restored site CBW05583-086186. This was a result of the complete channel reconstruction where the new channel was cut through soil/sod. Most of these fines are expected to migrate out after a few high water, scouring events.

Riparian vegetation cover was generally higher in the Minam and Little Minam Rivers than Catherine Creek (Table A 7). Mean canopy cover, which consists of trees above 5 m tall, for all 10 Minam sites were 18.5% and only 11% for Catherine Creek. Understory cover was also higher in Minam sites. Conversely, ground cover was higher in Catherine Creek sites, presumably due to the lack of higher level tree cover reducing low growing plants.

The distribution of habitat unit types (i.e. pools, riffles and runs) were dictated by local conditions. However, Catherine Creek generally had more pool area than Minam or Little Minam Rivers (Figure A 3). The restored reach had the most pools by far, as was designed in the restoration project.

Table A 5. Basic site-level metrics for Minam River and Catherine Creek sites, 2013.

	Site ID	Gradient (%)	Sinuosity	Mean Thalweg Depth (m)	Unit Type Distribution % Pool	Riffle	FNT[†]	D50 (mm)	Cobble Emb.(%)	Wet LWD /100 m	BF LWD /100 m	Fish Cover* (%)	Width: Depth Ratio
Minam River	CBW05583-113834	1.68	1.22	0.76	18.6	78.5	0.0	110	1.3	3.0	5.8	3	34.5
	CBW05583-344746	1.15	1.40	0.52	14.0	83.7	0.0	95	9.1	18.2	32.5	9	42.5
	MNM00001-000096	1.21	1.45	0.68	40.4	55.8	1.9	73	2.3	24.4	42.0	19	44.5
	MNM00001-000236	0.41	1.28	0.53	44.1	30.7	21.0	62	0.1	31.0	87.8	6	47.5
	MNM00001-M53240	0.47	1.11	0.44	26.2	25.9	46.4	89	5.3	3.9	7.3	8	75.0
	MNM00001-M53247	1.77	1.10	0.61	0.0	97.4	0.0	105	3.1	8.4	16.0	3	45.2
Little Minam River	MNM00001-000081	1.40	1.04	0.32	6.5	91.3	0.0	101	5.0	5.9	8.5	5	43.6
	MNM00001-000197	1.78	1.11	0.41	13.5	68.3	15.2	77	8.6	16.6	41.5	15	42.6
	MNM00001-000209	2.15	1.34	0.45	3.1	90.5	5.1	75	0.8	6.2	11.0	9	43.5
	MNM00001-000369	0.92	1.24	0.40	29.5	53.2	8.7	60	6.5	31.3	64.2	14	43.6
Catherine Creek	CBW05583-086186 Post-restoration	0.20	1.45	0.55	58.2	19.3	3.7	24	18.0	49.2	66.4	24	28.9
	CBW05583-147626 Pre-restoration	0.72	1.21	0.37	37.8	58.0	0.0	51	5.1	7.2	19.4	3	56.7
	CBW05583-278698 Pre-restoration	0.76	1.08	0.34	11.2	73.4	12.3	60	3.7	5.9	11.4	11	57.5

*fish cover is % of stream area with overhead concealment by undercut banks, overhanging vegetation, aquatic vegetation and artificial structures

†FNT = fast non-turbulent channel unit type, often called glides or runs

Table A 6. Distribution of substrate sizes measured with ocular estimation during habitat surveys.

Site ID	Stream	% Bedrock	%Boulders (256-4k mm)	%Cobbles (64-256 mm)	%Gravel (2-64 mm)	%Sand & Fines (<2 mm)
CBW05583-147626	Catherine Creek	0	1	21	69	9
CBW05583-278698	Catherine Creek	0	8	32	47	13
CBW05583-086186	Catherine Creek	1	6	6	38	49
MNM00001-000209	Little Minam River	4	27	40	23	6
MNM00001-000369	Little Minam River	0	2	26	55	17
MNM00001-000081	Little Minam River	0	14	54	32	0
MNM00001-000197	Little Minam River	1	20	27	44	8
MNM00001-000236	Minam River	0	4	28	55	13
CBW05583-344746	Minam River	5	21	21	35	18
MNM00001-000096	Minam River	2	10	22	41	25
CBW05583-113834	Minam River	0	43	36	13	8
MNM00001-M53247	Minam River	3	40	25	22	10
MNM00001-M53240	Minam River	0	12	47	33	8

Table A 7. Riparian vegetation cover estimates from habitat surveys, 2013. Percentage cover represents the areal obstruction of sunlight from reaching the ground (i.e., shading).

Site ID	Stream	% Understory Cover	% Canopy Cover	% Ground Cover
CBW05583-147626	Catherine Creek	12.5	6.6	57
CBW05583-278698	Catherine Creek	23	18	52.5
CBW05583-086186	Catherine Creek	11	8.5	57
MNM00001-000209	Little Minam River	15.7	10.1	51.8
MNM00001-000369	Little Minam River	34.6	16.5	46
MNM00001-000081	Little Minam River	33.5	28.5	35.5
MNM00001-000197	Little Minam River	28.7	27.5	46.5
MNM00001-000236	Minam River	18.5	9	39
CBW05583-344746	Minam River	29.8	22	40
MNM00001-000096	Minam River	25.4	14	38.5
CBW05583-113834	Minam River	17.9	16	48
MNM00001-M53247	Minam River	30.5	22	33
MNM00001-M53240	Minam River	33.6	19.7	56.5

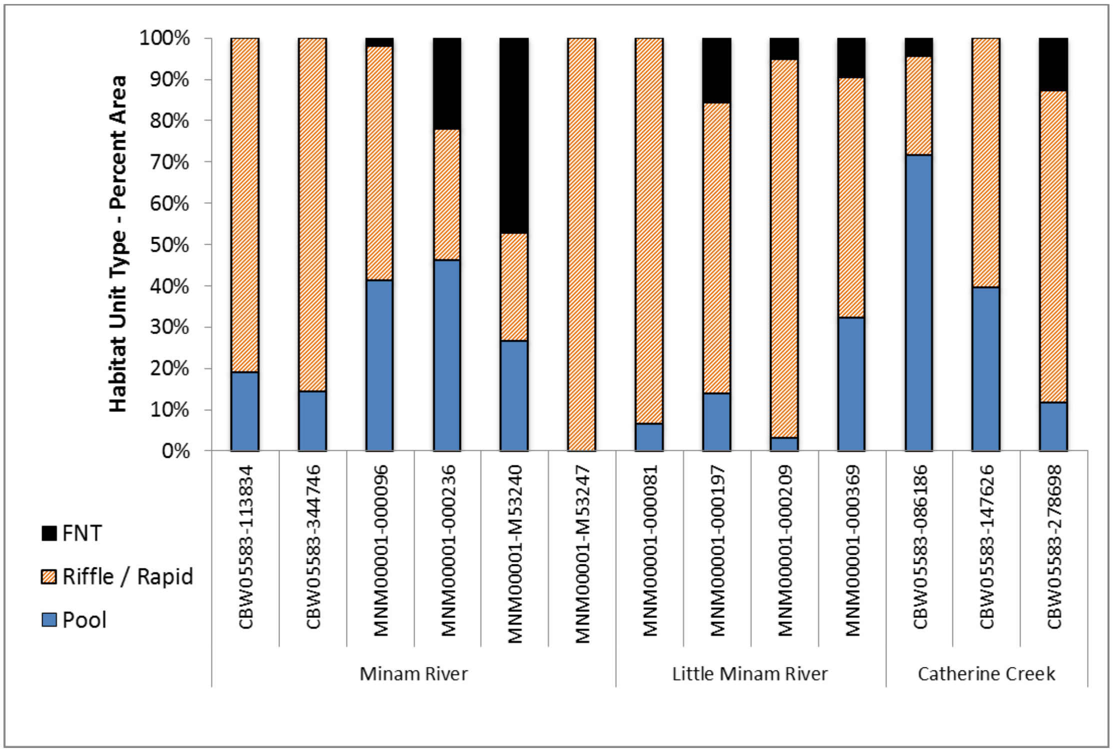

Figure A 3. Distribution of habitat unit types surveyed with CHaMP in 2013.

Snorkel Surveys

In the Minam basin both steelhead and Chinook salmon were observed at nine of the ten sites (Table A 8). Chinook salmon were slightly more common than steelhead overall and more abundant than steelhead at six of the nine populated sites (Figure A 4). Bull trout were observed at the two most upstream Minam River sites. Other fish taxa observed during snorkeling were mountain whitefish *Prosopium williamsoni* and sculpin *Cottis spp.* The three sites surveyed in Catherine Creek all contained steelhead and Chinook juveniles. The highest overall salmonid abundance was observed at site CBW05583-086186, the most downstream in Catherine Creek.

There was a significant decrease in our fish counts during the September surveys of Minam River sites. July and August surveys produced hundreds of Chinook and steelhead juveniles, but September surveys produced only dozens of fish, and one site showed zero fish. We do not believe this reflects juvenile salmonid use of these habitats during the growing season, but rather, movement patterns of Minam River fish. It seems most likely that fish began to move out of this general area in preparation for the oncoming winter. Although early September seems very early for such a movement, it seems the most likely reason for the absence of fish in our reaches, which had otherwise suitable rearing habitat and water conditions. In future years we will attempt to survey Minam sites before September to avoid the drastic reduction in fish numbers.

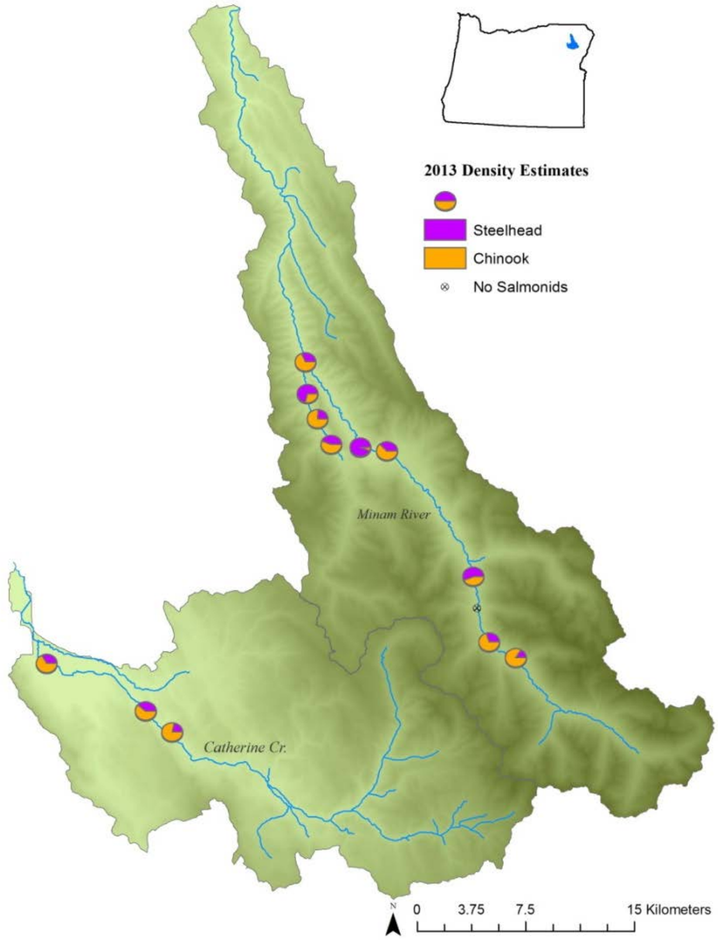

Figure A 4. Proportional distribution of salmonids observed during snorkel surveys of Minam River and Catherine Creek sites.

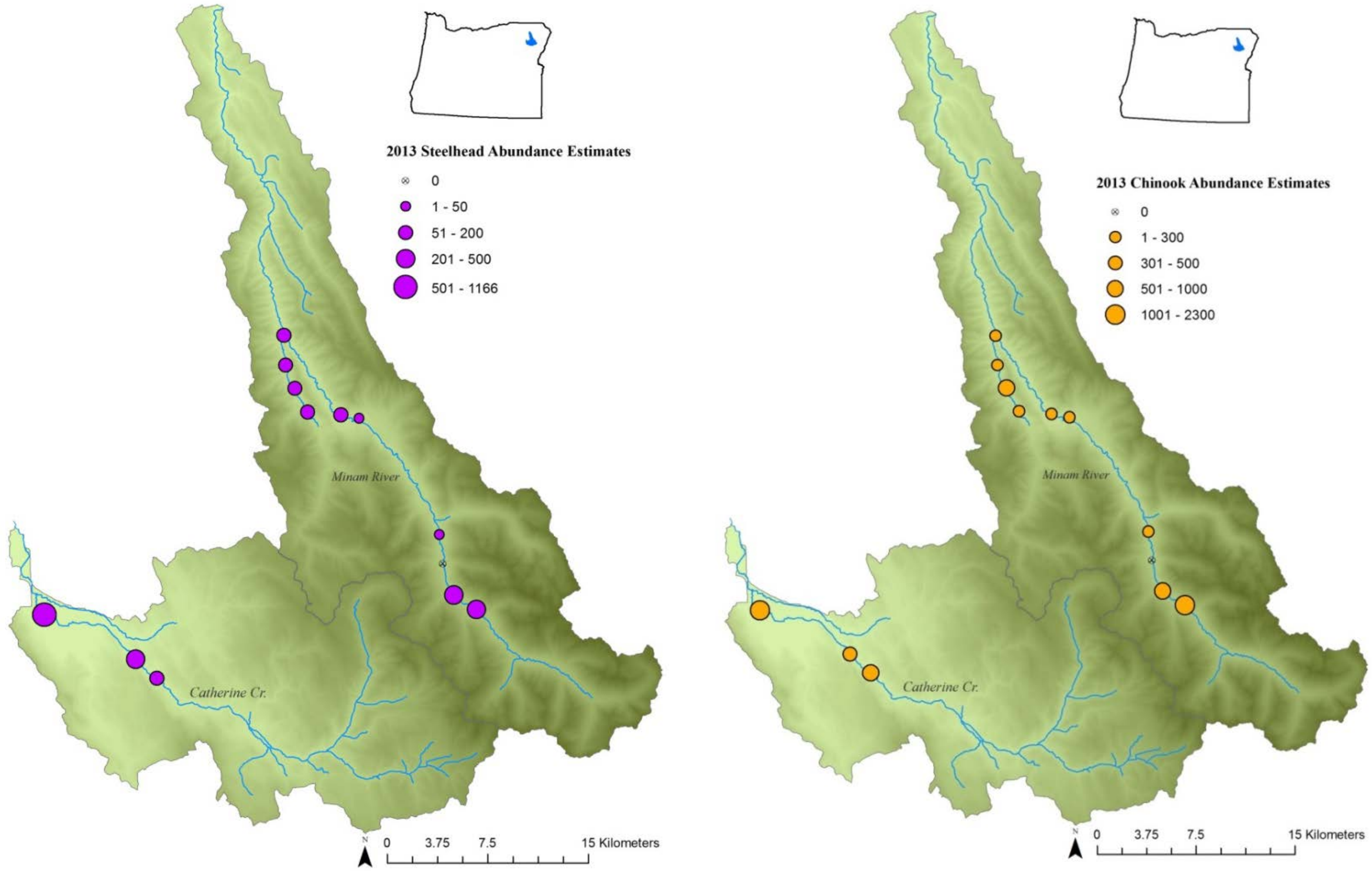

Figure A 5. Estimated abundance of juvenile steelhead and Chinook salmon within sample sites in the Minam River and Catherine Creek.

Table A 8. Raw counts of steelhead and Chinook size and estimated age classes from snorkel surveys, 2013.

			Steelhead Count					Chinook Count			
		Fork Length (mm)→	70-130	130-200	200-250	>250		50-80	>100		
Site ID	**Waterbody**	**Date**	**Age 1**	**Age 2**	**Age 3**	**Age 4+**	**Total**	**Age 0**	**Age 1+**	**Adult**	**Juv-Total**
CBW05583-086186	Catherine Creek	9/16	454	53	0	0	507	1009	38	0	1047
CBW05583-147626	Catherine Creek	9/9	62	2	0	0	64	231	3	2	234
CBW05583-278698	Catherine Creek	9/16	73	14	0	1	88	133	10	0	143
CBW05583-113834	Minam River	9/7	0	10	4	5	19	11	3	0	14
CBW05583-344746	Minam River	8/11	4	29	30	18	81	426	5	2	431
MNM00001-000081	Little Minam River	7/27	52	17	0	0	69	89	0	0	89
MNM00001-000096	Minam River	9/7	0	0	0	0	0	0	0	0	0
MNM00001-000197	Little Minam River	7/30	13	8	3	0	24	51	0	0	51
MNM00001-000209	Little Minam River	7/26	33	21	14	1	69	29	0	0	29
MNM00001-000236	Minam River	8/11	47	82	38	6	173	374	0	21	374
MNM00001-000369	Little Minam River	7/29	40	26	4	1	71	236	4	1	240
MNM00001-M53240	Minam River	9/8	2	47	11	2	62	3	1	0	4
MNM00001-M53247	Minam River	9/8	0	0	0	2	2	2	1	0	3

Table A 9. Estimated density of juvenile Chinook salmon (CH) and steelhead (ST) derived from snorkel surveys, 2013. Densities were estimated using correction factors generated for these surveys as described in methods. Fastwater units include riffles and rapids. FNT = fast non-turbulent.

			Density (fish/100 m^2) – Snorkel correction factor used					
			Pool Units		FNT Units		Fastwater Units	
Site ID	Stream Name	Date	ST	CH	ST	CH	ST	CH
CBW05583-086186	Catherine Creek	9/16	32.30	83.82	96.34	319.98	54.85	22.74
CBW05583-147626	Catherine Creek	9/9	1.95	8.47	NA	NA	3.00	10.31
CBW05583-278698	Catherine Creek	9/16	11.92	31.09	3.36	20.24	4.60	2.74
CBW05583-113834	Minam River	9/7	0.78	0.32	NA	NA	0.66	0.58
CBW05583-344746	Minam River	8/11	4.23	36.54	NA	NA	3.85	18.24
MNM00001-000081	Little Minam River	7/27	34.22	17.59	NA	NA	8.29	7.18
MNM00001-000096	Minam River	9/7	0	0	0	0	0	0
MNM00001-000197	Little Minam River	7/30	8.33	1.59	5.34	2.74	2.14	1.43
MNM00001-000209	Little Minam River	7/26	9.80	11.28	6.50	2.49	1.32	4.39
MNM00001-000236	Minam River	8/11	13.40	8.85	26.41	5.07	16.61	6.86
MNM00001-000369	Little Minam River	7/29	28.87	4.102	9.48	3.79	3.81	3.92
MNM00001-M53240	Minam River	9/8	0.22	2.57	0.051	0.74	0	1.60
MNM00001-M53247	Minam River	9/8	NA	NA	NA	NA	0.098	0.06

DISCUSSION

There was a significant decrease in our fish counts during the September surveys of Minam River sites. July and August surveys produced hundreds of Chinook and steelhead juveniles, but September surveys produced only dozens of fish, and one site showed zero fish. We do not believe this reflects juvenile salmonid use of these habitats during the growing season, but rather, movement patterns of Minam River fish. It seems most likely that fish began to move out of this general area in preparation for the oncoming winter. Although early September seems very early for such a movement, it seems the most likely reason for the absence of fish in our reaches, which had otherwise suitable rearing habitat and water conditions. In future years we will attempt to survey Minam sites before September to avoid the drastic reduction in fish numbers.

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Appendix D Draft Journal Article Relating CHaMP Habitat Data to Land Use Characteristics

Modeling relationships between key fish habitat metrics and landscape characteristics in the Upper Grande Ronde River basin

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March 11, 2015

Abstract

We analyzed the relationship of three important fish habitat metrics (fine sediment, large woody debris, and pool area) with landscape/land use characteristics in the Grande Ronde River basin with the objective of extrapolating site-level habitat data from CHaMP surveys to a larger spatial scale that would be more useful for life cycle modeling. We used both mixed-effects models and spatial statistical network models to fit relationships between CHaMP habitat metrics and landscape/land use data derived from remote sensing. The best fitting mixed-effects model for large woody debris (LWD) frequency included the explanatory variables elevation (positive effect), bankfull width (negative effect), and tree cover (positive effect), and together explained approximately 90% of the variation in LWD. The top model for percentage pool area included elevation (positive effect), valley width index (positive effect), watershed area (negative effect), slope (negative effect), and large woody debris frequency (positive effect) as explanatory variables, together explaining 88% of the variation in pools. In contrast with LWD frequency and percentage pools, the best fitting model for pool tail fines <2 mm was relatively weak ($r^2 = 0.44$). Despite statistically significant effects of elevation, valley width index, road density, and drainage density, this model was not a reliable predictor of fine sediment in pool tails. Spatial statistical network models showed promise for predicting LWD frequency as a function of landscape/land use characteristics and position in the watershed, but did not compare favorably with mixed-effects models for fine sediment or pool area metrics. These models will be used to predict habitat conditions at unsampled prediction points spaced every 500 m across the stream network. Prediction sites will then be rolled up using block kriging or simple averaging to calculate average habitat conditions at the scale of Biologically Significant Reaches (BSRs), the spatial unit used in our life cycle model.

Introduction

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. Critical uncertainties for fisheries managers in the

Columbia Basin are whether habitat restoration actions will yield a net improvement in basin-wide habitat quality, and whether expected improvements in fish production can be brought about by improvements in the quality and quantity of salmon habitat.

In order to address these uncertainties, CRITFC and the Oregon Department of Fish and Wildlife are working collaboratively to develop a life cycle model for spring Chinook salmon in the Grande Ronde basin that incorporates all key limiting factors throughout the salmon life cycle including freshwater habitat conditions. The habitat data necessary to parameterize this type of life-cycle model is being collected by CRITFC, ODFW and the Confederated Tribes of the Umatilla Indian Reservation using the Columbia Habitat Monitoring Program (CHaMP) protocol.

The CHaMP protocol produces an information-rich set of standardized habitat metrics quantifying fish habitat conditions across a wide swath of the Columbia River basin. These data were collected at randomly selected sites measuring approximately 20 times the bankfull channel width. One challenge with utilizing this type of data in a population modeling context is aggregating, or rolling up, the site-specific data to a larger spatial scale (e.g., HUC6, Biologically Significant Reach (BSR), and Distinct Population Segment (DPS)) that is more appropriate for modeling. This roll-up can be accomplished in various ways including: 1) the analysis tools from the Generalized Random Tessellation Stratified (GRTS) survey design which accounts for the original survey design and sample weights; 2) correlation analysis with other habitat data that were collected on a spatially continuous basis (e.g., Oregon Aquatic Inventories or other rapid habitat surveys); 3) spatial statistical network models which account for spatial autocorrelation among sites; or 4) general linear models which correlate CHaMP habitat data with spatially continuous remote sensing data. Although we are actively exploring all of these options for roll-up of the CHaMP data, this analysis focuses on the latter 2 options.

This analysis seeks to quantify the relationships between CHaMP habitat data and landscape/land use characteristics derived from widely available remote sensing data. Because the remote sensing data are spatially continuous, it will allow us to make model predictions of habitat conditions in unsampled locations and thereby extrapolate our habitat data to a more spatially continuous coverage across the landscape. The results from this analysis will be used to roll-up the site-level data to the level of Biologically Significant Reaches (BSRs), which represents the spatial resolution that we intend to use for life cycle modeling. In addition, it is important to quantify how in-channel habitat conditions measured by CHaMP are related to land use and other landscape characteristics so that projections can be made about how fish habitat conditions will change in the future under different land use, climate and restoration scenarios.

Methods

We used linear-mixed-effects models to evaluate relationships between in-channel CHaMP-derived metrics and landscape/land use characteristics. Mixed effects models are recommended for repeated measures survey designs like that used by CHaMP in which some sites are surveyed every year and some sites are surveyed every 3 years. Inclusion of “Site” as a random grouping effect allows us to use all of

the data available through CHaMP without violating the assumption of independence (i.e., pseudoreplication). In addition, we included a random year effect to account for random variation that may have resulted from year-specific factors (water levels, differences in the sampling protocol, or differences in survey crews). Model fitting was implemented in the lme4 package in Program R.

We downloaded fish habitat metric data from the CHaMP website (https://www.champmonitoring.org/) on February 26, 2015. At this time, the data had not been officially released for use by the CHaMP program because some aspects of the QA/QC process were still ongoing. Specifically, a small portion of the site visits (33 out of 269) had not successfully processed through the River Bathymetry Toolkit (RBT) and the metrics that relied on RBT for these visits were not available. However, we were assured from the CHaMP team that the metrics we used in this analysis were accurate and would not change upon completion of QA/QC.

We focused on three dependent variables for this analysis including pool tail fines less than 2 mm, large woody debris pieces per 100 m in the wetted channel, and percentage pool area. These metrics have either been demonstrated to relate significantly to juvenile Chinook salmon abundance in the Grande Ronde basin (see Fish Population RM&E section of this report) or, as in the case of fine sediment, have strong support in the literature for relating to salmonid productivity (Jensen *et al*. 2009). Pool tail fines and percentage pools were first converted to proportions and then logit transformed to ensure normality of the residuals. Because the logit transformation produces undefined values when the sample proportions are equal to 0 and 1, we added a small value *k* to both the numerator and denominator of the logit function as in Warton and Hui (2011) ($y = \log(\frac{p+k}{1-p+k})$). The value of *k* was taken to be the minimum observed value of the dependent variable, which was 0.001 and 0.014 for pool tail fines and percentage pools, respectively. Similarly, large woody debris frequency was log transformed to satisfy model assumptions. A value of 1 was added to the large woody debris metric prior to log transforming to avoid errors associated with taking the log of a zero.

We assembled and/or calculated an initial set of 30 independent variables (Appendix D-Table 1) from publically available sources, primarily the National Hydrography Dataset (NHDPlus) (http://www.horizon-systems.com/nhdplus/), NetMap (http://www.terrainworks.com/), and the National Land Cover Dataset (NLCD 2011) (http://www.mrlc.gov/). We calculated road density and tree cover metrics for a range of different buffer sizes upstream of each site as well as the entire upstream watershed. To do this, we developed an ArcGIS tool to delineate buffer area polygons based on a stream layer and the 10-meter DEM. Watershed boundary polygons for each site were generated using the StreamStats tools (http://water.usgs.gov/osw/streamstats/). Some of the independent variables were log transformed because the distribution of the raw data was highly skewed and because a logarithmic relationship made more sense ecologically. Specifically, we log transformed valley width index, percentage erodible area, and watershed area.

Because many of the explanatory variables were highly correlated and/or redundant, we used a manual model selection procedure based on Akaike's Information Criterion (AIC) to narrow down the set of explanatory variables to exclude highly correlated variables. This model selection procedure resulted in a single global model (i.e., fully parameterized model) for each of the dependent variables. We then

used a backward stepwise AIC model selection routine to systematically remove variables from the global model that did not increase model fit. Model assumptions were assessed using standard diagnostic plots. The variables included in both the global and best fitting models are provided in Appendix D-Table 2.

Once the best fitting model structure was determined for each dependent variable, we used the same variables to fit spatial statistical network models (or spatial linear models) using the SSN package in Program R (Ver Hoef *et al*. 2014). Spatial linear models account for spatial autocorrelation among sites, including the volume and direction of flowing water. The details of this modeling methodology are beyond the scope of this report (see Ver Hoef *et al*. 2014 and Peterson *et al*. 2013 for more details). For each dependent variable, we fit three spatial linear models which included different covariance structures including: 1) a tail-up exponential model, a tail down linear-with-sill model, and a Gaussian Euclidian distance model; 2) a tail-up exponential model and a Gaussian Euclidian distance model; and 3) a tail-up exponential model. Model fit of the spatial linear models was compared with the linear mixed-effects models using AIC. In addition, we examined plots of the raw data on the stream network as well as plots of the spatial autocorrelation (i.e., Torgegrams) to determine if there was good evidence to support the use of spatial statistical network models.

Appendix D-Table 1. Description of dependent and independent variables used in the analysis.

Number	Metric	Variable Type	Category	Description	Source
1	SlowWatPct	dependent	Pools	Percentage of the water surface area classified as slow water (pools)	CHaMP
2	SubLT2	dependent	Substrate	Percentage of pool tail substrate less than 2 mm	CHaMP
3	LWFreq_Wet	dependent/ independent	Wood	Count of wood pieces >= 1 m length and 0.10 m diameter in the wetted channel per 100 m channel length	CHaMP
4	BFQ	independent	Flow	Bankfull Flow (cms)	Netmap
5	MEANANNCMS	independent	Flow	Modeled mean annual streamflow (cms)	Netmap
6	Q0001E_08	independent	Flow	Modeled mean August streamflow (cfs)	NHDPlus
7	Q0001E_MA	independent	Flow	Modeled mean annual streamflow (cfs)	NHDPlus
8	UnitStrPow	independent	Flow	Unit stream power (1000 kg/m³ * 9.8 m/s² * mean annual flow (cms) * channel slope)/bankfull width (m)	Netmap
9	siteid	independent	Random	Site identification number	CHaMP
10	VisitYear	independent	Random	Year the habitat survey was completed	CHaMP
11	AreaKm2Wat	independent	Reach intrinsic	Watershed area (km²) calculated from StreamStats watershed polygons	StreamStats
12	ELEV_M	independent	Reach intrinsic	Mean levation (m)	Netmap
13	ErodPct	independent	Reach intrinsic	Percentage area with highly erodible geology within the upstream watershed.	CHaMP
14	GRADIENT	independent	Reach intrinsic	Gradient (rise/run) of nearest stream segment	Netmap
15	SLOPEpct	independent	Reach intrinsic	Slope (rise/run) of nearest stream segment * 100	NHDPlus
16	StDen_wat	independent	Reach intrinsic	Stream density (drainage density) in km/km² for the upstream watershed	NHDPlus
17	VWI_Floor	independent	Reach intrinsic	Valley width index (bankfull width/valley width)	Netmap
18	WIDTH_M	independent	Reach intrinsic	Modeled bankfull width (m)	Netmap

Number	Metric	Variable Type	Category	Description	Source
19	rd1km100m	independent	Roads	Road density (km/km²) in a buffer area of length 1 km upstream from the bottom of site and width 100 m on either side of the stream.	CRITFC
20	rd1km200m	independent	Roads	Road density (km/km²) in a buffer area of length 1 km and width 200 m	CRITFC
21	rd2km100m	independent	Roads	Road density (km/km²) in a buffer area of length 2 km and width 100 m	CRITFC
22	rd2km200m	independent	Roads	Road density (km/km²) in a buffer area of length 2 km and width 200 m	CRITFC
23	rdwat	independent	Roads	Road density (km/km²) within the upstream watershed	CRITFC
24	tco1km100m	independent	Tree Cover	Percentage canopy cover from trees > 5 m tall in a buffer area of length 1 km and width 100	NLCD 2011
25	tco1km200m	independent	Tree Cover	Percentage canopy cover from trees > 5 m tall in a buffer area of length 1 km and width 200	NLCD 2011
26	tco1km30m	independent	Tree Cover	Percentage canopy cover from trees > 5 m tall in a buffer area of length 1 km and width 30	NLCD 2011
27	tco2km100m	independent	Tree Cover	Percentage canopy cover from trees > 5 m tall in a buffer area of length 2 km and width 100	NLCD 2011
28	tco2km200m	independent	Tree Cover	Percentage canopy cover from trees > 5 m tall in a buffer area of length 2 km and width 200	NLCD 2011
29	tco2km30m	independent	Tree Cover	Percentage canopy cover from trees > 5 m tall in a buffer area of length 2 km and width 30	NLCD 2011
30	tcowat	independent	Tree Cover	Percentage canopy cover from trees > 5 m tall within the upstream watershed.	NLCD 2011
31	LWFreq_Bf	independent	Wood	Count of wood pieces >= 1 m length and 0.10 m diameter in the bankfull channel per 100 m channel length	CHaMP
32	LWVol_Bf	independent	Wood	Total volume of wood pieces >= 1 m length and 0.10 m diameter in the bankfull channel (m³)	CHaMP
33	LWVol_Wet	independent	Wood	Total volume of wood pieces >= 1 m length and 0.10 m diameter in the wetted channel (m³)	CHaMP

Appendix D-Table 2. Summary of variables included in the global and best fitting linear mixed-effects models of pool tail fines <2 mm (*SubLT2*), large woody debris pieces per 100 m in the wetted channel (*LWFreq_Wet*), and percentage pool area (*SlowWatPct*).

	Independent variables	
Dependent variables	**Fixed effects**	**Random effects**
Global Models		
Logit(SubLT2)	*ELEV_M + Log(VWI_Floor) + Log(AreaKm2Wat) + SlopePct + Log(ErodPct) + tcowat + rdwat + StDen_wat*	*siteid + VisitYear*
Log(LWFreq_Wet+1)	*ELEV_M + Log(VWI_Floor) + WIDTH_M + SLOPEpct + tcowat + StDen_wat*	*siteid + VisitYear*
Logit(SlowWatPct)	*ELEV_M + Log(VWI_Floor) + Log(AreaKm2Wat) + SLOPEpct + tco1km200 m + StDen_wat + Log(LWFreq_Wet+1)*	*siteid + VisitYear*
Best Fitting Models		
Logit(SubLT2)	*ELEV_M + Log(VWI_Floor) + rdwat + StDen_wat*	*siteid + VisitYear*
Log(LWFreq_Wet+1)	*ELEV_M + WIDTH_M + tcowat*	*siteid + VisitYear*
Logit(SlowWatPct)	*ELEV_M + Log(VWI_Floor) + Log(AreaKm2Wat) + SLOPEpct + Log(LWFreq_Wet+1)*	*siteid + VisitYear*

Results

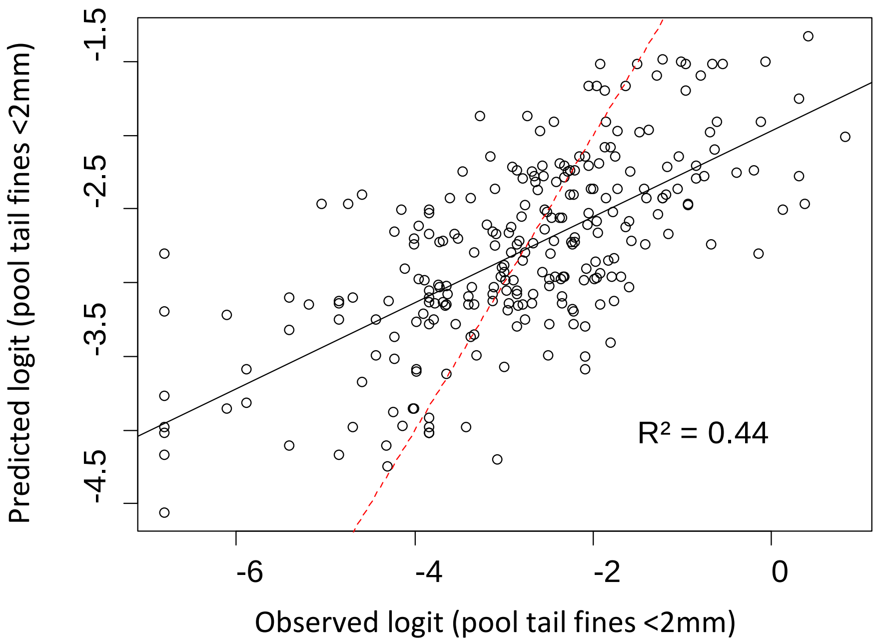
The best fitting linear mixed-effects model for pool tail fines <2 mm (*SubLT2*) included elevation, valley width index, road density within the upstream watershed, and drainage density as fixed-effect explanatory variables and site and year as random effects. Although the model coefficients were all statistically significant at the $\alpha = 0.05$ level (Appendix D-Table 3), this model was quite weak, explaining only about 44% of the observed variation in pool tail fines. In addition, a plot of the observed versus predicted values from this model indicated substantial bias in the model predictions, with lower values of pool tail fines (<4.5%) being over-predicted and values > 4.5% being under-predicted (Appendix D-Figure 1).

The direction of the fixed-effects was all positive for the pool tail fines model and generally agreed with our expectations (Appendix D-Table 3, Appendix D-Figure 2). Predicted mean pool tail fines increased by approximately 1.4 % for every 100 meter increase in elevation, although the relationship was not linear. The logarithmic relationship between pool tail fines and valley width index (VWI) showed a relatively steep increase in pool tail fines of about 8 % as the VWI increased to about 50, but then started to level off reaching a max of about 21% at a VWI of 275. Road density within the upstream watershed was positively related to pool tail fines, with fines increasing by roughly 1% for every 1 km/km^2 increase in road density. Higher drainage density also contributed to higher levels of fine sediment, with pool tail fines increasing by about 8.3% for every 1 km/km^2 increase in drainage density, although this effect was not highly significant ($p = 0.031$).

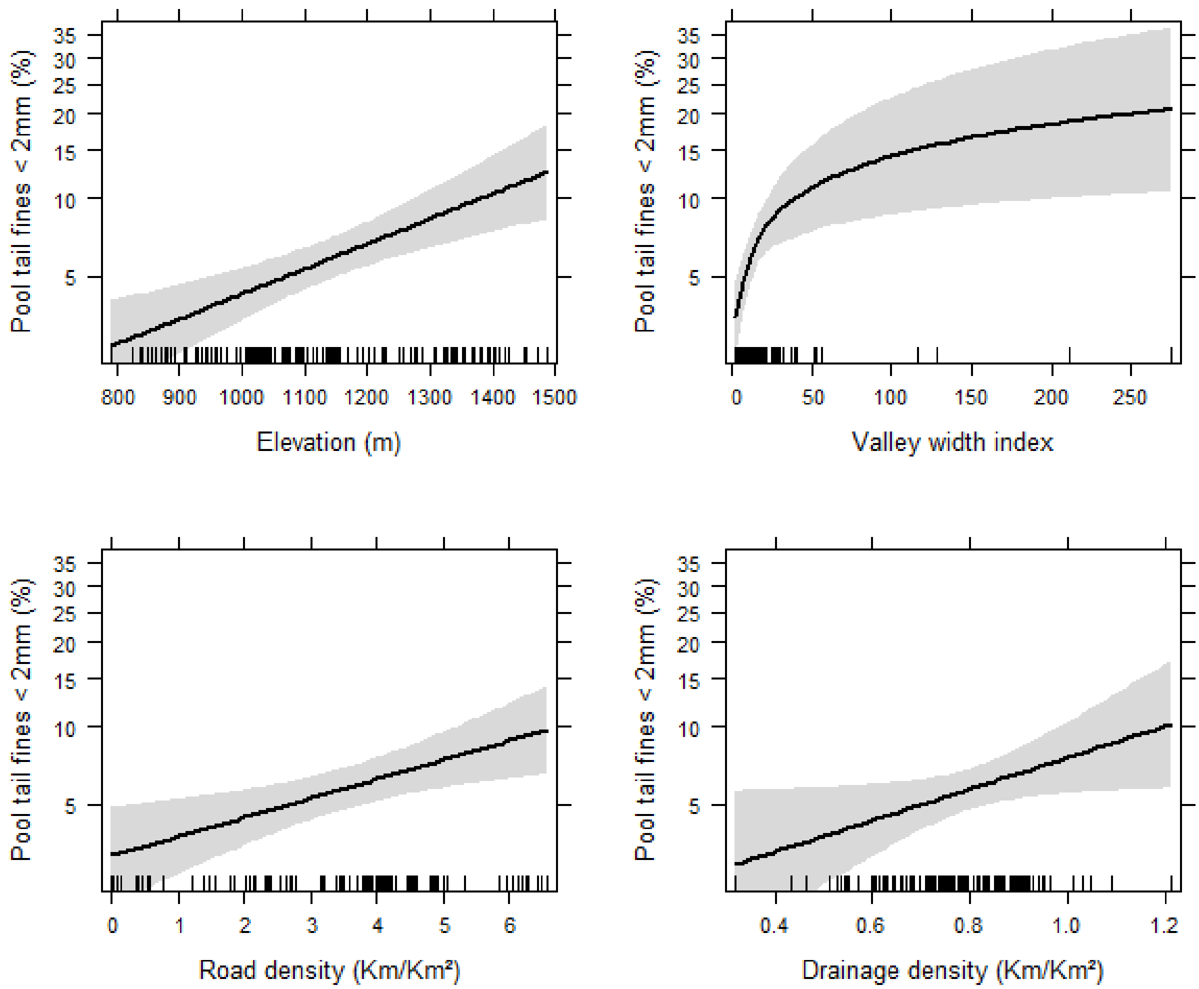
A comparison between the best fitting mixed-effects and the spatial statistical network models indicated little support for a spatial model as a better fitting model. AIC differences between the best fitting non-spatial model and the three spatial models ranged from 0.7 and 9.5. Although a ΔAIC value < 2 indicates substantial empirical support for one of the spatial models as a good competing model, the higher number of parameters in the spatial model and the added complexity of generating model predictions for a spatial model made it less desirable from our perspective to use this model. In addition, a map of the raw pool tail fines data across the drainage network indicated very little spatial pattern in the data (Appendix D-Figure 3). Finally, a Torgegram plot of the pool tail fines data showed no indication of spatial autocorrelation for either flow-connected or flow-unconnected sites (Appendix D-Figure 4). A Torgegram plot for a dataset with strong spatial autocorrelation would show a clear increase in semivariance as the distance between sites increased, especially for flow-connected sites. No such pattern was observed in the pool tail fines data.

Appendix D-Table 3. Model results summary from the best-fitting mixed-effects model for pool tail fines less than 2 mm.

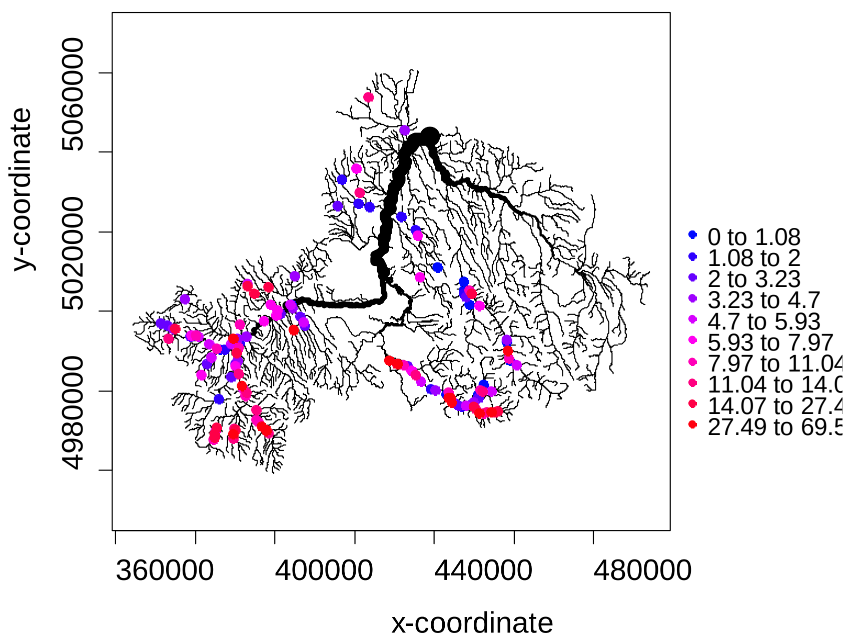
Fixed effects:	Estimate	Std. Error	Pr(>|t|)
(Intercept)	-8.3440	0.9387	3.33E-15
ELEV_M	0.0024	0.0006	4.28E-05
Log(VWI_Floor)	0.4378	0.1140	0.000198
rdwat	0.1827	0.0588	0.002313
StDen_wat	1.4990	0.6890	0.031381
Random effects:	Variance	Std.Dev.	
siteid	0.2936	0.5418	
VisitYear	0.0000	0.0000	
Residual	1.4478	1.2032	
Number of obs: 259, groups: Site, 143; Year, 4			



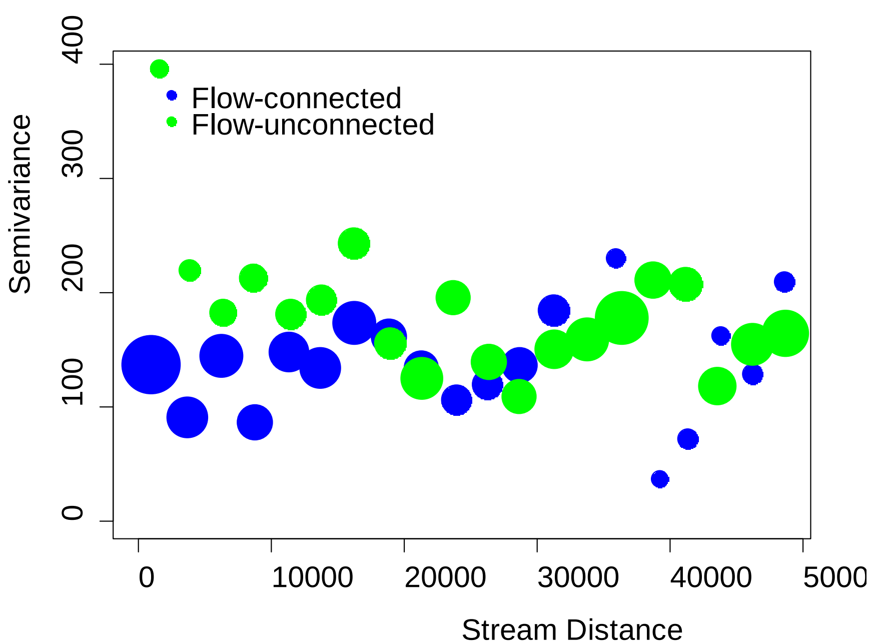
Appendix D, Figure 1. Observed versus predicted values from the best fitting model for pool tail fines < 2 mm. The solid black line represents a fitted linear regression and the red dashed line represents the 1:1 line.



Appendix D, Figure 2. Fixed-effects relationships from the best fitting model for pool tail fines < 2 mm. Gray bands represent 95% confidence intervals. Hash marks on the X axis represent sample size.



Appendix D-Figure 3. Pool tail fines less than 2 mm measured at 142 sites across the Upper Grande Ronde River basin.



Appendix D-Figure 4. Torgegram plot for pool tail fines less than 2 mm. The Torgegram displays semivariance as a function of hydrologic distance for flow-connected and flow-unconnected sites, with the size of the circle proportional to the number of locations used to estimate the semivariance.

The best fitting mixed-effects model for large woody debris pieces per 100 m included the fixed effects elevation, bankfull width, and tree cover in the upstream watershed and the random effects site and year. All model coefficients were highly significant ($p < 0.001$) (Appendix D-Table 4), and together explained approximately 90 percent of the variation in LWD frequency. In contrast with pool tail fines, a plot of the observed versus predicted values did not indicate substantial bias in the model predictions (Appendix D-Figure 5). LWD frequency increased by approximately 1.2 pieces/100 m for every 100 m increase in elevation (Appendix D-Figure 6). LWD frequency was negatively correlated with bankfull width, with LWD frequency decreasing by approximately 2 pieces/100 m for every 5-m increase in channel width. As expected, LWD frequency was positively related to tree cover in the watershed, with LWD frequency increasing by approximately 2.7 pieces/100 m for every 10% increase in tree cover.

Comparison of the best fitting mixed-effects model with the spatial statistical network models indicated that the spatial model with an exponential tail-up correlation structure was a better fitting model (AIC mixed effect model = 477.3; AIC best spatial model = 472.5; ΔAIC = 4.8). Often inclusion of spatial autocorrelation in a model will result in a substantial increase in the p values for the fixed effects, sometimes resulting in a substantial reduction in the number of explanatory variables that are considered statistically significant. In this case, the p values did indeed increase for all fixed effects in the model, but all coefficients remained highly significant ($p < 0.001$, Appendix D-Table 5). A map of LWD frequency across the stream network adds additional evidence for the presence of substantial spatial patterns in the LWD data (Appendix D-Figure 7). Appendix D-Figure 7 shows higher accumulations of LWD in the headwaters and generally lower LWD frequency in the lower elevation, mainstem stream segments. The Torgegram indicated a general increase in semivariance for flow-connected sites as would be expected if spatial autocorrelation was an important factor, although the relationship between semivariance and distance was highly variable (Appendix D-Figure 8)

Given time constraints, the results from the spatial model for LWD frequency will not be discussed in further detail in this analysis. However, a follow-up analysis will explore in greater depth the utility of spatial statistical network models for predicting LWD frequency and rolling up the model predictions to the biologically significant reach level using block kriging.

Table 4. Model results summary from the best-fitting mixed-effects model for large woody debris pieces per 100 m.

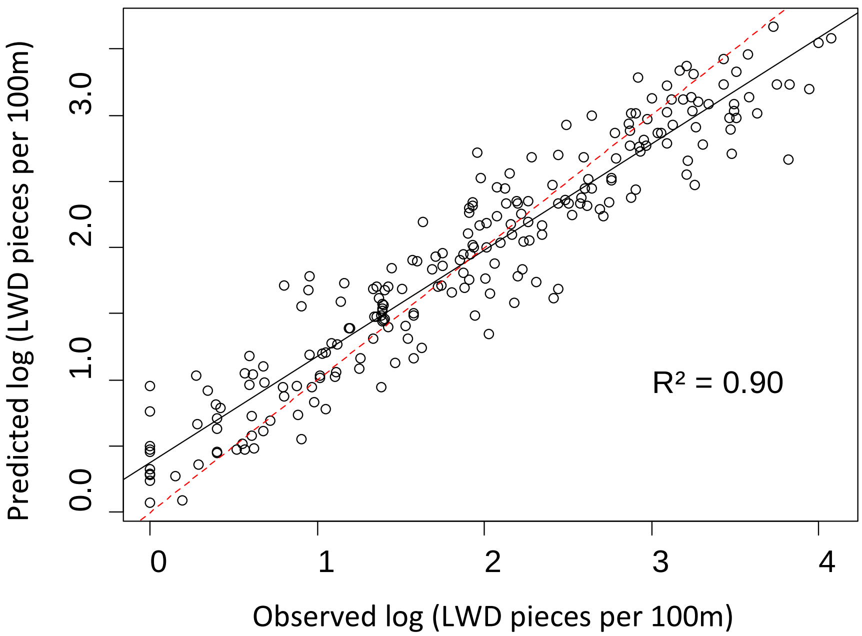
Fixed effects:	Estimate	Std. Error	Pr(>|t|)
(Intercept)	-0.8096	0.6010	0.180223
ELEV_M	0.0016	0.0004	0.000228
WIDTH_M	-0.0649	0.0161	9.32E-05
tcowat	0.0393	0.0070	1.36E-07
Random effects:	Variance	Std.Dev.	
siteid	0.3799	0.6163	
VisitYear	0.0125	0.1119	
Residual	0.2118	0.4602	
Number of obs: 222, groups: Site, 132; Year, 4			

Appendix D-Table 5. Model results summary from the best-fitting spatial statistical network model for large woody debris pieces per 100 m.

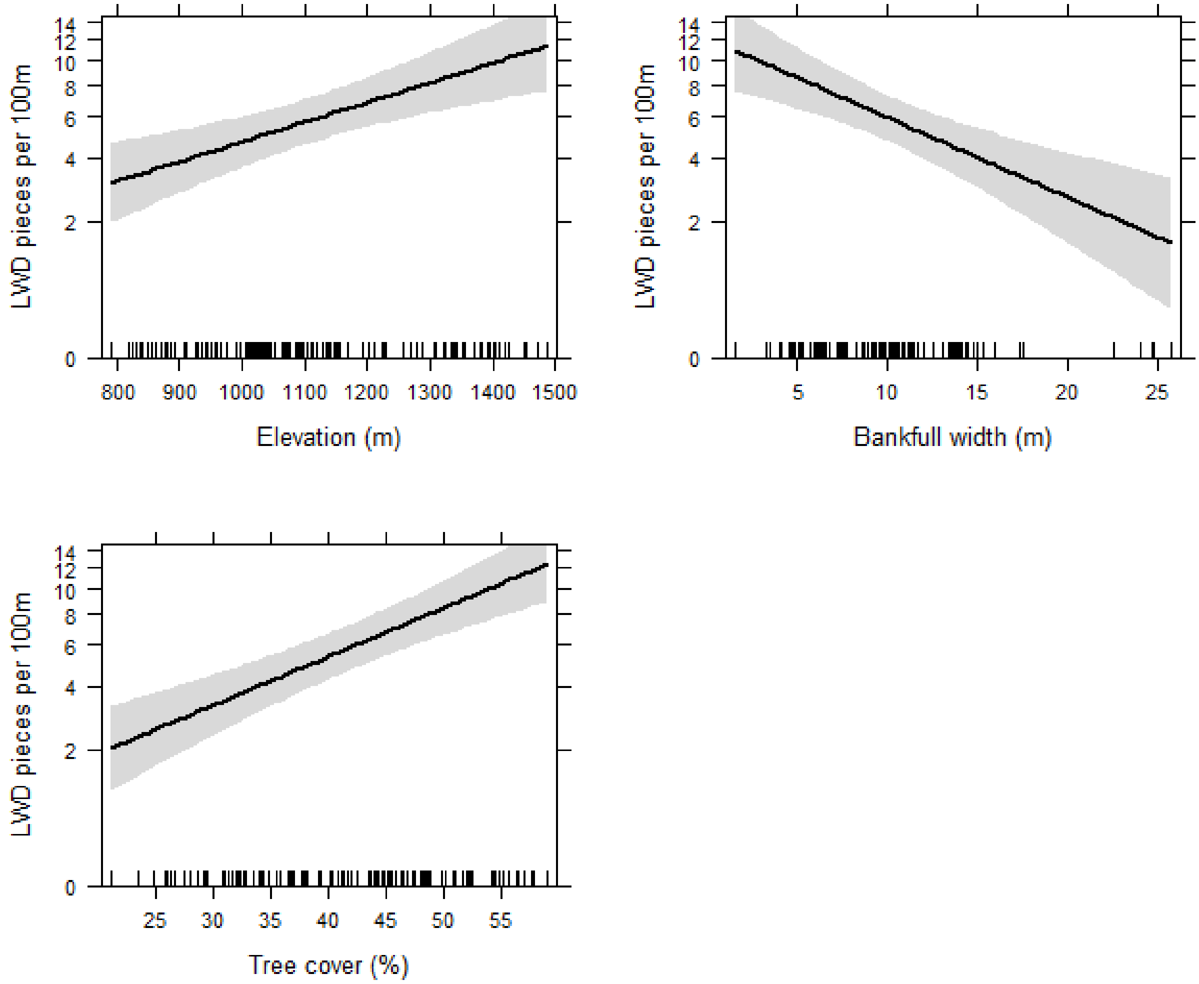
Fixed effects:	Estimate	Std. Error	Pr(>|t|)
(Intercept)	-0.858704	0.696077	0.21867
ELEV_M	0.001698	0.000514	0.00112
WIDTH_M	-0.065833	0.01822	0.00038
tcowat	0.037247	0.00879	3.00E-05

Covariance Parameters:	Parameter	Estimate
Exponential.tailup	parsill	0.3290
Exponential.tailup	range	6554.7324
siteid	parsill	0.0776
VisitYear	parsill	0.0119
Nugget	parsill	0.2093

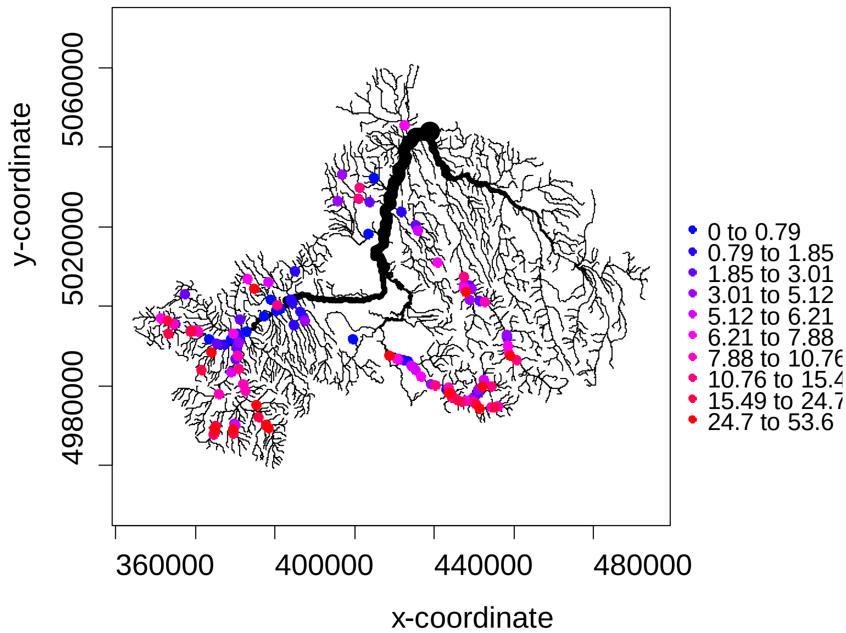
Residual standard error: 0.7922643



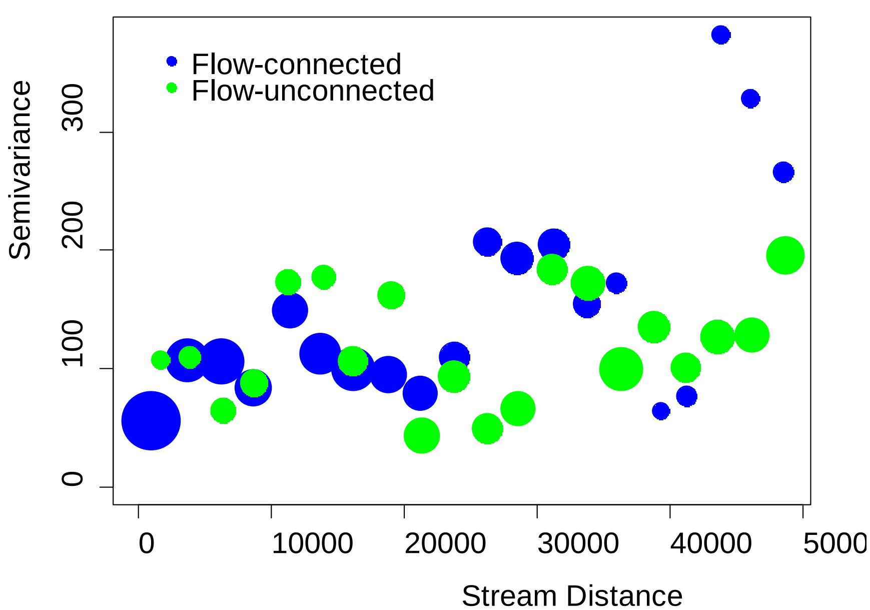
Appendix D-Figure 5. Observed versus predicted values from the best fitting model for large woody debris pieces per 100 m in the wetted channel. The solid black line represents a fitted linear regression and the red dashed line represents the 1:1 line.



Appendix D-Figure 6. Fixed-effects relationships from the best fitting model for large woody debris pieces per 100 m in the wetted channel. Gray bands represent 95% confidence intervals. Hash marks on the X axis represent sample size.



Appendix D-Figure 7. Large woody debris pieces per 100 m in the wetted channel measured at 130 sites across the Upper Grande Ronde River basin.



Appendix D-Figure 8. Torgegram plot for large woody debris pieces per 100 m in the wetted channel. The Torgegram displays semivariance as a function of hydrologic distance for flow-connected and flow-unconnected sites, with the size of the circle proportional to the number of locations used to estimate the semivariance.

The best fitting mixed-effects model for percentage pool area included elevation, valley width index, watershed area, slope, and large woody debris pieces per 100 m as fixed effects and site and year as random effects. All model coefficients were statistically significant at the $\alpha=0.05$ level, and together explained approximately 88 percent of the variation in percentage pool area (Appendix D-Table 6, Appendix D-Figure 9).

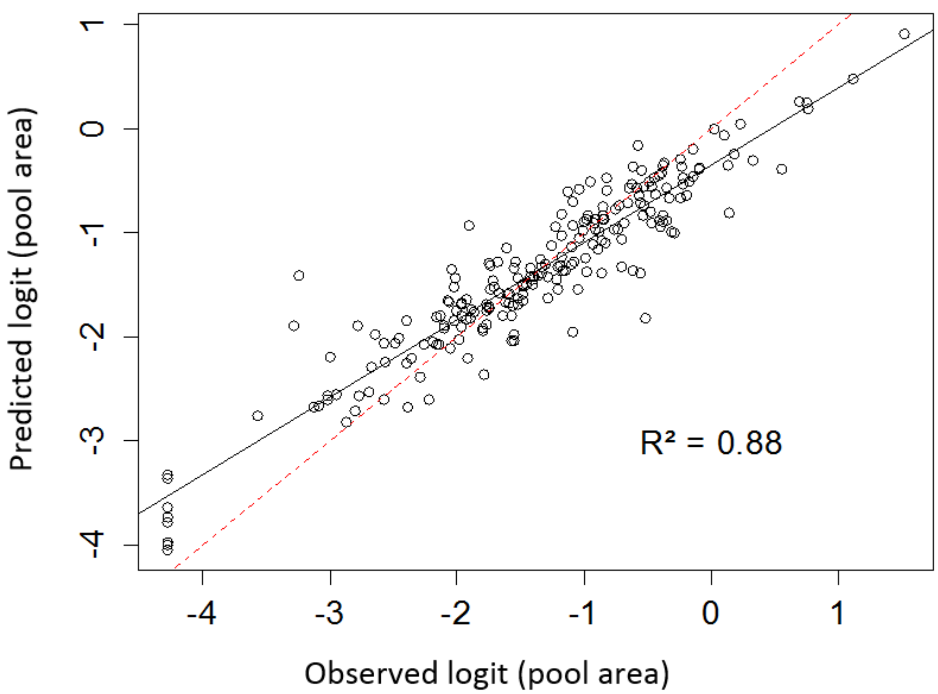
Percentage pool area was positively related to elevation, with pool area increasing by approximately 1.7% for every 100 m in elevation gain (Appendix D-Figure 10). The relationship between pool area and valley width index (VWI) was logarithmic, with pool area increasing from about 3% at a VWI of 3 to 21% at a VWI of 275. Increases in VWI beyond about 60 had relatively little impact on pool area, although this effect may be driven somewhat by small sample size for sites with VWI > 60. Percentage pool area was negatively related to watershed area, decreasing from about 34% at a watershed area of 7 km^2 to 12% at a watershed area of 1400 km^2. The most rapid decrease in percentage pools (-16%) occurred as watershed area increased from about 7 km^2 to 230 km^2. Similar to VWI, the distribution of the watershed area data is heavily skewed to the right, with very few data points informing the relationship for watershed areas greater than about 500 km^2. Pool area decreased by approximately 2.4% for every 1% increase in channel slope. Large woody debris frequency had a positive logarithmic influence on percentage pool area, with pools increasing from about 14% at a LWD frequency of 0 to 31% at a LWD frequency of 58 pieces per 100 m. Pool area increased most rapidly as LWD frequencies increased to about 10 pieces per 100 m, then gradually leveled off.

None of the spatial statistical models we examined compared favorably with the best fitting mixed-effects model for percentage pool area in terms of AIC (ΔAIC for the best spatial model = 3.9). Although a map of percentage pools across the drainage network tended to indicate a general pattern with higher pool frequency at sites closer to the headwaters, there was a high degree of variability in percentage pools and quite a few exceptions to this general pattern (Appendix D-Figure 11). The Torgegram plot for percentage pools indicated a reasonably consistent positive increase in semivariance with increasing stream distance between sites, which one would expect if there was substantial spatial autocorrelation in the data (Appendix D-Figure 12). Strangely, this spatial model was not strongly competitive in terms of AIC, suggesting that it might not be worth the added effort to fit a spatial model for percentage pools.

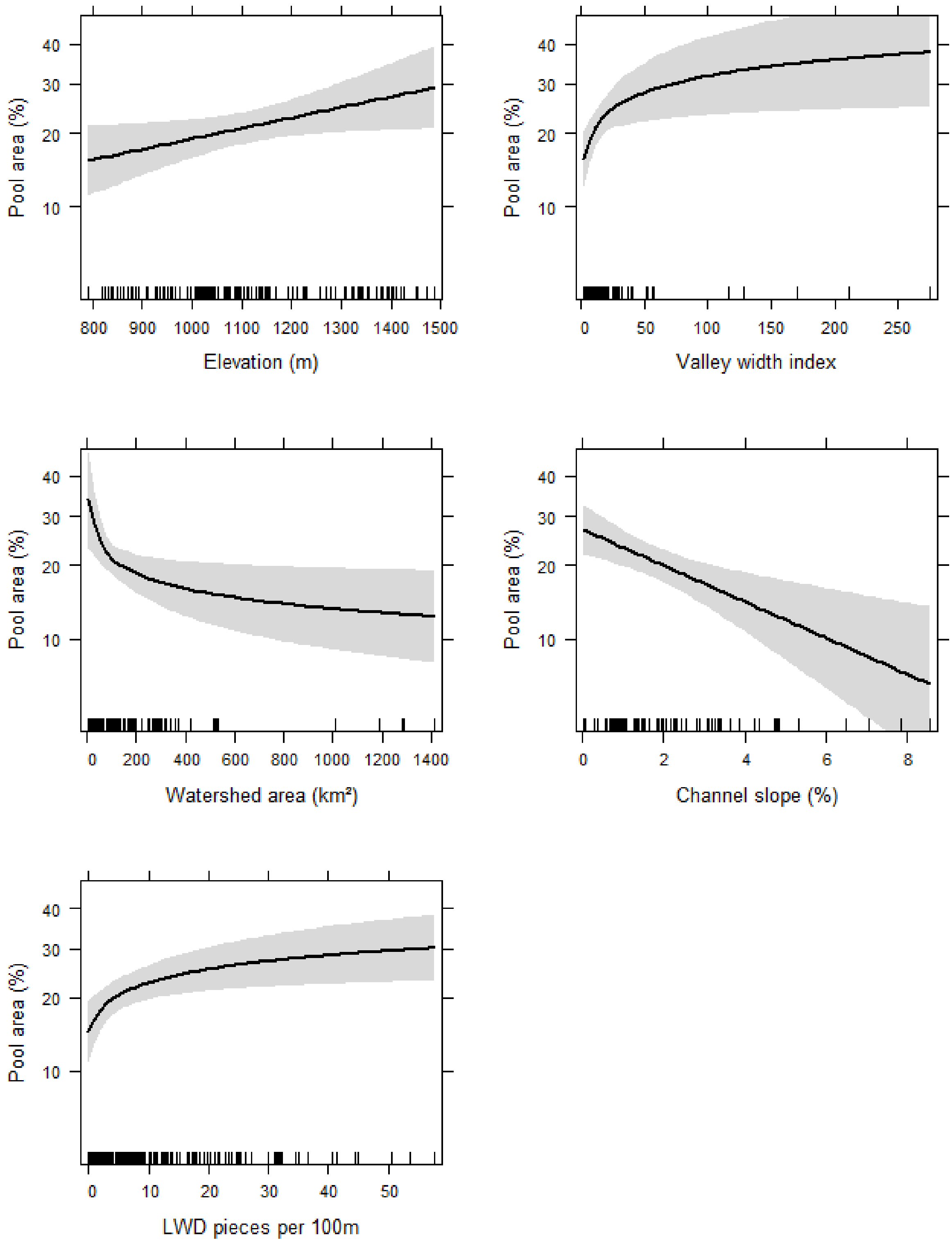
The next step in this process is to generate model predictions of LWD frequency and percentage pool area for a set of prediction sites that are densely distributed across the watershed. We've generated a set of prediction sites that are spaced approximately every 500 meters throughout the Chinook salmon distribution area in the Upper Grande Ronde River, Catherine Creek, and Minam River. Once predictions are made for each prediction site, these values can be averaged for each Biologically Significant Reach (BSR) to create the data required for life cycle modeling. We also intend to use spatial statistical network models and block kriging to generate estimates of mean LWD frequencies for each BSR, which can be compared with the average values generated from the mixed-effects modeling approach. We also intend to expand this modeling effort to include other important habitat metrics that likely relate to salmonid abundance and/or productivity, namely water temperature, depth fines (measured with a McNeil core sampler), and weighted usable area (derived from hydrological modeling and habitat suitability analyses).

Appendix D-Table 6. Model results summary from the best-fitting mixed-effects model for percentage pool area.

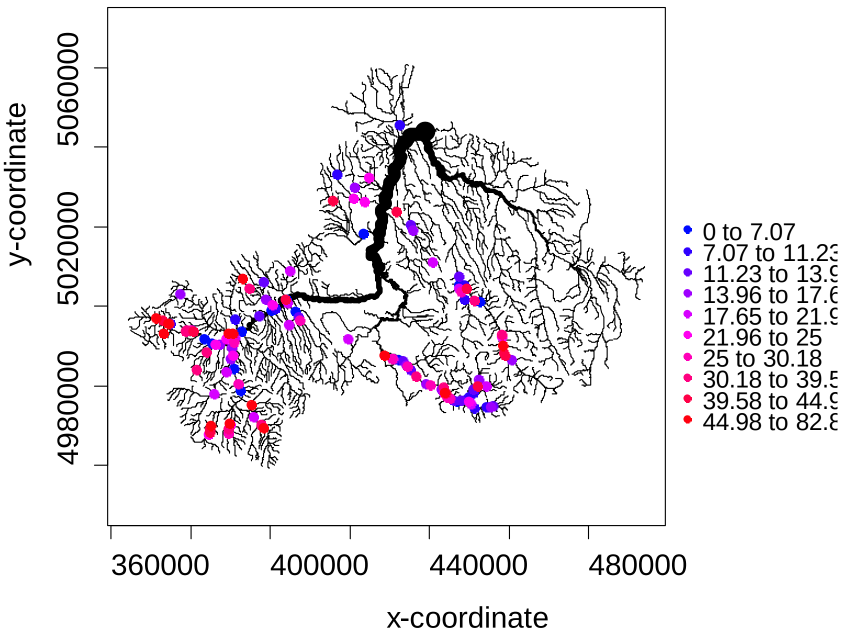
Fixed effects:	Estimate	Std. Error	Pr(>|t|)
(Intercept)	-2.1730	0.9231	0.02004
ELEV_M	0.0012	0.0005	0.03482
Log(VWI_Floor)	0.2571	0.0886	0.00439
Log(AreaKm2Wat)	-0.2424	0.0908	0.00849
SLOPEpct	-0.1977	0.0603	0.0013
Log(LWFreq_Wet+1)	0.2242	0.0716	0.00197
Random effects:	Variance	Std.Dev.	
siteid	0.518456	0.72004	
VisitYear	0.005282	0.07268	
Residual	0.272817	0.52232	
Number of obs: 222, groups: Site, 132; Year, 4			



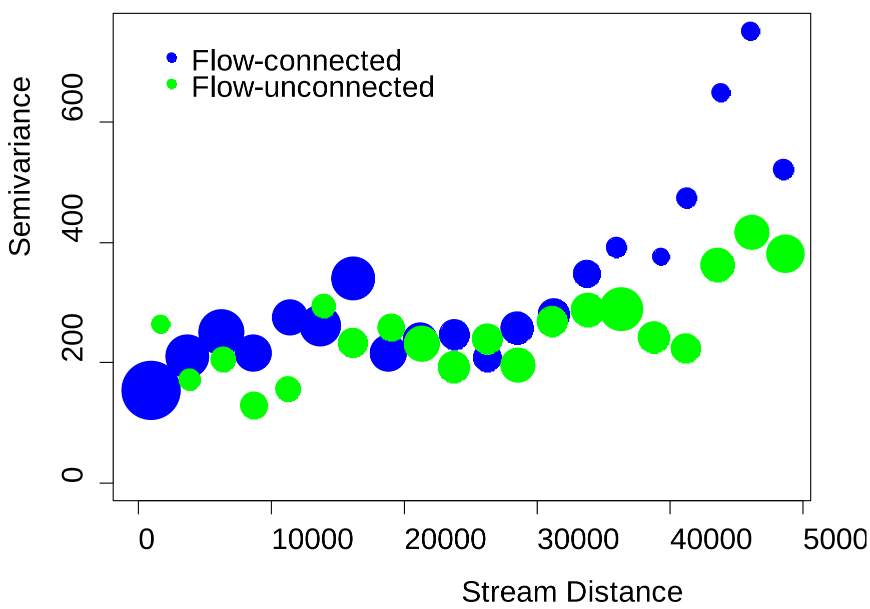
Appendix D-Figure 9. Observed versus predicted values from the best fitting model for percentage pool area. The solid black line represents a fitted linear regression and the red dashed line represents the 1:1 line.



Appendix D-Figure 10. Fixed-effects relationships from the best fitting model for percentage pool area. Gray bands represent 95% confidence intervals. Hash marks on the X axis represent sample size.



Appendix D-Figure 11. Percentage pool area measured at 130 sites across the Upper Grande Ronde River basin.



Appendix D-Figure 12. Torgegram plot for percentage pool area. The Torgegram displays semivariance as a function of hydrologic distance for flow-connected and flow-unconnected sites, with the size of the circle proportional to the number of locations used to estimate the semivariance.

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Appendix E Hydrology—Low flows

In cooperation with Columbia River Inter-Tribal Fish Commission

Characterizing late-season low-flow regime in the Upper Grande Ronde River Basin

By Valerie J. Kelly and Seth White

Report Series XXXX–XXXX

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [(Mgal/d)/mi^2]	1,461	cubic meter per day per square kilometer [(m^3/d)/km^2]

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Vertical Datum of 1988 (NAVD 88).”

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Datum of 1983 (NAD 83).”

Altitude, as used in this report, refers to distance above the vertical datum.

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	0.0002642	million gallons (Mgal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per year (m^3/yr)	0.000811	acre-foot per year (acre-ft/yr)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second per square kilometer [(m^3/s)/km^2]	91.49	cubic foot per second per square mile [(ft^3/s)/mi^2]
cubic meter per day (m^3/d)	35.31	cubic foot per day (ft^3/d)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
cubic meter per day per square kilometer [(m^3/d)/km^2]	0.0006844	million gallons per day per square mile [(Mgal/d)/mi^2]

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here, for instance, “North American Vertical Datum of 1988 (NAVD 88)”

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here, for instance, “North American Datum of 1983 (NAD 83)”

Altitude, as used in this report, refers to distance above the vertical datum.

Characterizing late-season low-flow regime in the Upper Grande Ronde River Basin

By Valerie J. Kelly and Seth White

Abstract

This report describes the rationale for and application of a protocol for estimation of ecologically relevant low-flow metrics that quantify late-season streamflow regime for ungaged sites in the Upper Grande Ronde River Basin, Oregon. The analysis presented here is focused on sites sampled by the Columbia River Inter-Tribal Fish Commission as part of their efforts to monitor habitat restoration to benefit spring Chinook salmon recovery in the basin. Streamflow data are provided by the U.S. Geological Survey and the Oregon Water Resources Division. Specific guidance is provided for selection of gage sites, development of probabilistic frequency distributions for annual 7-day low-flow events, and regionalization of the frequency curves based on multivariate analysis of watershed characteristics. Evaluation of the uncertainty associated with the various components of this protocol indicates that the results are reliable for the intended purpose of hydrologic classification to support ecological analysis. They should not be considered suitable for more standard water-resource evaluations that require greater precision, especially those focused on management and forecasting of extreme low-flow conditions.

Introduction

The Columbia River Inter-Tribal Fish Commission (CRITFC) assists four major tribes—the Nez Perce Tribe, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation of Oregon, and the Confederated Tribes and Bands of the Yakama Nation—to restore stocks of ecologically, culturally, and economically important fish populations (CRITFC 2014). Funding from the Columbia Basin Fish Accords agreement between three CRITFC tribes and Bonneville Power Administration supports efforts to evaluate recovery trends in important habitat variables for spring Chinook salmon in the Upper Grande Ronde River Basin (McCullough and others, 2014). The work described in this report is a component of this larger project, and is focused on characterizing low-flow regime as a primary feature of habitat quality for salmon spawning and juvenile rearing areas

during the late summer season. Low summer streamflow is implicated as one of several key limiting factors leading to the critical status of spring Chinook salmon in the project area. 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, based on the relationship between landscape characteristics and streamflow at gaged streams in the region. This report provides detailed analytical protocols for each step of the analysis, and demonstrates their application for selected streams within the CRITFC study area.

Description of study area

The Grande Ronde River is a tributary to the Snake River, originating in the Blue Mountains ecological province of northeast Oregon (Figure 1). It drains the Blue Mountains to the west and northwest and the Wallowa Mountains to the southeast for a total area of about 4,000 square miles, flowing 212 miles roughly north-northeast from the headwaters to its confluence with the Snake River at Hells Canyon. Mountainous areas where headwater streams originate peak at elevations ranging from 7,500 to 10,000 feet, and two large river valleys are defined at lower elevation by the mainstem Grande Ronde and Wallowa Rivers (elevations 2,600-2,800 and 2,800-4,700 feet, respectively) (NPCC, 2004). Major tributaries include the Wenaha, Wallowa and Minam Rivers, and Catherine and Lookingglass Creeks. Much of the upper basin at high elevation is public land, primarily forested, while the lowland areas are private lands and subject to agricultural and grazing effects (McIntosh, 1992). Surface geology in the basin is dominated by Columbia River Basalt with older volcanic and granitic intrusive rocks largely confined to high elevation headwater areas; the Columbia Plateau aquifer system underlies about 75 percentage of the basin (NPCC, 2004).

1. Map of study area showing (A) all gages and (B) ungaged sites.

Climate in the Grande Ronde Basin is influenced by the diversity of topography between high mountain ranges and deep canyons, which creates localized climatic effects. Regional climate is shielded from the maritime influence of the Pacific Ocean by the Cascade Mountains, 200 miles to the west, so that the dominant climate pattern is considered to be modified Continental (NPCC, 2004). Winters are cold and wet while summers are warm and dry, with air temperature varying according to elevation. Mean annual precipitation ranges from 14 inches in the valleys to more than 60 inches in the mountains (NPCC, 2004). The range in elevation defines two snow zones in the basin: the Warm Snow Zone (between about 2,000 – 5,000 feet of elevation) and the Cold Snow Zone (> 5,000 feet). Snow cover may become intermittent in the Warm Snow Zone when temperatures between 50 to 60^{o} f develop during the winter (Wissmar and others, 1994). These warm conditions are often associated with moderate to heavy precipitation, so that snowmelt may be coincident with rain and result in large winter floods.

Streams in the Grande Ronde Basin are dominated by snowmelt, with peak flows occurring in the spring (April-June). Timing of snowmelt runoff varies with elevation of headwaters, with earlier runoff associated with streams originating in the relatively low elevation Blue Mountains while snowmelt peaks generally occur later in those arising in the higher Wallowa Mountains (NPCC, 2004). Runoff declines

through the summer and the lowest flows generally occur in August or September, sometimes extending into the winter.

Importance of low-flow regime to salmon

Low flows in the upper Grande Ronde River Basin are hypothesized to fall into two general categories: surface-dominated and groundwater-dominated regimes. The range in geology across the basin indicates two large-scale geologic zones, characterized by relatively old intrusive and volcanic deposits in the headwater areas at higher elevation and younger Columbia River Basalt further downstream. These different rock types are presumed to be associated with contrasting patterns of groundwater storage, since older and less permeable formations generally store less water. Basaltic rocks, which tend to be more permeable, are more likely to function as groundwater reserves, capturing snowmelt and storing it during the melt season, releasing it slowly as baseflow during the summer and fall.

The extent of groundwater influence on streamflow affects habitat quality in the late summer season for stream fishes in several ways: through augmentation of baseflow, modulation of water temperature, and provision of refugia from temperature extremes (Power and others, 1999). Groundwater augmentation of summer baseflow is beneficial because higher flows during that time provide greater volume of habitat, as well as exert a potentially significant cooling influence on stream temperature. Even a relatively small input of groundwater can provide critical protection for cold-water fishes like salmon from potentially lethal temperatures during the late summer months (Torgersen and others, 2012).

Historically, the Upper Grande Ronde River supported large runs of spring Chinook salmon (*Oncorhynchus tshawytscha*) as well as summer steelhead (*O. mykiss*), although these stocks are now much reduced (McIntosh, 1992). Snake River spring Chinook salmon in the Snake River Basin, including the Grande Ronde, were listed as threatened in 2005 under the Endangered Species Act and populations in the Grande Ronde River Basin are considered as high priority for recovery (NOAA, 2007). Natural spawning of spring Chinook salmon occurs in the upper Grande Ronde River and its principle tributaries: the Wenaha River in the lower basin, the Wallowa River in the middle basin with its tributaries the Minam and Lostine Rivers, as well as in smaller streams including Bear and Hurricane Creeks in the Wallowa Basin, Lookingglass Creek in the middle basin, and Catherine Creek in the upper basin (CRITFC, 1995).

Snake River spring Chinook salmon life history is of the stream type, where juveniles remain in fresh water for one full year before they migrate to the ocean. Adults re-enter fresh water in late winter and early spring and move upstream to relatively high elevation areas where they rely on cool and deep pool habitat before spawning in late summer and early fall. The most important flow-related impacts on salmon in the basin include the loss of pool habitat and extreme water temperatures during the late summer season (Wissmar and others, 1994), both of which depend on the relative influence of groundwater during late-season baseflow conditions.

Rationale for approach

Analysis of streamflow patterns is frequently based on annual streamflow frequency information that, in the United States, is supplied primarily by data from the U.S. Geological Survey (USGS) streamflow database. The necessary data are available only for sites where long-term gaging stations are located, however, and many streams are ungaged. Regional frequency analysis provides a way to estimate the frequency distribution for a variety of low-flow metrics at ungaged sites, based on pooled data from gaged sites within a homogeneous region (Riggs, 1973; Stedinger and others, 1993). In this study, an index procedure was used, whereby the regional frequency curve was scaled by a site-specific scaling factor (termed the “index flow,” e.g. the mean peak or low-flow value for the site) (Hosking and Wallis, 1993). This curve defines the dimensionless frequency distribution for the region, from which specific quantile estimates for ungaged sites can be determined on the basis of estimated values for the index flow for those sites. The steps involved in regional index-flow analysis include the following: (1) identification of homogeneous regions, (2) choice and estimation of a regional frequency distribution, and (3) estimation of index flow.

A critical assumption for any index-flow procedure is that the scaled frequency distributions for all sites within the region are similar. Geographically contiguous regions have frequently been defined according to physiographic and political boundaries, which do not always correspond to similarities in hydrologic response (Simmers, 1975). For this analysis, a “region of influence” approach was used to group sites according to basin features that are presumed to control streamflow characteristics (Wiltshire, 1986). In this approach to regionalization, every site potentially has a unique set of basins defined as its hydrological “region” that is not necessarily spatially contiguous (Burn, 1990a, 1990b; Zrinji and Burn, 1994). These sites are selected from the correspondence between selected hydrologic and watershed characteristics, as determined by canonical correlation analysis (CCA) (Ribeiro-Corea and others, 1995). CCA provides canonical scores that reflect the correlation structure between the two sets of variables for gaged sites. These scores, in turn, can be used to determine the associated score on the hydrologic vector from watershed data for individual ungaged sites where no hydrologic data are available. An ellipsoidal region around each hydrologic score can be identified with a defined level of confidence based on a chi-squared distribution. This region identifies the basins that compose the corresponding so-called hydrologic neighborhood or site-specific region for the target site.

After identifying the appropriate hydrologic region for each site, the next step is to select an appropriate frequency distribution to describe the regional frequency curve. Because of the focus on extreme events, the generalized extreme value distribution (GEV), based on probability-weighted moments (PWM), was selected for this analysis (Greenwood and others, 1979; Landwehr and Matalas, 1979; Hosking and others, 1985). This procedure is flexible and easy to implement, and has proven to be especially reliable when regions are not homogeneous (Lettenmaier and others, 1987). Additionally, a comparison of six theoretical distributions for minimum flows found the PWM/GEV distribution to have the best performance (Onoz and Mayazit, 1999; Vicente-Serrano and others, 2012). For these reasons, this approach was selected as an appropriate one for this analysis.

Methods

Data assembly

Streamflow data

Previous work by Risley and others (2009), estimating low-flow frequency statistics for unregulated streams in Oregon, provided the first estimation of a set of streamflow gages suitable for this analysis. Data for daily mean streamflow were obtained from the online USGS National Water Information System (NWISWeb; http://waterdata.usgs.gov/nwis) and from the online data service provided by the Oregon Water Resources Department (OWRD) (http://www.oregon.gov/owrd/Pages/sw/index.aspx) for those gages (N=61) identified in Risley and others (2009) as Region 6, which they assumed to represent a homogeneous hydrologic region containing the Grande Ronde River. These gages were further augmented by additional OWRD gages (N=14) on streams that were not included in Region 6 for the Risley analysis. Gages were excluded from further consideration if their upstream watershed area exceeded 500 square miles, the largest watershed included as a target CRITFC ungaged site. Additionally, if two gages were located along the same stream, the ratio of their watershed areas was evaluated and if the ratio was greater than 0.25, the gage with the shorter period of record was excluded from further analysis.

The daily data were first subset to include data only for the late-season summer time period (Julian days 200-300, mid-July through most of October), prior to determining the annual 7-day minimum flow for each year of record. Once these data were compiled, in order to conform to the assumptions of stationarity for the frequency analysis, they were evaluated for temporal trend as defined by Kendall's tau-b ($p<.01$) (SAS, 1990). Trend analysis proceeded in an iterative process in an attempt to maximize the period of record. First the data for the entire record were evaluated. For gages where no trend was observed, the entire dataset was included in the regional analysis. For gages where a significant trend was observed, a subset of the data was evaluated again to determine if a shorter period of record would be suitable for the regional analysis. The period of record was first limited to the record beginning in 1960 and subsequently for the record beginning in 1980. All gages that exhibited a significant trend over the entire period of record continued to show trends over these shorter periods. Sites were further limited so that each had a minimum of 10 years of record. Based on this screening, the total number of suitable gages for analysis was 39 (Table 1).

Table 1. Final set of streamflow gages used in analysis.

Basin characteristics

A number of candidate basin characteristics were obtained for each gaging station and CRITFC site, including drainage area, topography, precipitation, soil characteristics, underlying geology, and several metrics of basin shape and aspect. All basin characteristics were extracted from GIS databases using Arc Macro Language programs written for Arc/Info (Environmental Systems Research Institute, Inc., 1999). Drainage area was determined by digitizing basin boundaries using 1:24,000 USGS topographic maps. Elevation was determined from data from the USGS National Elevation Database (NED), with 30-meter resolution; further evaluation of elevation was based on the proportion of each watershed within

selected elevation criteria. Annual precipitation was calculated as the sum of area-weighted estimates, based on raster precipitation data for monthly average precipitation totals (1961-1990), with 2-km resolution (Daly and others, 1994). Precipitation intensity metrics for selected recurrence intervals were calculated from raster data, including both local (site-specific) and watershed-wide characteristics (USDC, 1961; NOAA, 1973). Soil characteristics were described by the sum of area-weighted values for the watershed, based on data from the State Soil Geographic (STATSGO) database (Schwarz and Alexander, 1995). Metrics of basin shape were determined by the Basinsoft program (Harvey and Eash, 1995). Data to describe aspect direction were derived as the mean overall deviation of the watershed from the south in degrees. Data for underlying geology were derived from integrated geologic map databases (Ludington and others, 2005; Stoeser and others, 2005). Watershed characteristics evaluated in this analysis are described in Appendix 1; data to describe watershed characteristics for gaged sites are presented in Appendix 2.

Regionalization process

Streamflow frequency analysis

Frequency analysis provides a way to assign probabilities to the occurrence of low-flow events of a specified size based on fitting a theoretical probability distribution to the observed data. The use of theoretical distributions provides an objective method for deriving estimates of metrics that succinctly describe the streamflow regime, based on parameters that are determined directly from the annual data series. These include measures to describe location (i.e. mean), scale (i.e. standard deviation), and shape (i.e. coefficient of skewness). Annual data are ranked and assigned a plotting position that approximates the associated probability, and the theoretical curve is estimated based on this position and appropriate parameters.

As previously discussed, frequency analysis of annual 7-day low flow data from gaged sites was based on an index-flow procedure, using PWM estimators of the GEV distribution (Hosking and others, 1985). The GEV distribution of any random variable (x) is described by

$$F(x) = exp\left\{-\left[1-\frac{g(x-u)}{a}\right]^{\frac{1}{g}}\right\}, \text{ where } g \neq 0 \qquad (1a)$$

$$F(x) = exp\left\{-exp\left[-\left(\frac{x-u}{a}\right)\right]\right\}, \text{ where } g = 0 \qquad (1b)$$

and *u, a,* and *g* represent parameters of location, scale, and shape. For this analysis, the probability-weighted moments (M_j) for each site were first determined as

$$M_j = \frac{1}{n}\sum_{i=1}^{n}\left(p_i^j, Q_i\right), \text{ for } j = 0,1,2 \qquad (2)$$

where $p_i=(i-0.35)/n$ is the plotting position estimate of F(Q) and Q_i is the series of annual 7-day minimum streamflow. For this analysis, the series was ordered from smallest to the largest so that the plotting

position (*pi*) represents Px(x), the probability of an event equal to or smaller than the designated value (Gordon and others, 1992).

Next, the PWMs for each site were normalized by their mean ($M_j^* = M_j - M_0$). The parameters of the GEV distribution were estimated as follows:

$$c = \frac{2M_1 - M_0}{3M_2 - M_0} - \frac{log2}{log3} \quad (3a)$$

$$g = 7.8590c + 2.9554c^2 \quad (3b)$$

$$a = \frac{(2M_1 - M_0)g}{\backslash Gamma(1+g)(1-2^{-g})} \quad (3c)$$

$$u = M_0 + a[\backslash Gamma(1+g) - 1]/g\ . \quad (3d)$$

Finally, the selected quantiles (T-year flow events) of the GEV distribution were determined by

$$Q_T^* = \frac{\left\{1 - \left[-ln\left(1 - \frac{1}{T}\right)\right]^g\right\}}{g} \quad (4)$$

where $g \neq 0$.

The presence of zero flow values was dealt with by adjustment of probabilities based on the theorem of total probability (Haan, 2002). In other words, it was assumed that all the probability was accounted for simply by the sum of the probability of flow equal to zero plus the probability of flow greater than zero. On this basin, the frequency distribution for each site was first determined for all 7-day low-flow values greater than zero. The resulting probabilities were then adjusted by the fraction of non-zero values observed in the data for that site, effectively shifting the frequency curve along the probability axis to reflect the probability of zero flow (Gordon and others, 1992).

A probability plot correlation test was conducted to test how well the sample data from each gage fit the GEV distribution (Stedinger and others, 1993). This test is based upon the correlation *r* between the sample data, ordered as described above, and the corresponding predicted values based upon their plotting positions. Values of *r* close to 1 indicate a close correspondence between the data and the theoretical distribution. Selected probability plots are presented to describe the range of goodness of fit that was observed.

Finally, hydrologic metrics were determined for each site, either directly from the frequency curve or calculated from the time-series data (Table 2; Appendix 3).

Table 2. Definitions of ecologically relevant streamflow metrics to describe low-flow regime.

Canonical Correlation Analysis

We utilized canonical correlation analysis (CCA) to analyze the relationship between selected watershed characteristics and streamflow metrics. The method is comparable to multiple regression with sets of variables on both sides of the equation. These are combined to produce multivariate dimensions that maximize the linear relationship between the two sets of variables (Tabachnick and Fidell, 2001). The solution depends both on the correlations among variables in each set (which are best minimized) and on correlations among variables between the sets (which are best maximized).

CCA was performed between selected sets of watershed variables and sets of hydrologic metrics using SAS CANCORR (SAS, 1989). Where appropriate, watershed variables were normalized (maximum January temperature) to the maximum value to improve normality of distribution and linearity of relationship between variables. Variables for each set were selected on the basis of principle component analysis (PCA) ordination of hydrologic metrics, using the Euclidian distance measure (McCune and Mefford, 1999). All data were first relativized to the maximum value to account for differences in scale.

Estimation of metrics for ungaged sites

The estimation of metrics for ungaged sites was based on a regionalization process that assumes that areas of similar watershed characteristics associated with low flow metrics from gaged sites will respond similarly for the ungaged sites. The results from CCA provided the basis for identification of site-specific regions for each ungaged site based on comparable watershed attributes.

Utilizing output from the CCA of gaged sites, scores on the first two canonical watershed variates were determined for each ungaged site using SAS SCORE (SAS, 1989). The distance between gaged sites and each target ungaged site along the watershed variate was identified by Mahalonobis distance, a multivariate distance measure that conforms to a chi-square distribution. This distribution was evaluated for canonical watershed scores (v_0) for each ungaged site along the first two canonical variates according to the following:

$$(w - \backslash Lambdav_0)'\left(I_p - \backslash Lambdav_0\right)^{-1}(w - \backslash Lambdav_0) \leq X^2_{a,p} \qquad (5)$$

where w is the score on the hydrologic variate for each gaged site, Λ is the eigenvalue, or squared canonical correlation between the pair of canonical variates, and I_p is the p x p identify matrix (p = 2) (Ourda and others, 2001). Regions were defined by 90 percent confidence when possible, with a further requirement to contain a minimum of three sites; for some sites it was necessary to limit confidence in order to obtain the minimum number of sites.

Once the site-specific regions were determined for each ungaged site, the regional PWMs were calculated as weighted averages of the PWMs for the gaged sites with each region:

$$M_{j_r} = \frac{\sum_{k=1}^{K} n_k M_j^*}{\sum_{k=1}^{K} n_k}, \; j = 0,1,2 \qquad (6)$$

where the denominator is the total number of years of record for the region. Regional average PWMs were used to estimate the parameters of the GEV distribution based on equation 3(a-d), and quantiles of the regional GEV distribution were calculated using regional parameter values and equation 4.

Streamflow metrics were derived directly from the regional frequency curve for each ungaged site, as described in Table 2. Metrics describing timing (mean for Julian day) of onset of 7-day low flow and baseflow index (mean for BFI) were estimated from data for each site-specific region. The proportion of intermittent 7-day low flow was estimated directly from the regional frequency curve.

Quantifying uncertainty in the estimates

An evaluation of the errors in the regionalization process on the metrics estimated for the ungaged sites was provided by two additional analyses. First, cross-validation of data from the gaged sites was conducted to evaluate how well frequency distributions derived from regions defined by CCA compared with those derived from observed data. Watershed scores for gaged sites were used to generate regions for each gaged site considered separately, each of which was excluded from inclusion in the potential pool of sites to comprise the region. Regional frequency curves were derived for each gaged site from those regions in the same manner used for CRITFC sites and the differences between the metrics derived from these regional curves and those determined from the individual frequency curves were evaluated.

Another measure of uncertainty in the estimated metrics is the standard error of the estimate for the selected quantiles, which were determined according to the method described in Rosbjerg and Madsen (1995). The mean and variance of each T-year event estimator (e.g. Q/Q_m) were first approximated by:

$$E\{x_T\} = \frac{a}{g}\left(1 - K_T^g\right) + u - \frac{a}{N}\left\{Bw_{23} + \left[\frac{1}{2g}K_T^g(lnK_T)^2 - \frac{1}{g}B\right]w_{33}\right\} \quad (7)$$

$$Var\{x_T\} = \frac{a^2}{N}[w_{11} + A(Aw_{22} + 2w_{12}) + B(Bw_{33} - 2w_{13} - 2w_{23})] \quad (8)$$

where *a*, *g*, and *u* are from equation 3(b-d), *N* is the total number of years of record for all sites within the site-specific region, $K_T = -ln\left(1 - \frac{1}{T}\right)$, and *A* and *B* were determined as follows:

$$A = \frac{1}{g}\left(1 - K_T^g\right) \quad (9)$$

$$B = \frac{1}{g^2}\left(1 - K_T^g\right) + \frac{1}{g}K_T^g lnK_T \quad (10)$$

The terms w_{ij} are elements of the asymptotic covariance matrix of the PWM estimators of the GEV parameters, and were derived by Hosking and others (1985) for several values of *g*; the values used in this analysis were based on a mean value of *g* of -0.4 (cf. Rosberg and Madsen, 1995) (Table 3).

Table 3. Selected elements of the asymptotic covariance matrix.

Finally the standard errors associated with each T-year event estimator (or quantile) were determined as $\sqrt{var\{x_T\}}/\sqrt{N}$.

Results

Streamflow metrics for gaged sites

This section presents results for selected streamflow metrics for gaged sites (Figures 2-6, Appendix 3). Results for Q2, which provides a measure of the stability of common low-flow conditions, suggest that low flow is generally fairly stable across the range of gaged sites (Figure 2). Only two sites were associated with Q2 values < 0.25, while the remainder were associated with Q2 values > 0.5. Much greater variability was found for Q98 across the range of gaged sites, which represents a measure of extreme low-flow conditions (and thereby an indication of the variability in low flow) (Figure 3). Thirteen sites were associated with Q98 values < 0.25, indicating that extreme low-flow conditions represent a significant reduction from average flow conditions. Results for the mean timing of onset of annual 7-day low-flow conditions show that only four gaged sites exhibit early mean onset of low flow (prior to September 1), while most were associated with low-flow onset after September 15 (Figure 4). For baseflow index, results indicate that only three gaged sites are subject to high influence of groundwater, with BFI values > 0.4 (Figure 5). The remainder of the sites were roughly divided between those with BFI values between 0.1 and 0.4 (N=18), suggesting a slight tendency for groundwater input, and those associated with BFI values < 0.1 (N=17), suggesting little influence of groundwater. Finally, the probability of zero flow was zero for the majority of gaged site, with only three sites showing any probability of intermittent flow (Figure 6).

2. Estimated Q2 for gaged sites in study area
3. Estimated Q98 for gaged sites in study area
4. Mean timing of onset of low-flow for gaged sites in study area
5. Estimated BFI for gaged sites in study area
6. Probability of zero flow for gaged sites in study area

Canonical correlation analysis

Examination of correlations of the flow metrics with the PCA ordination provided the justification for identification of two relatively independent (i.e. non-redundant) dimensions of low-flow regime—one identified with a measure of low-flow variability (Q_{98}) and one identified with a measure of low-flow timing (jday) (Figure 7). The selection of watershed variables was based on examination of a joint plot, which portrayed the direction and strength of the correlation between the two sets of variables. The variables selected were those that showed the strongest linear relationship with the ordination structure of the hydrologic regime, and included mean annual precipitation, maximum January temperature, and stream density (Figure 8). An additional consideration which limited the total number of variables for CCA was the relatively small number of gaged sites (Tabachnick and Fidell, 2001).

7. Principle component ordination of flow metrics.
8. Joint plot of watershed attributes on ordination of flow metrics.

Figures 9-11 show the distribution of these watershed characteristics across the study area.

9. Mean annual precipitation in study area
10. Mean maximum January temperature in study area
11. Stream density in study area

Results from the canonical correlation analysis indicate that the first canonical correlation was significant (P<.001) and accounted for a large proportion of the variation, while the second variate was not significant (p=.13) (Table 4). The first canonical correlation was high (0.80) and accounted for 64 percent of overlapping variance (squared canonical correlation) (Figure 12). The second was reduced (0.42), accounting for an additional 18 percent of overlapping variance. These results indicate that only the first pair of canonical variates were strongly related. Full results for canonical correlation are presented in Appendix 4.

Table 4. Canonical correlation analysis results.

12. Relationship between hydrologic and watershed scores for first canonical variate.

Estimation of streamflow metrics for ungaged sites

The relationship between selected watershed characteristics and streamflow metrics that was derived from CCA was utilized to select subsets (or hydrologic neighborhoods) of gaged sites to serve as the basis for generating regional low-flow frequency curves for ungaged sites. As previously described, the selection of these neighborhoods was based on similarity of watershed characteristics between gaged and ungaged sites. Figures 13-15 show the distribution of selected watershed characteristics alongside ungaged sites within the Upper Grande Ronde River Basin.

13. Mean annual precipitation in Upper Grande Ronde River Basin
14. Annual maximum January temperature in Upper Grande Ronde River Basin
15. Stream density in Upper Grande Ronde River Basin

Each assignment of a gaged site to an ungaged site was associated with a probability value that described the likelihood of that association. Figure 16 shows the range of probability associated with the selection of site-specific regions for ungaged sites, limiting outliers depicted to the 5^{th} and 95^{th} percent. While most probabilities were close to 0.90 (median=0.87), five percent were associated with a confidence level less than 0.69. The list of gaged sites in each site-specific region and the associated probability are listed in Appendix 5; watershed data for selected characteristics used in regional analysis and estimated flow metrics are presented in Appendix 6.

16. Range of probability for site-specific regions

Figures 17-21 show the distribution of estimated streamflow metrics for ungaged sites in the Upper Grande Ronde River Basin.

17. Estimated Q2 for ungaged sites in Upper Grande Ronde River Basin.
18. Estimated Q98 for ungaged sites in Upper Grande Ronde River Basin

19. Estimated timing of onset of low flow for ungaged sites in Upper Grande Ronde River Basin
20. Estimated BFI for ungaged sites in Upper Grande Ronde River Basin
21. Estimated probability of zero flow for ungaged sites in Upper Grande Ronde River Basin

Quantifying uncertainty

Many sources of uncertainty are associated with estimates of flow characteristics in the absence of gage data. The cross-validation analysis provides a means to compare estimates derived from the regionalization process with those derived directly from streamflow data, and thereby provide some context for assessing the reliability of the estimates for ungaged sites. Results from the cross-validation analysis of metrics derived from observed data and those estimated by the regionalization process are presented in figure 22. These results indicate that Q98 was estimated within$\pm$ 0.4 by the regionalization process for 75 percent of the gaged sites; the median difference between estimated and observed metrics was close to zero though a slight tendency was shown for estimates to be larger than observed metrics. Because the estimated values of Q98 are normalized by mean annual flow, larger values for this metric represent an extreme low-flow condition that is closer to the mean annual 7-day low flow; this means that smaller values indicate a higher degree of variability. Results for BFI show a closer correspondence in general with a contrasting pattern: estimated values were generally within $\pm$.05 for 75 percent of the gaged sites with a tendency to be smaller than observed metrics. Finally, results for the timing of onset of annual 7-day low-flow conditions indicate that estimates were generally within $\pm$ ten days for 75 percent of the gaged sites.

22. Cross-validation results for low-flow analysis (difference between metrics derived from regional and individual frequency curves for gaged sites)

Many sources of uncertainty are associated with estimates of flow characteristics in the absence of gage data. The cross-validation analysis provides a means to compare estimates derived from the regionalization process with those derived directly from streamflow data, and thereby provide some context for assessing the reliability of the estimates for ungaged sites. Results from the cross-validation analysis of metrics derived from observed data and those estimated by the regionalization process are presented in figure 22. These results indicate that Q98 was estimated within$\pm$ 0.4 by the regionalization process for 75 percent of the gaged sites; the median difference between estimated and observed metrics was close to zero though a slight tendency was shown for estimates to be larger than observed metrics. Because the estimated values of Q98 are normalized by mean annual flow, larger values for this metric represent an extreme low-flow condition that is closer to the mean annual 7-day low flow; this means that smaller values indicate a higher degree of variability. Results for BFI show a closer correspondence in general with a contrasting pattern: estimated values were generally within $\pm$.05 for 75 percent of the gaged sites with a tendency to be smaller than observed metrics. Finally, results for the timing of onset of annual 7-day low-flow conditions indicate that estimates were generally within $\pm$ ten days for 75 percent of the gaged sites.

Standard errors provide a measure of the precision of each T-year event estimator (or quantile), and are presented in figure 23.

23. Standard errors for quantiles estimated for ungaged sites.

Reliability and Limitations

This report presents a protocol for estimation of flow metrics for ungaged sites based on regional analysis of data from streamflow gages and watershed characteristics. Interpretation of these results is beyond the scope of this analysis. Nevertheless, any regional analysis is associated with an unavoidable level of uncertainty in the predictions, which should be considered carefully in order to understand the limitations of the analysis. This uncertainty arises in part because of the inherent difficulties in the probabilistic approach, especially when focused on the long-term distribution of events from comparatively short-term data series. Any probabilistic analysis of streamflow distribution increases in reliability when based on long periods of record, ideally more than 20 years, which were simply not available for this analysis. Another source of error is the regionalization process itself, even when focused on site-specific hydrologic neighborhoods to define regions as was done in this analysis, especially given the assumption of sufficient similarity within regions that are defined by a small number of attributes. For this analysis, additional uncertainty occurs as a result of the relatively small number of gaged sites within the study area. Accordingly, the evaluation of errors associated with the streamflow metrics is a critical element of this protocol.

The first component of the analysis subject to potential error is the selection of streamflow data and the subsequent application of the GEV theoretical frequency distribution to describe the components of the low-flow regime for gaged sites. As previously mentioned, data were screened to simultaneously eliminate any temporal trend ($p<0.01$) and maximize the period of record, with a minimum of 10 years. These screening allowed the basic assumptions of the distribution to be met by focusing on a relatively "ideal" set of sites. In the process, however, sites were excluded where streamflow was most likely to be influenced by significant human activity, a major factor in causing temporal trend. As a result, the metrics generated by this analysis should be considered less reliable for those watersheds that are similar to the excluded gaged sites, especially regarding human impact. Because of the limitations of the frequency analysis, as well as the data that are currently available for human water use, it is not possible to accurately describe the nature of these errors or the sites that may be most affected. The fact that these metrics do not well describe the effect of human modification of low-flow regime represents an important source of uncertainty in the analysis.

Additional error is associated with the regionalization component of the analysis, including both the correspondence between watershed and flow attributes determined by CCA, and the subsequent assignment of site-specific regions for ungaged sites based on watershed characteristics. The uncertainty associated with CCA is described by the canonical correlation results presented in Appendix 4, and graphically by the relationship between canonical variates depicted in figure 12. As previously mentioned, the CCA results indicate that the first canonical variate explained most of the variability in the watershed and flow data (64 percent). A generally strong correspondence was observed between the first pair of canonical variates, indicating that a moderately high degree of confidence is warranted for the characterization of the multivariate relationship between the selected hydrologic and watershed

variables. The analysis is limited, however, by the selection of variables that are included, and especially by the assumption of linearity and independence among them. While an attempt was made to focus on non-redundant hydrologic metrics and watershed characteristics that are strongly and linearly correlated, it is unrealistic to assume that the available data perfectly describe the complex array of factors that determine low-flow regime.

Further errors are associated with the process of region definition, and essentially represent the lack of similarity in key watershed attributes between gaged and ungaged sites. These are described by the probabilities associated with each site-specific region represented in figure 16 and Appendix 5, and reflect differences in the range of confidence among the ungaged sites. In other words, the probabilities represent how close of a correspondence exists within the watershed context defined by the selected characteristics between the gaged site and the target ungaged site. Most values are greater than 0.8 indicating a high degree of correspondence, although a small number of regions for ungaged sites were associated with probabilities < 0.6 (Appendix 5), presumably reflecting the lack of similarity of those watersheds with gaged sites.

An evaluation of the effect of these errors in the regionalization process on the metrics estimated for ungaged sites was provided by two additional analyses. First, cross-validation analysis of data from gaged sites was conducted to evaluate how well frequency distributions derived from site-specific regions defined by CCA compared with those derived from observed data. Watershed scores for gaged sites were used to generate regions, and regional frequency curves were then derived from those regions in the same manner used for ungaged sites. The differences between the metrics derived from these regional curves and those determined from the individual frequency distributions show generally close agreement between the two sets of metrics, with median differences consistently close to 0 (Figure 22). Moderately large differences were found for Q98, ranging generally between $\pm$ 0.2, reflecting the general uncertainty associated with these extreme flow events. Differences for BFI were also sometimes relatively large, up 0.6, with estimates tending to be biased relatively low compared to metrics derived from the data. Differences for the timing of the onset of low flow were generally within $\pm$ 7 to 14 days or 1-2 weeks. These results suggest that (1) estimates for Q98 (a measure of low-flow variability) may be under-representing the true level of variability; (2) estimates for BFI (a measure of the potential for groundwater influence) may also be under-estimated; and (3) estimates for the timing of the onset of low-flow conditions are fairly reliable, generally within less than two weeks.

Another measure of uncertainty in the metrics estimated for ungaged sites is the standard error of the estimate for the selected quantile (Figure 23). These results indicate the greatest uncertainty is associated with the more extreme flow event (Q98), with errors ranging as high as 0.02, although the majority of errors were low (< 0.01). Errors associated with the 2-year low-flow event (Q2) were essentially nil, indicating a high degree of confidence can be associated with these metrics.

Summary and Conclusions

The estimates for low-flow metrics provided here are based upon a regionalization approach that utilizes multivariate analysis in the form of CCA to determine site-specific regions (or hydrologic neighborhoods). These regions were explicitly based on comparability in watershed characteristics that are associated with the distribution of selected low-flow metrics. This approach was utilized because it was assumed to provide an advantage over regionalization techniques that assume all sites within a contiguous region show the same characteristics of low-flow distribution.

Analysis of streamflow metrics for gaged sites showed that measures of variability based on extreme 7-day low-flow conditions (Q98), measures of the potential for groundwater influence (BFI), and measures of the timing of the onset of annual 7-day low-flow conditions were relatively independent. These metrics were strongly correlated with mean annual precipitation, maximum January temperature, and stream density in the watershed. CCA provided the means to select gaged watersheds most closely similar to the target ungaged sites in terms of these characteristics, with probabilities that were generally greater than 0.8, reflecting a high degree of correspondence. Results for cross-validation and standard errors for the estimates indicate that measures that describe more extreme conditions show a higher degree of uncertainty.

The various components of this analysis represent a series of abstractions from observed data to derived metrics. Because of the nature of the problem, that is, the description of low-flow regime for sites without streamflow data, these metrics are necessarily based on a range of assumptions. While founded on an empirical base and well-developed theoretical techniques, each step in the analysis provides an opportunity for some level of uncertainty to enter into the final result. These uncertainties have been minimized to the greatest extent possible, and yet it is not possible to eliminate uncertainty completely. As a result, the estimates derived from this analysis should not be assumed appropriate for other types of water-resource evaluations, especially those focused on management and forecasting of extreme flow conditions that require greater precision. Nonetheless, they can be considered suitable for the stated purpose, that is, hydrologic classification of stream systems to support ecological analysis.

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Appendix

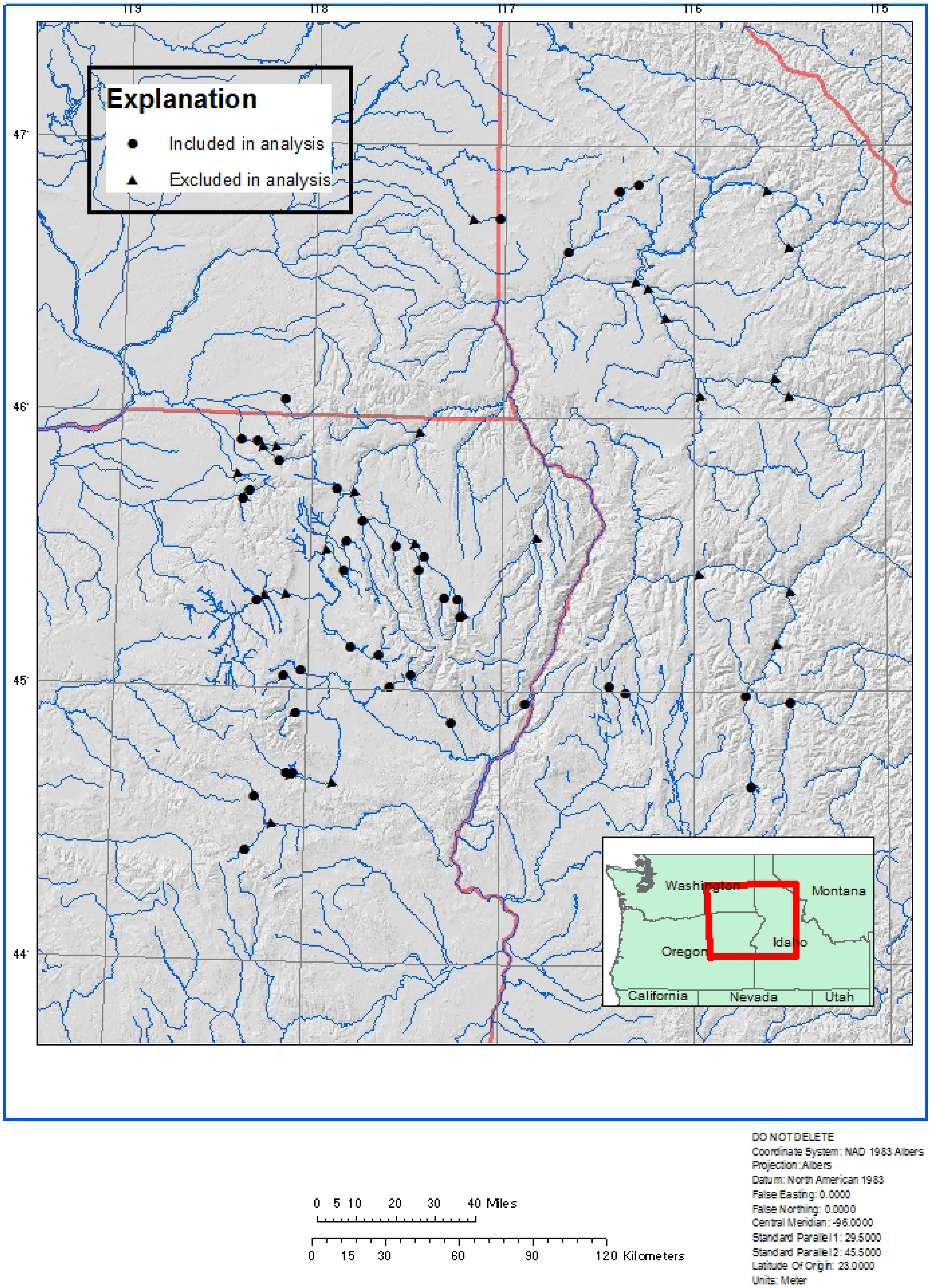

Figure 1A. Study area showing all gages.

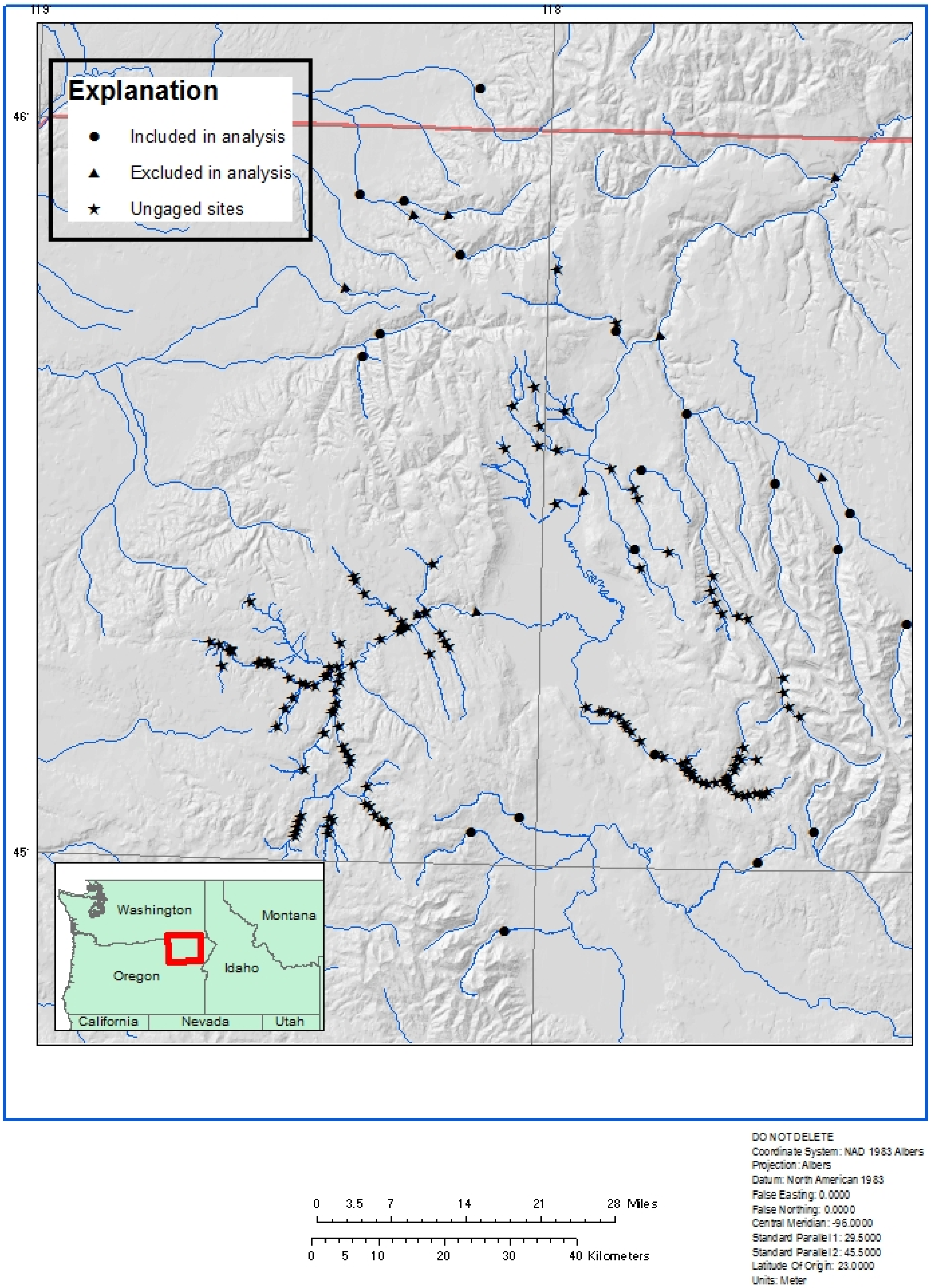

Figure 1B. Study area showing target ungagged sites.

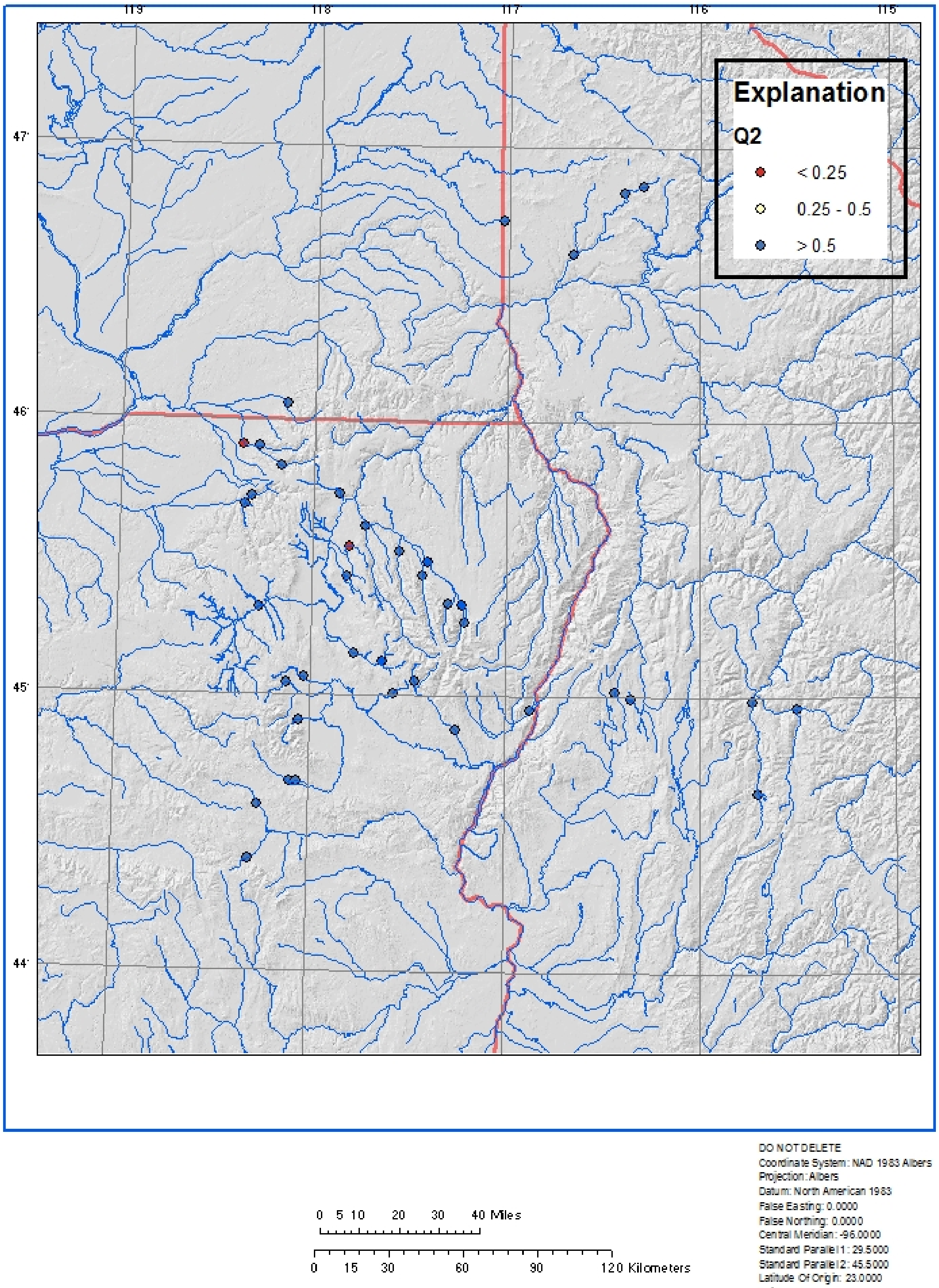

Figure 2. Estimated Q2 for gaged sites in study area.

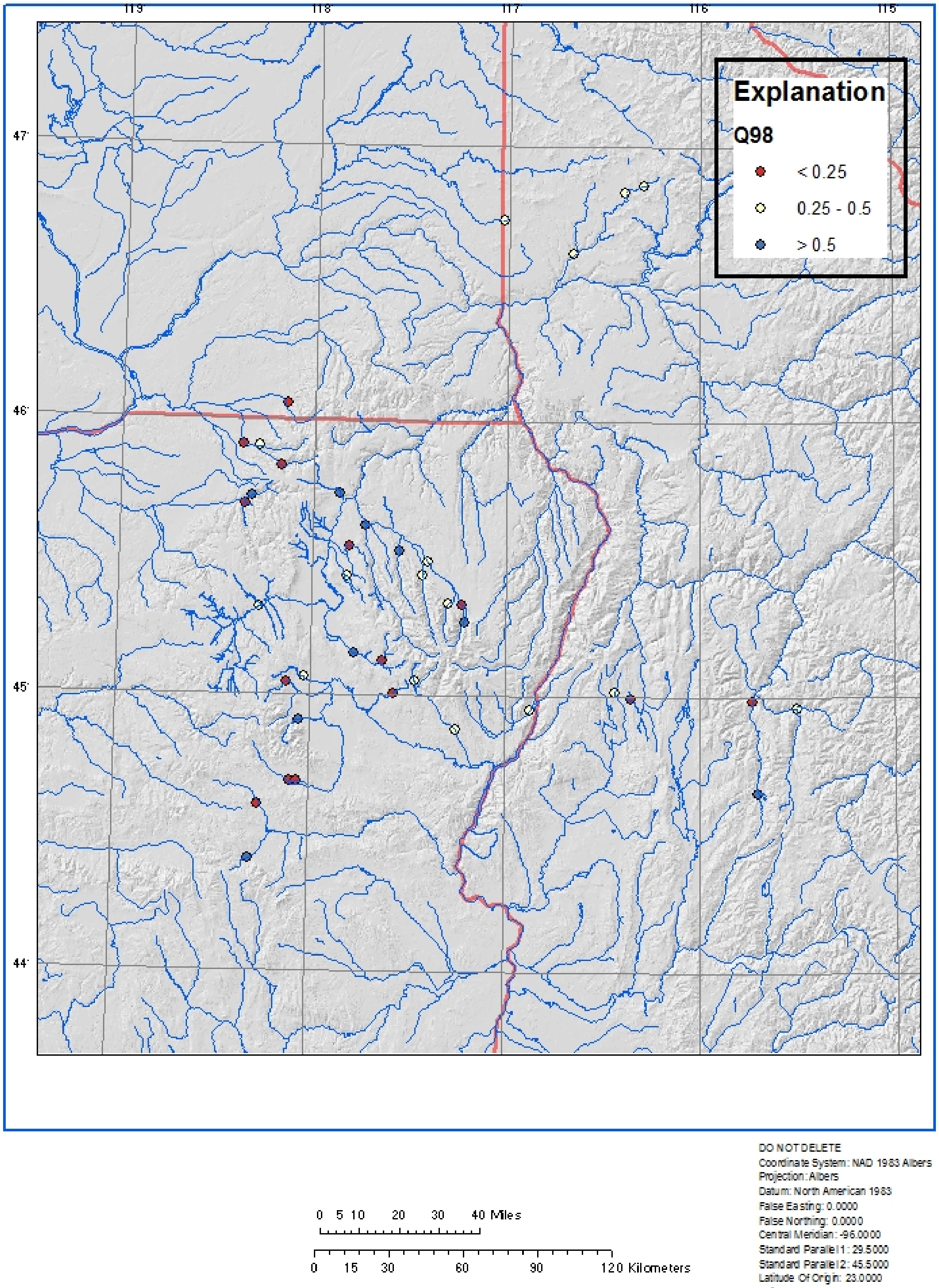

Figure 3. Estimated Q98 for gaged sites in study area.

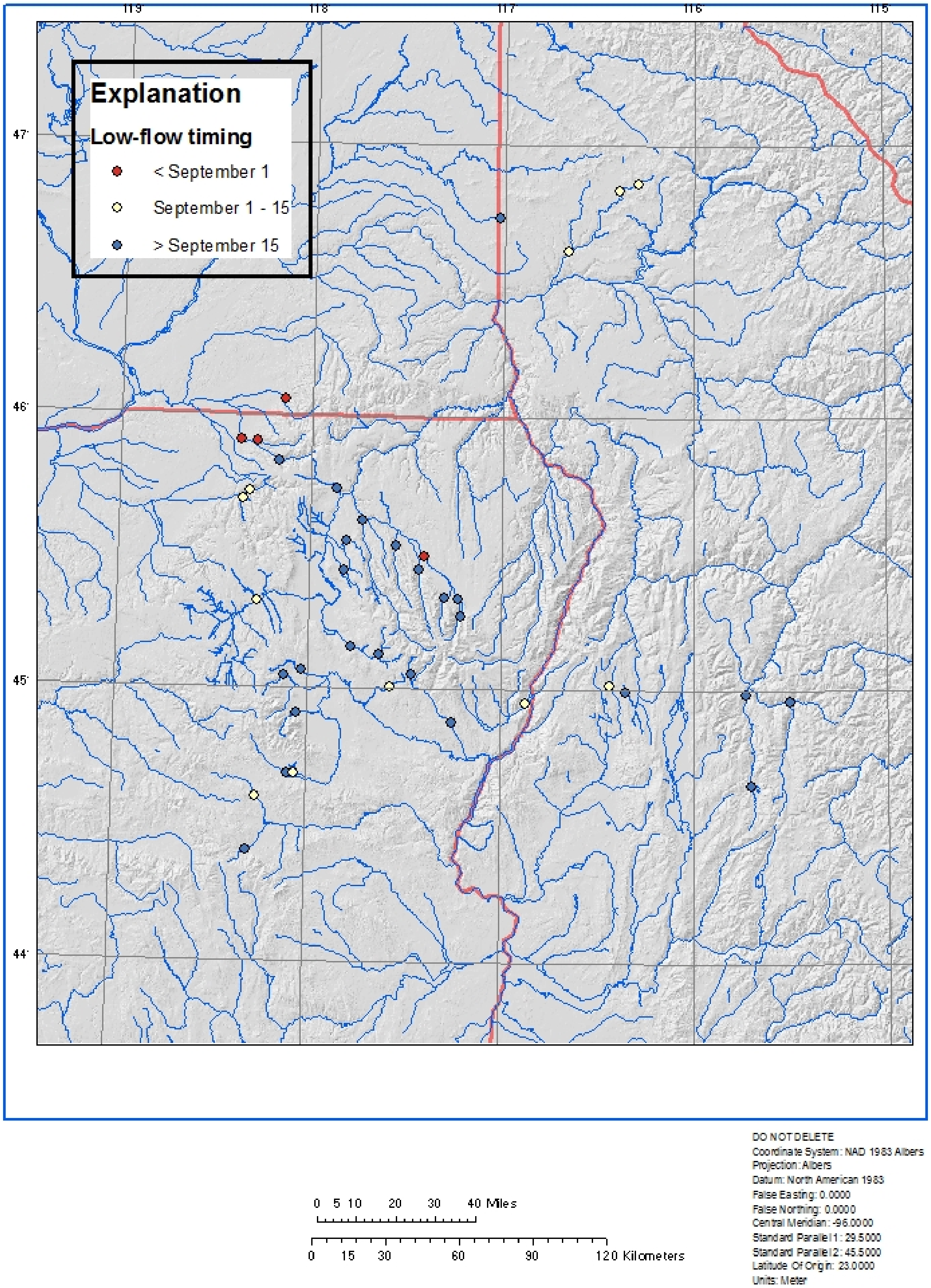

Figure 4. Mean timing of onset of low flow for gaged sites in study area.

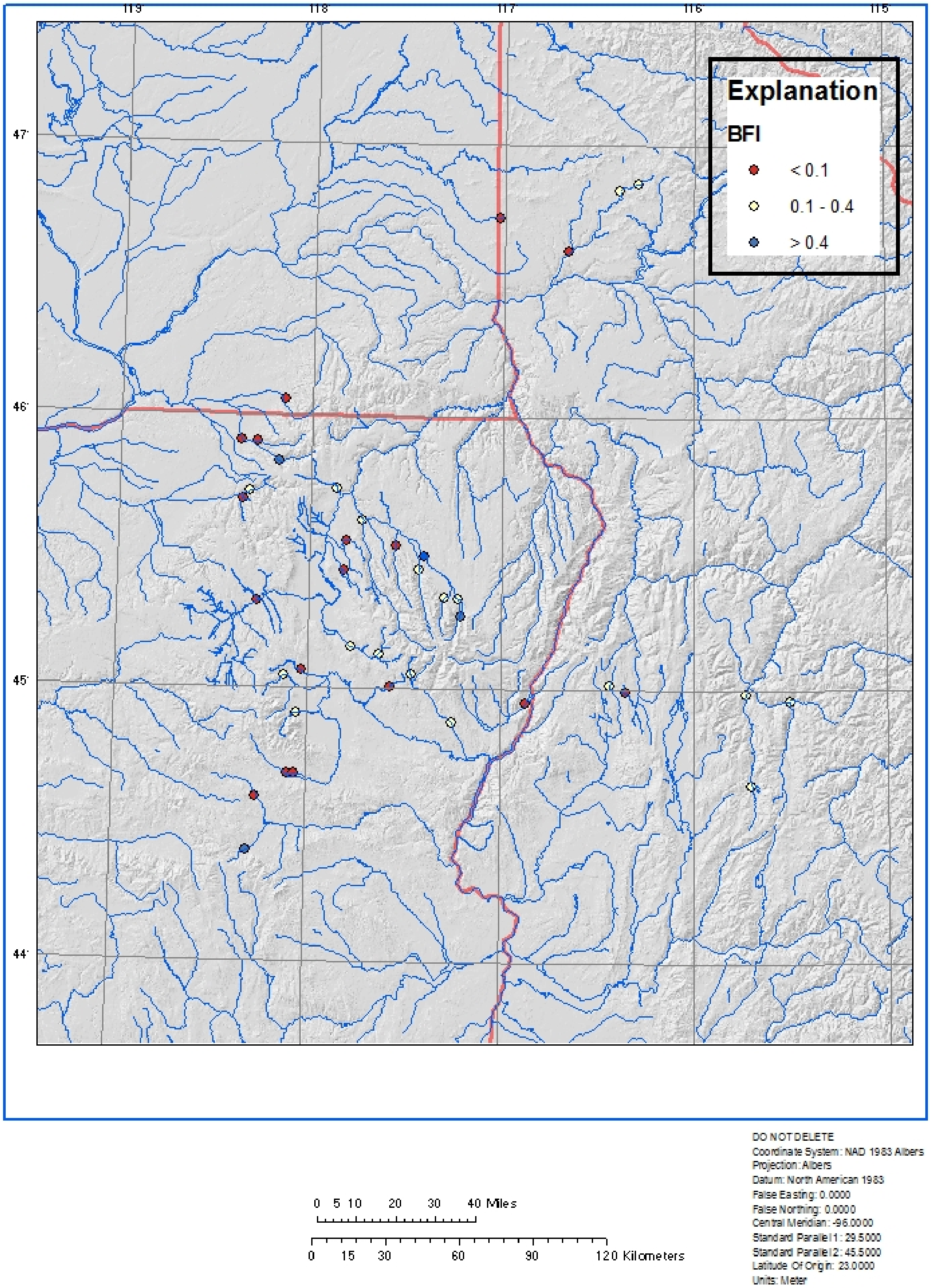

Figure 5. Estimated base-flow index (BFI) for gaged sites in study area.

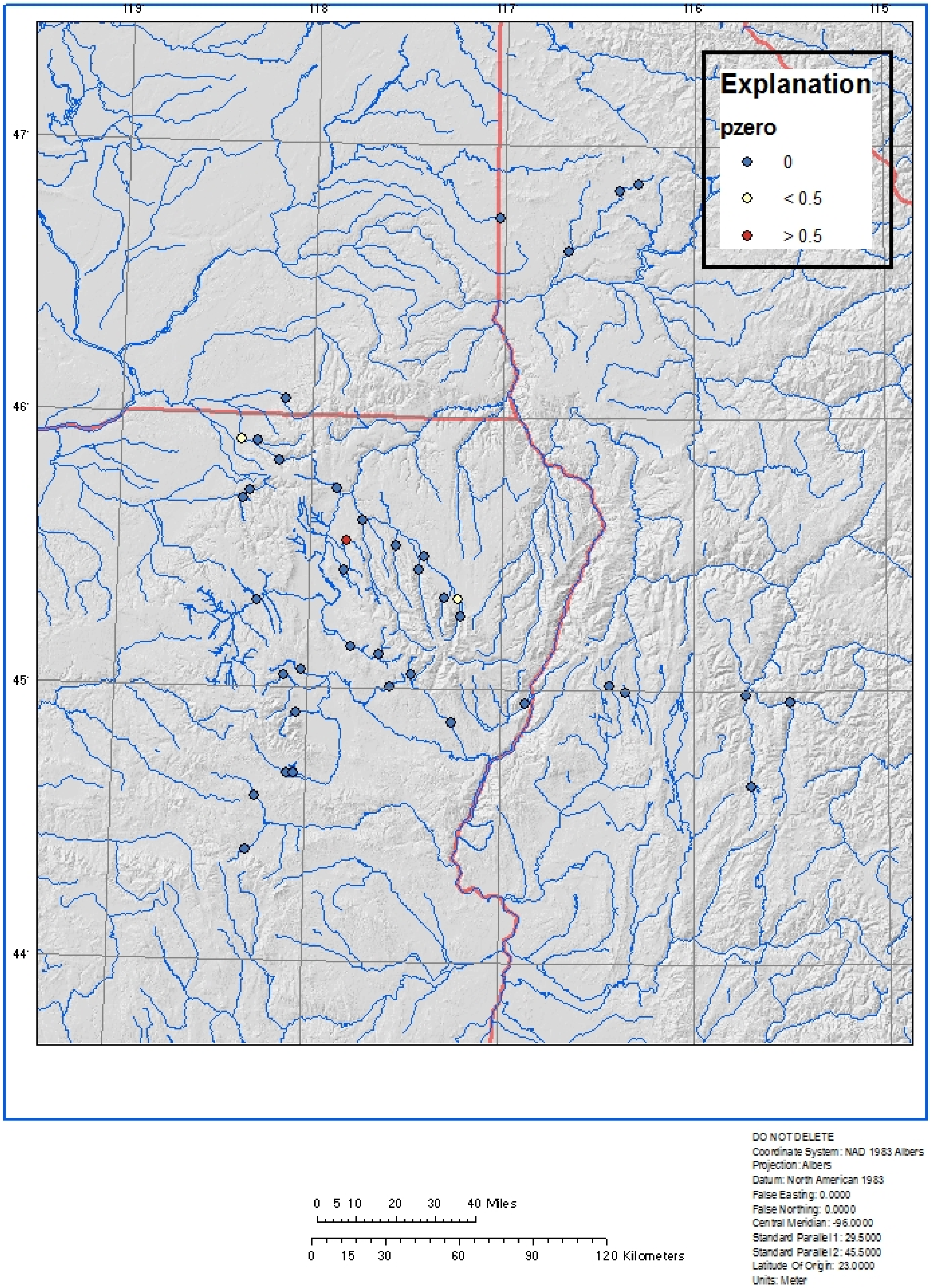

Figure 6. Probability of zero flow for gaged sites in study area.

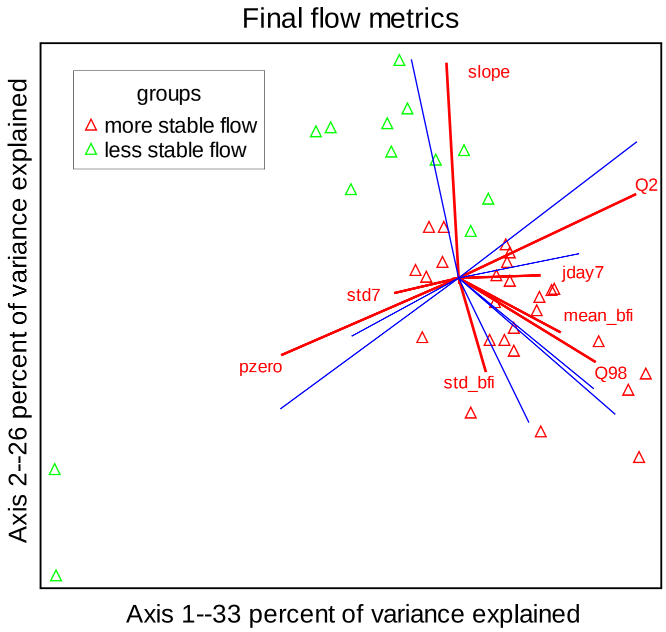

Figure 7. Principle component ordination of low-flow metrics for gaged sites.

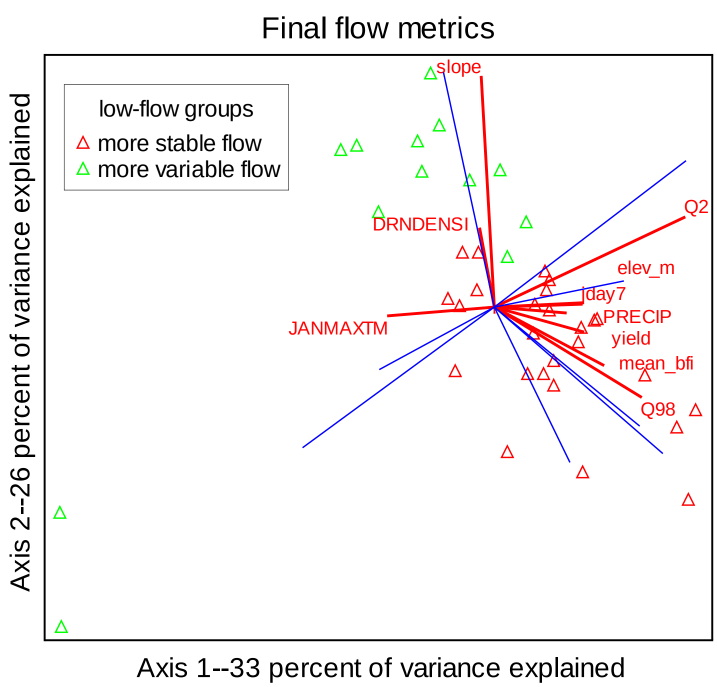

Figure 8. Joint plot of watershed attributes on ordination of low-flow metrics.

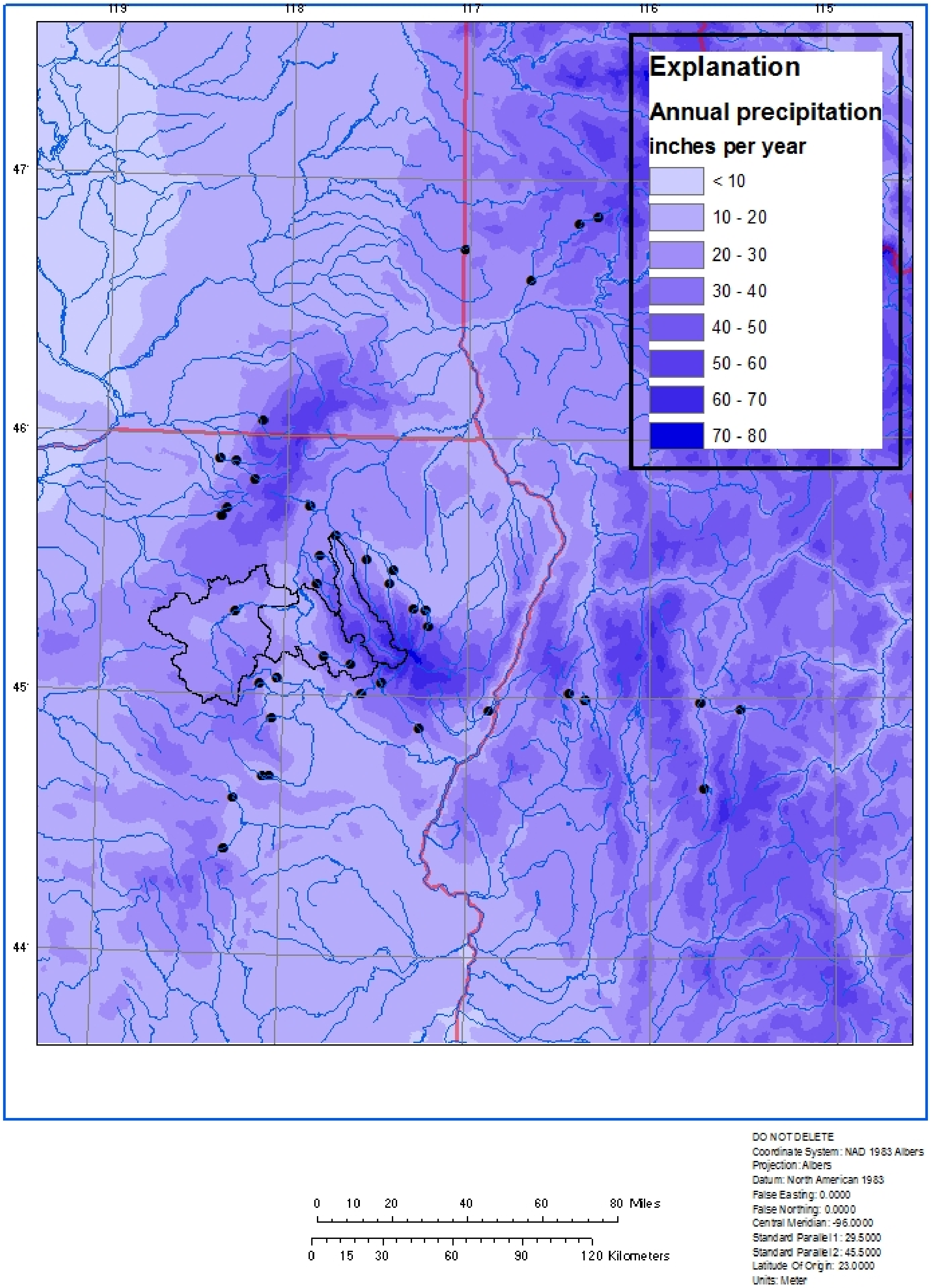

Figure 9. Mean annual precipitation in study area.

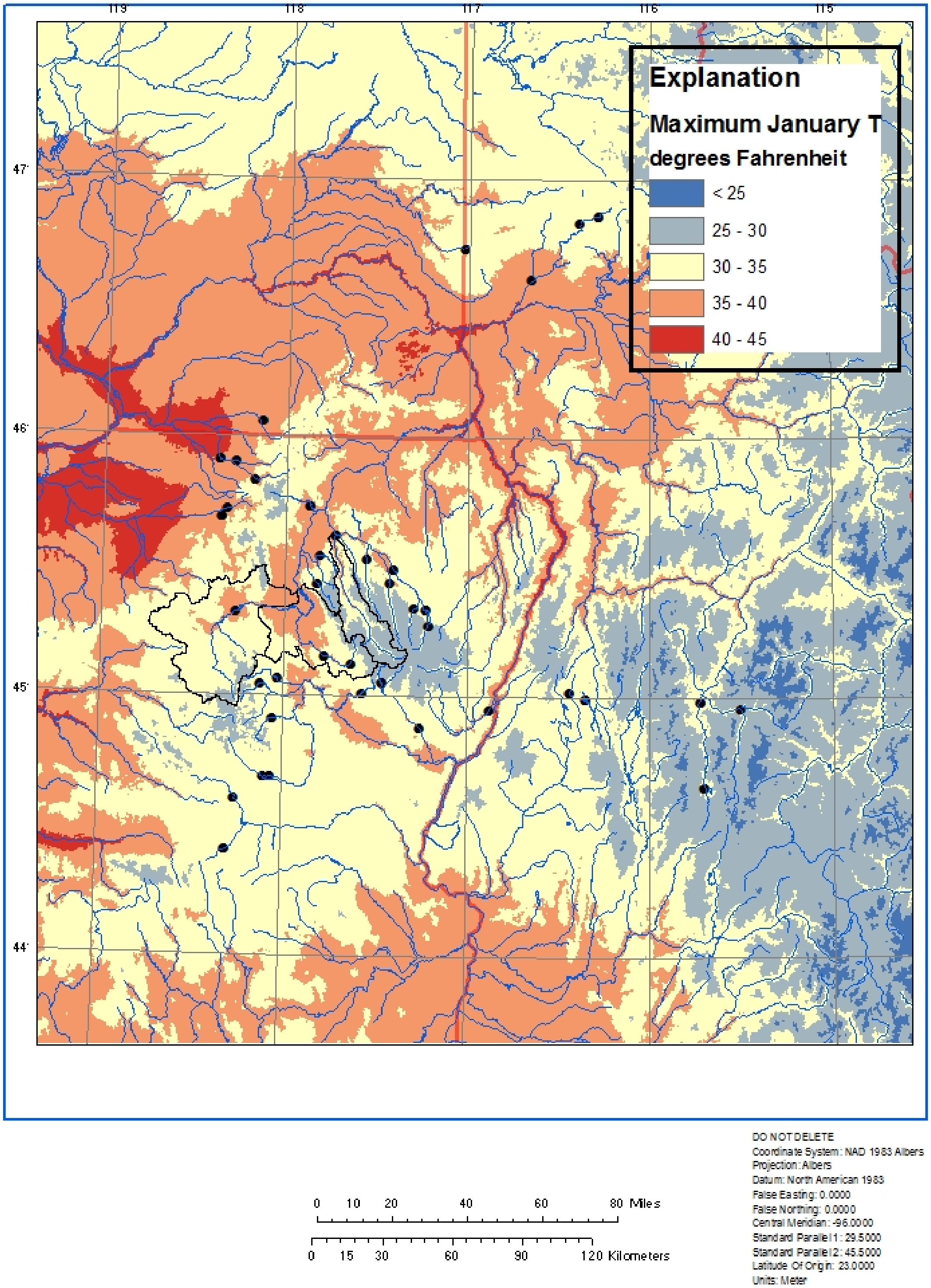

Figure 10. Mean maximum January temperature in study area.

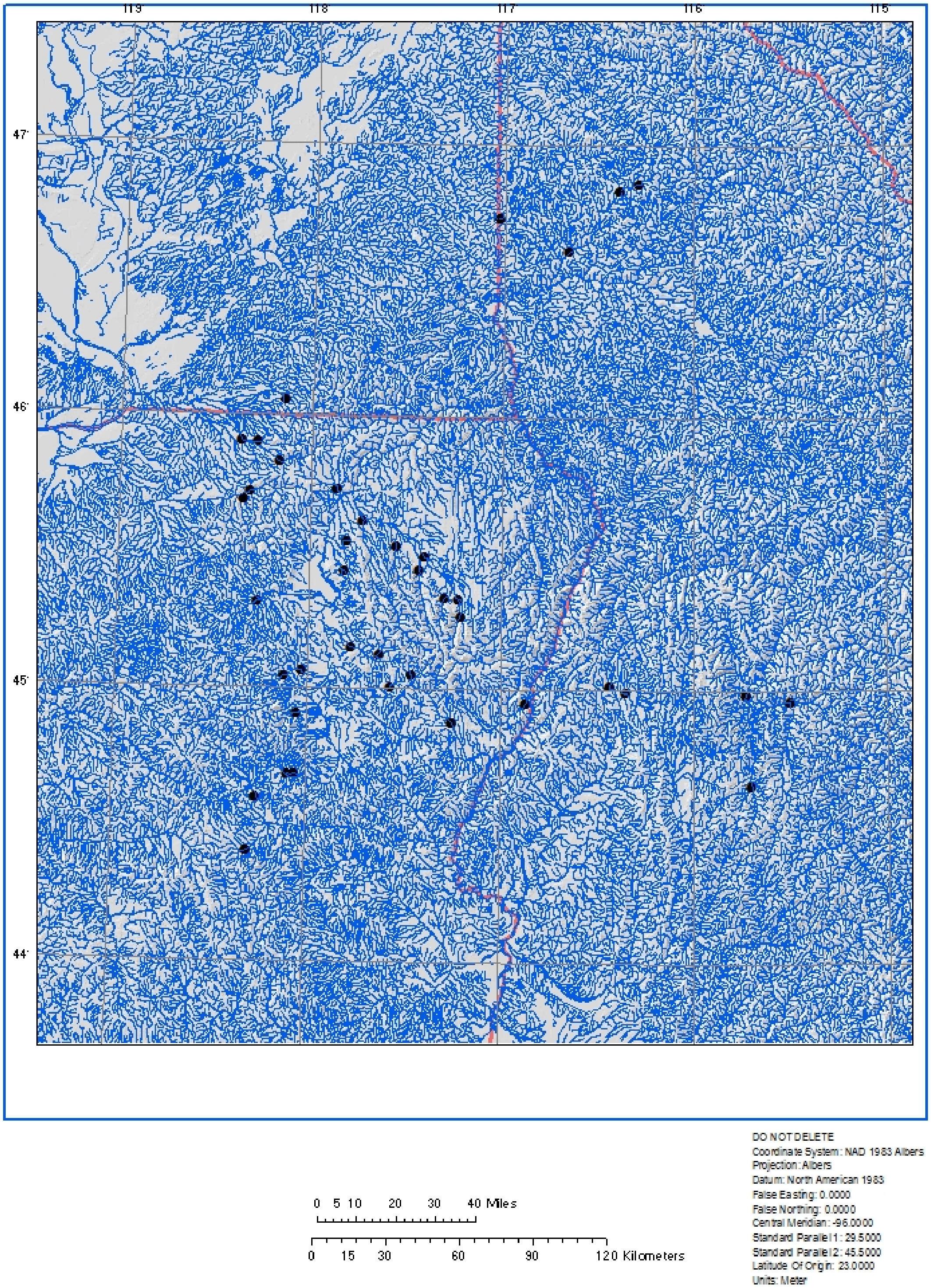

Figure 11. Stream density in study area.

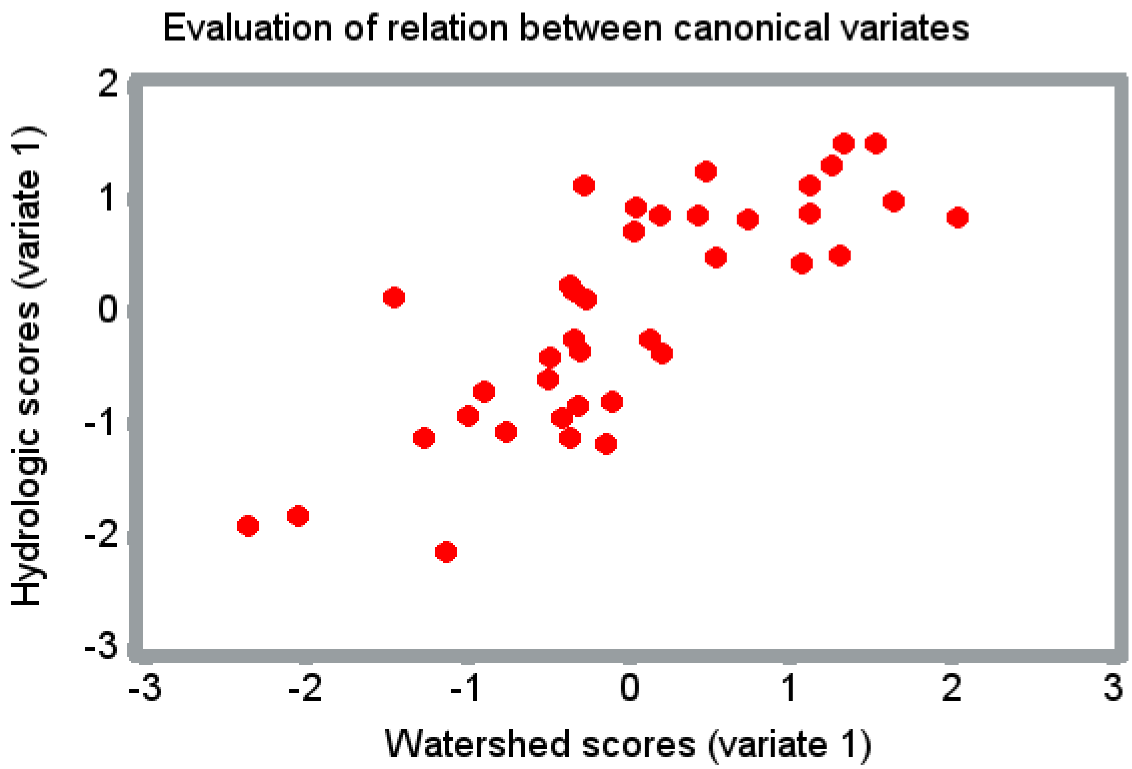

Figure 12. Relationship between hydrologic and watershed scores for first canonical variate.

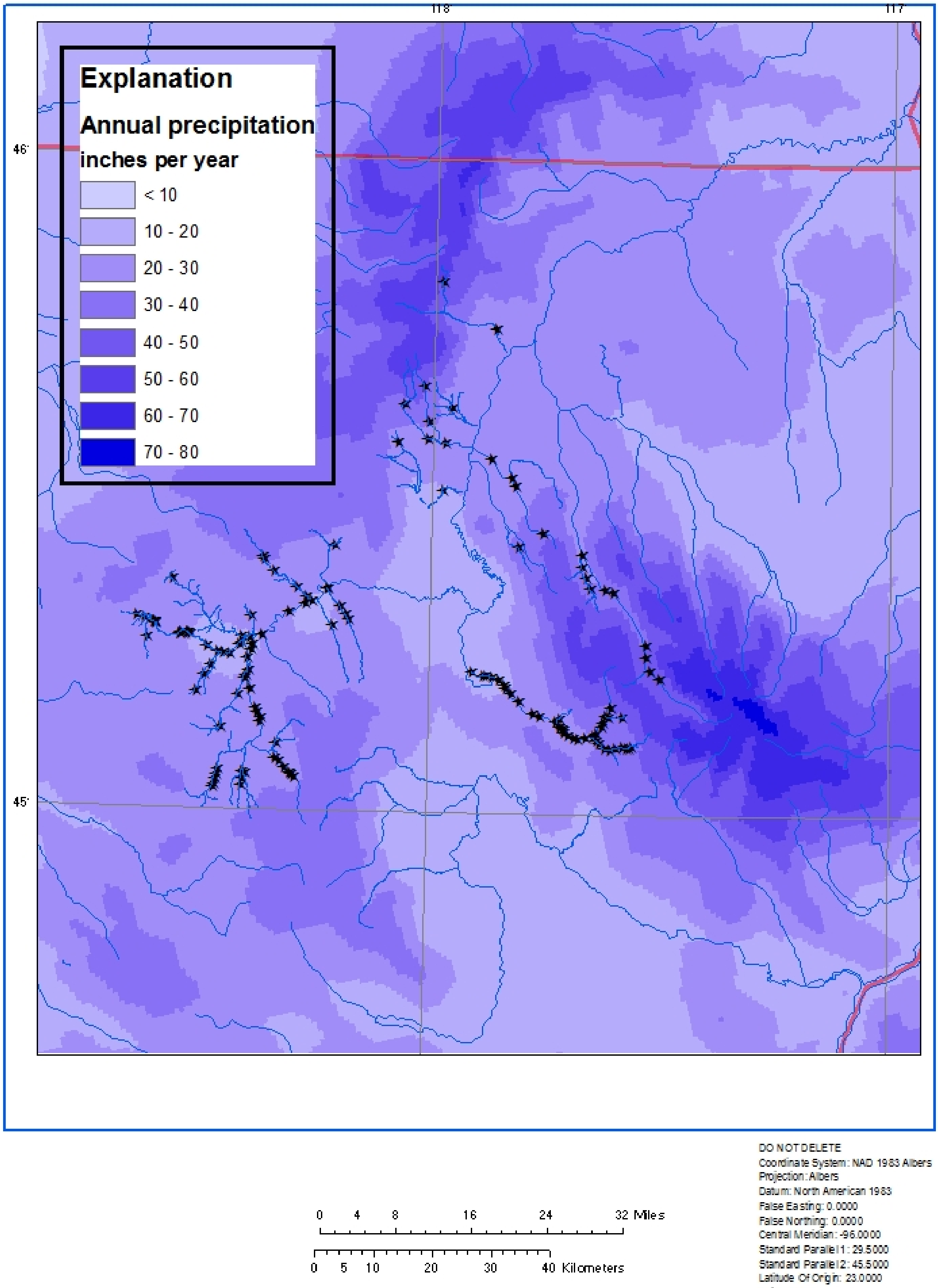

Figure 13. Mean annual precipitation in Upper Grande Ronde River Basin.

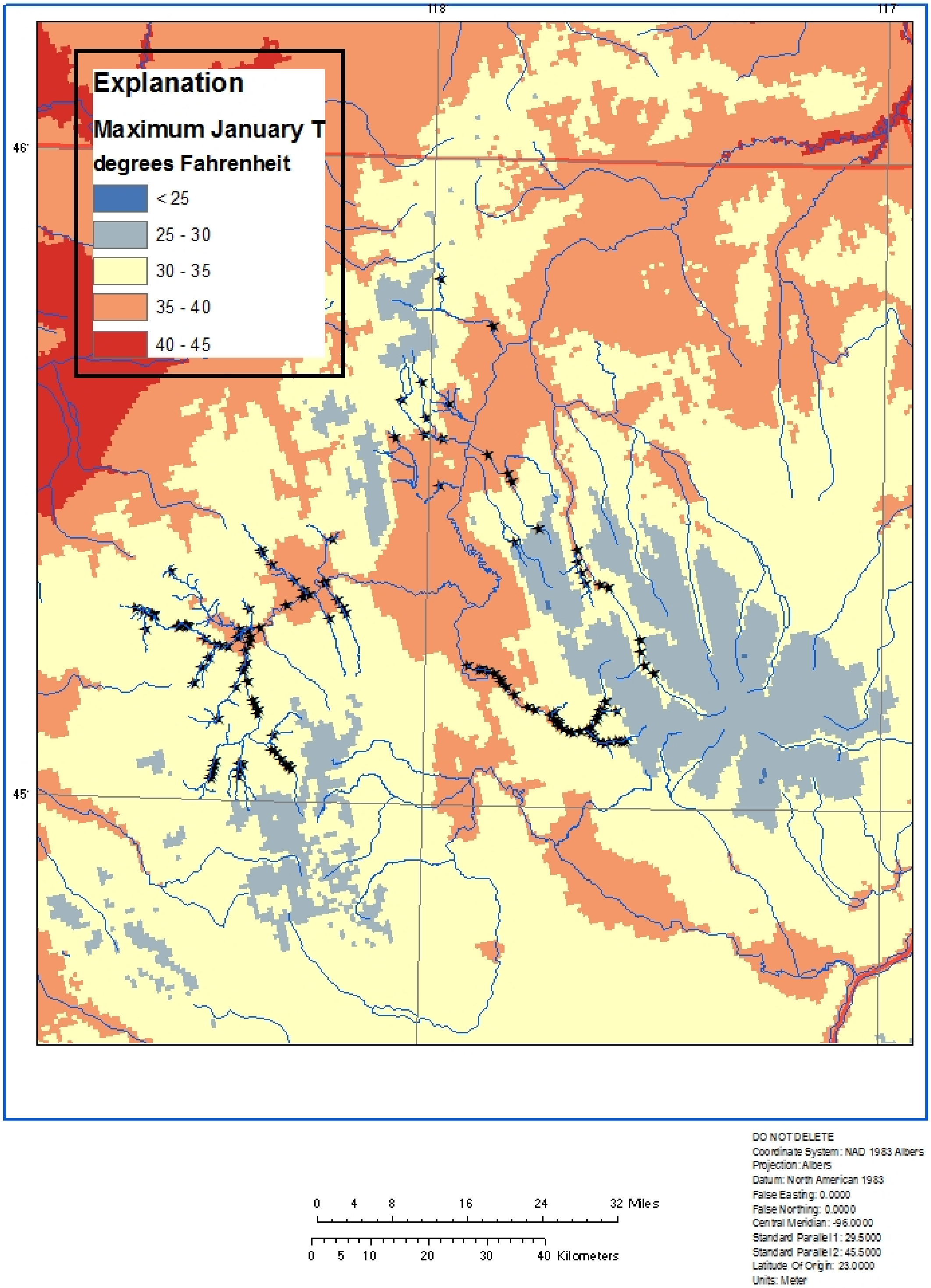

Figure 14. Annual maximum January temperature in Upper Grande Ronde River Basin.

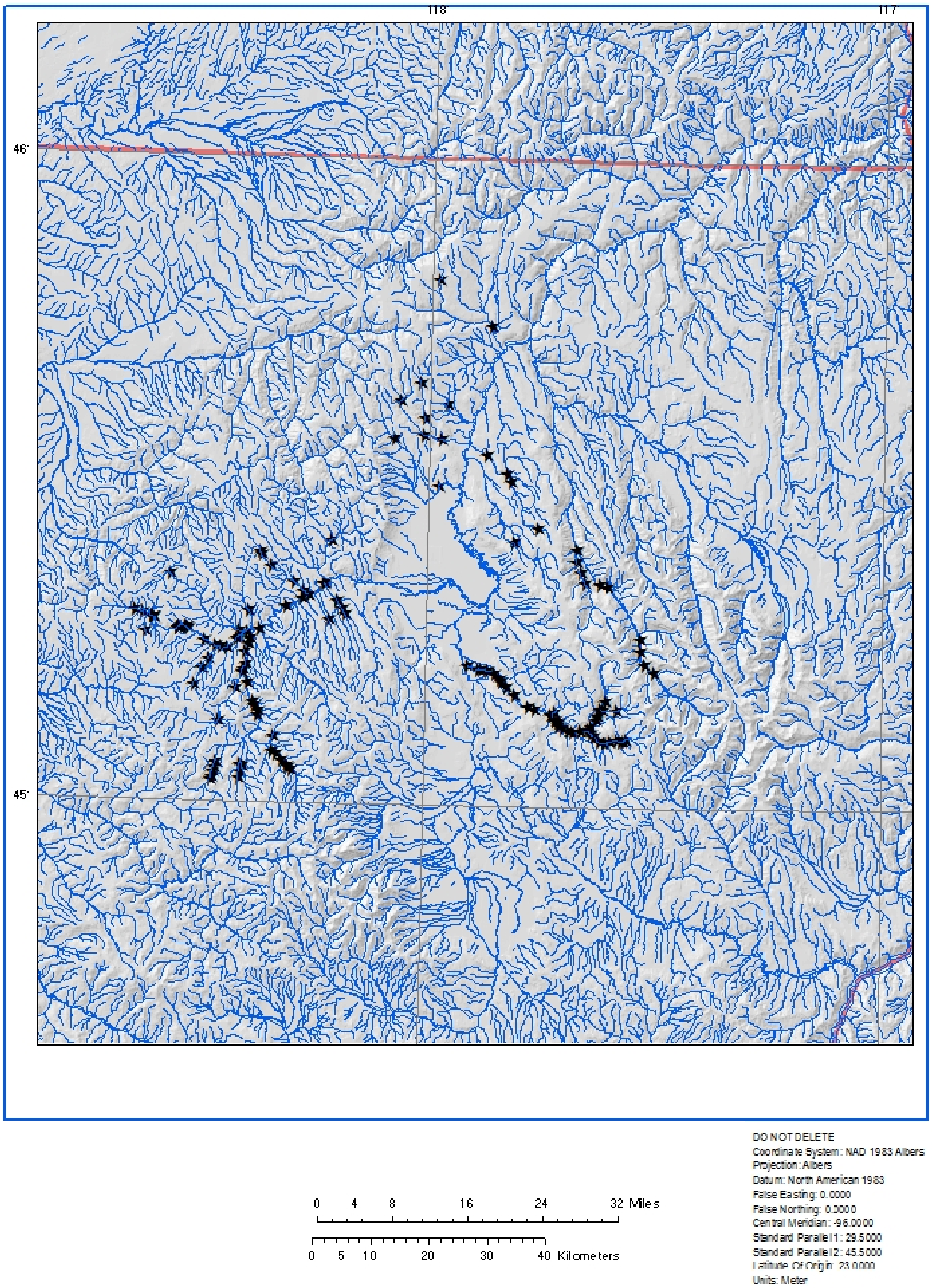

Figure 15. Stream density in Upper Grande Ronde River Basin.

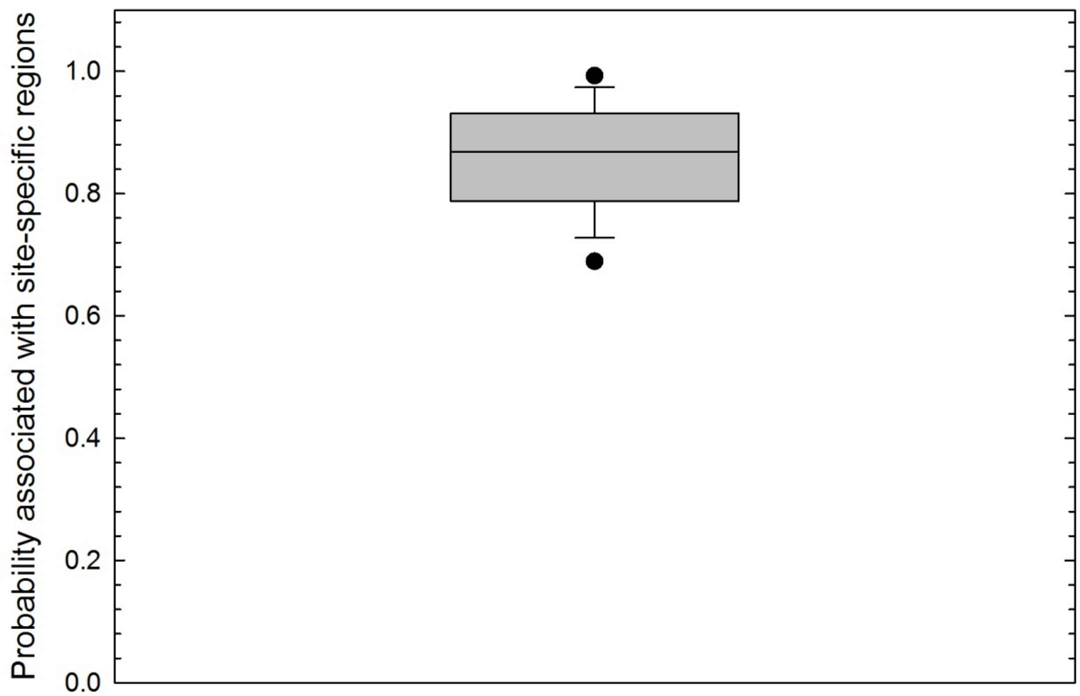

Figure 16. Range of probability for site-specific regions.

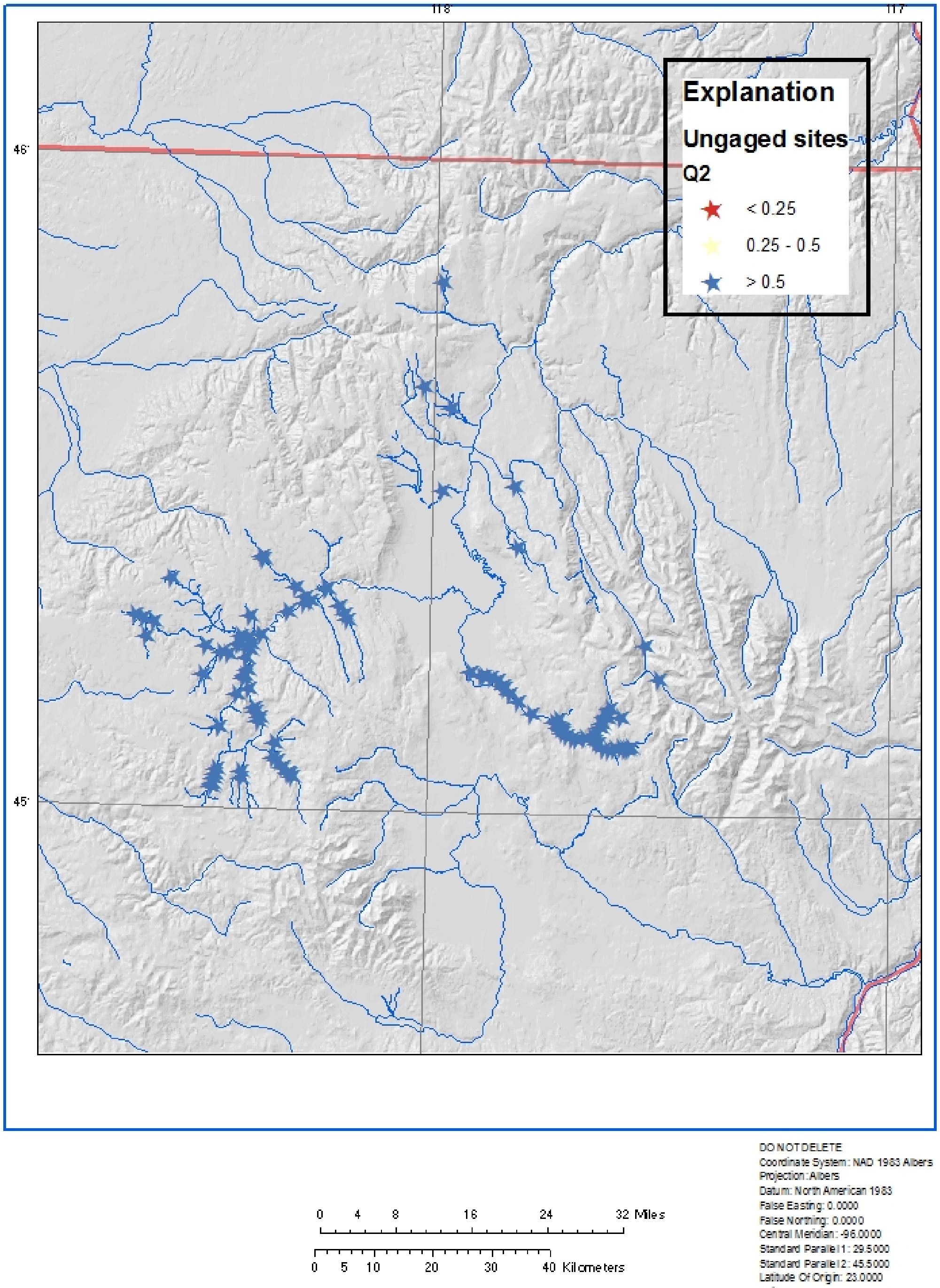

Figure 17. Estimated Q2 for ungaged sites in Upper Grande Ronde River Basin.

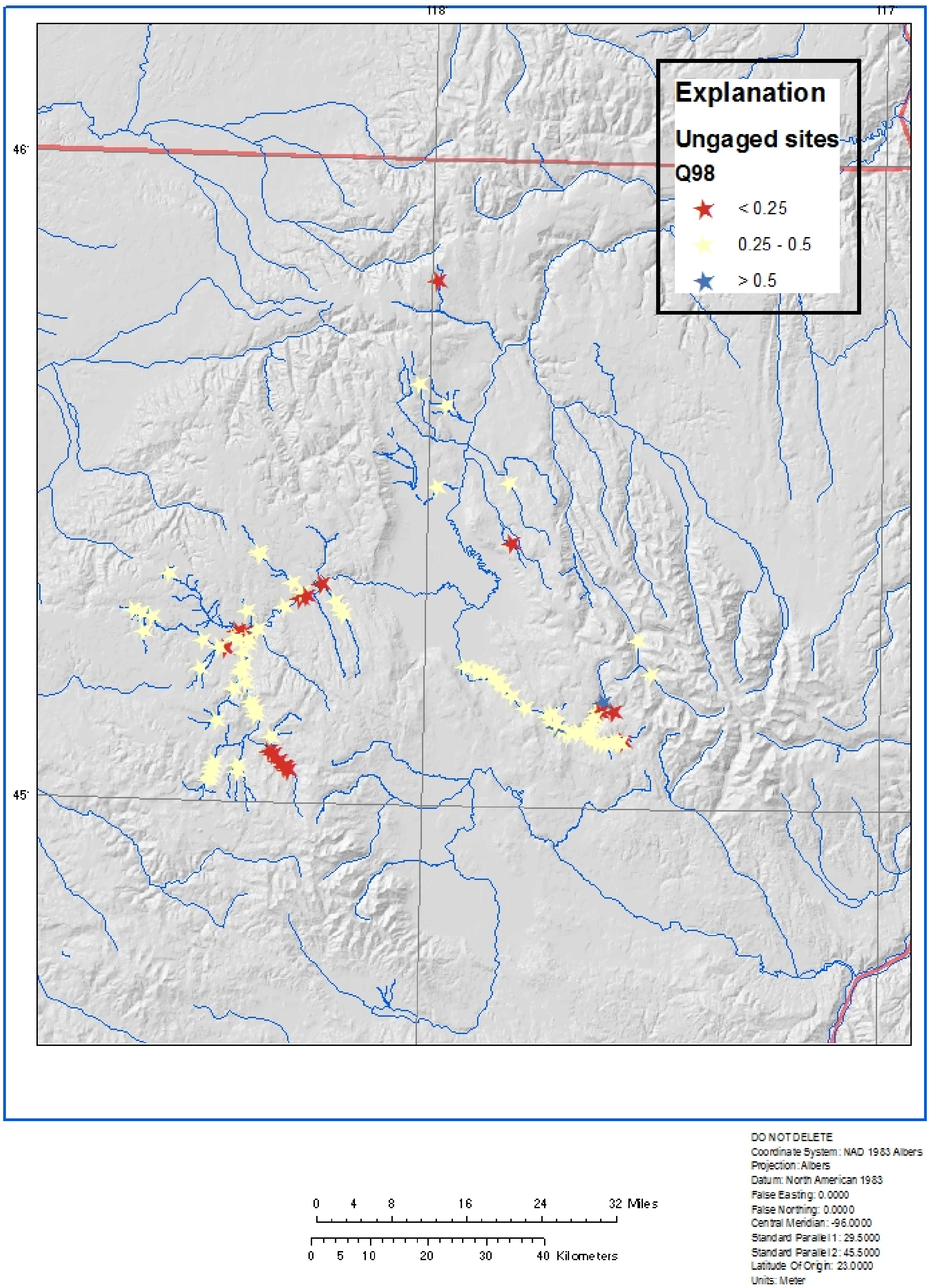

Figure 18. Estimated Q98 for ungaged sites in Upper Grande Ronde River Basin.

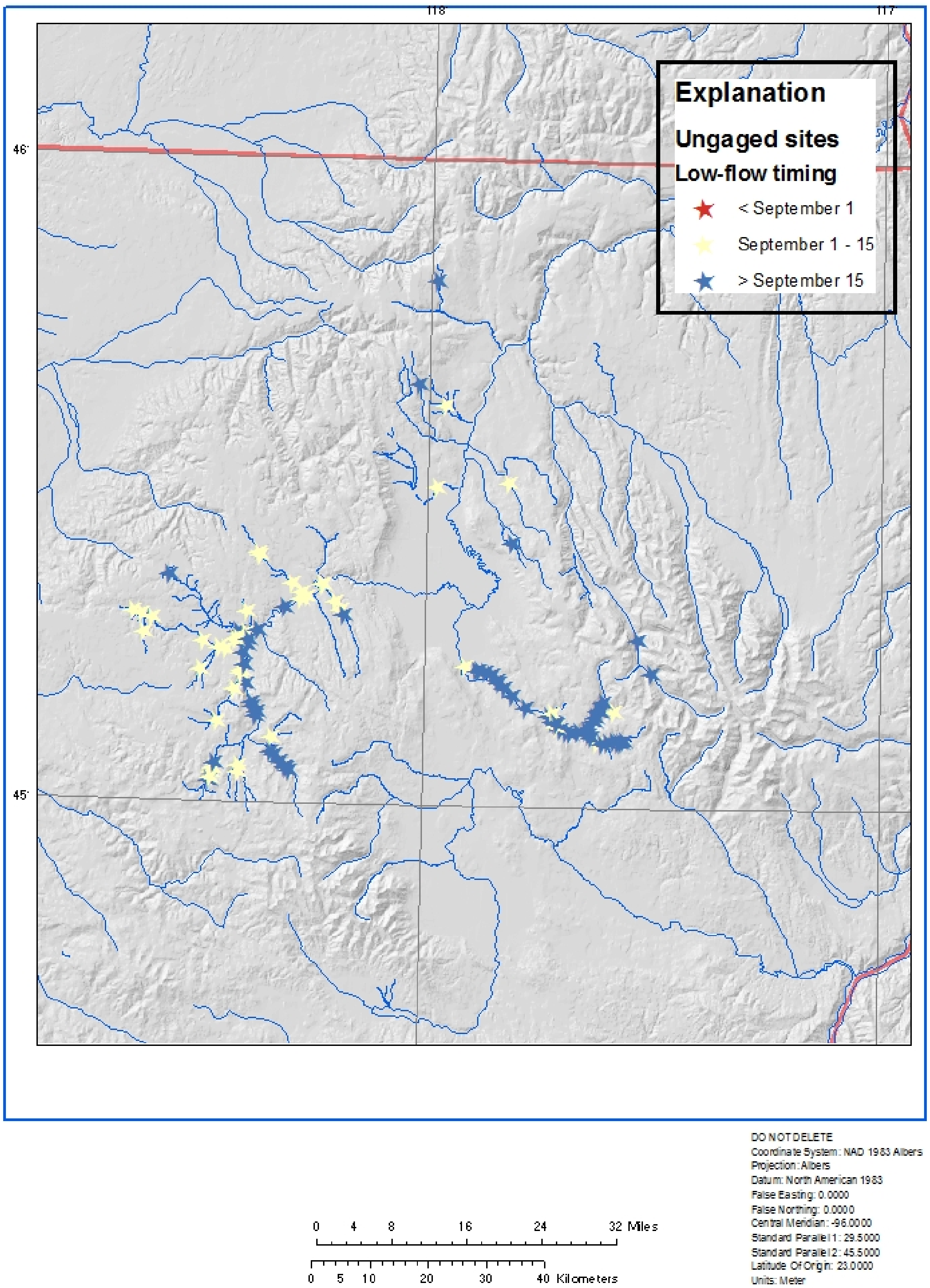

Figure 19. Estimated timing of onset of low flow for ungaged sites in Upper Grande Ronde River Basin.

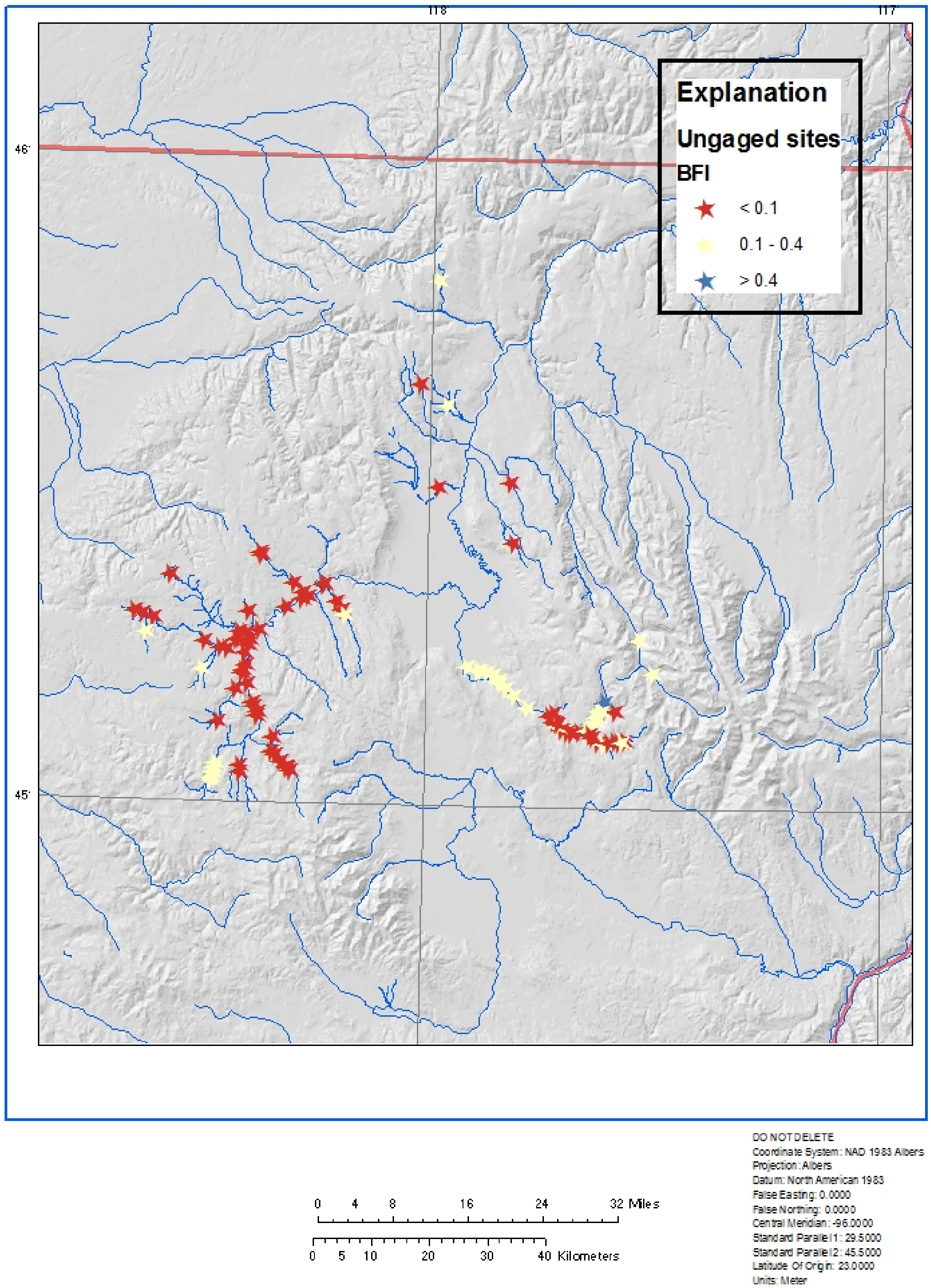

Figure 20. Estimated BFI for ungaged sites in Upper Grande Ronde River Basin.

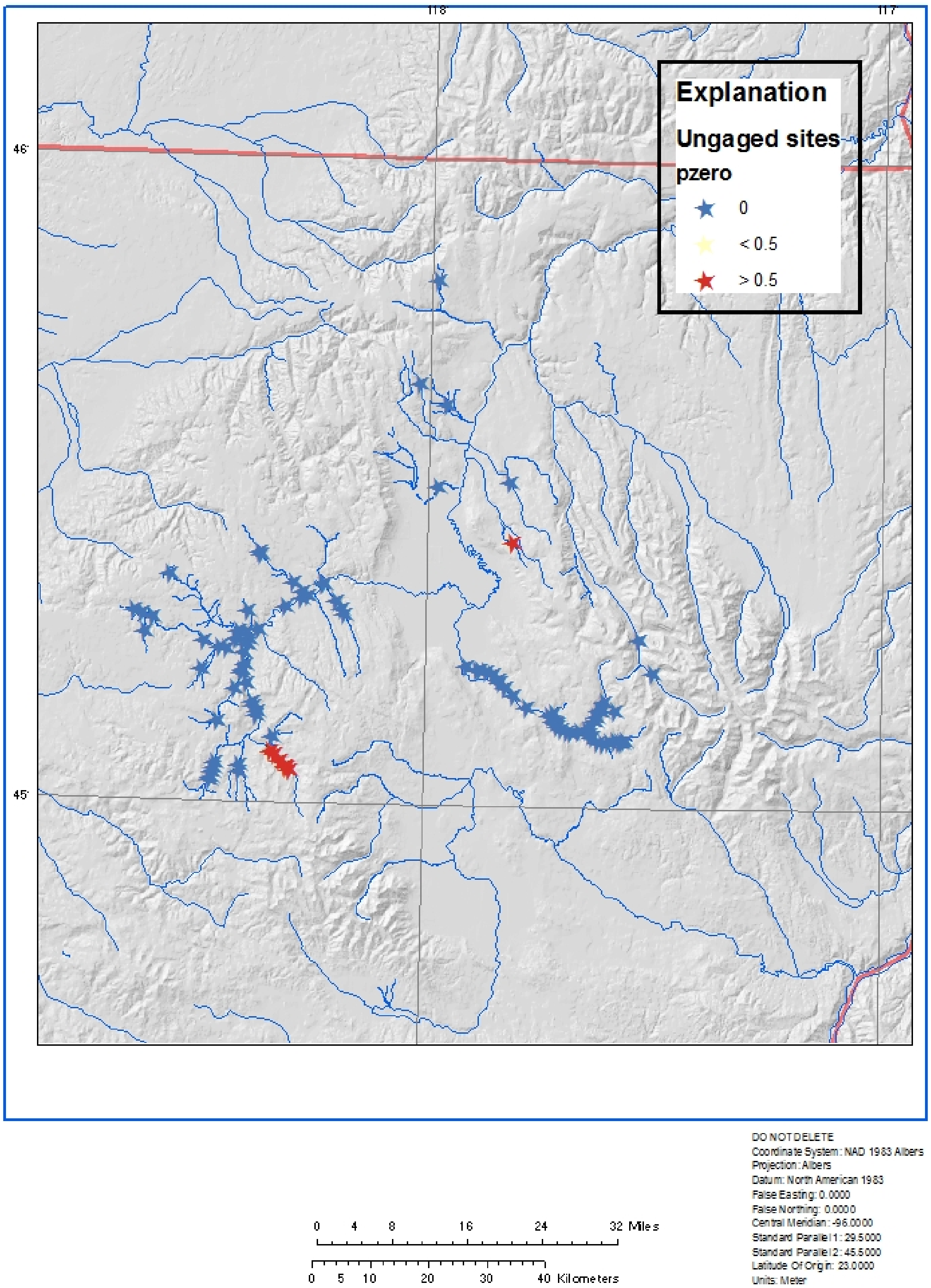

Figure 21. Estimated probability of zero flow for ungaged sites in Upper Grande Ronde River Basin.

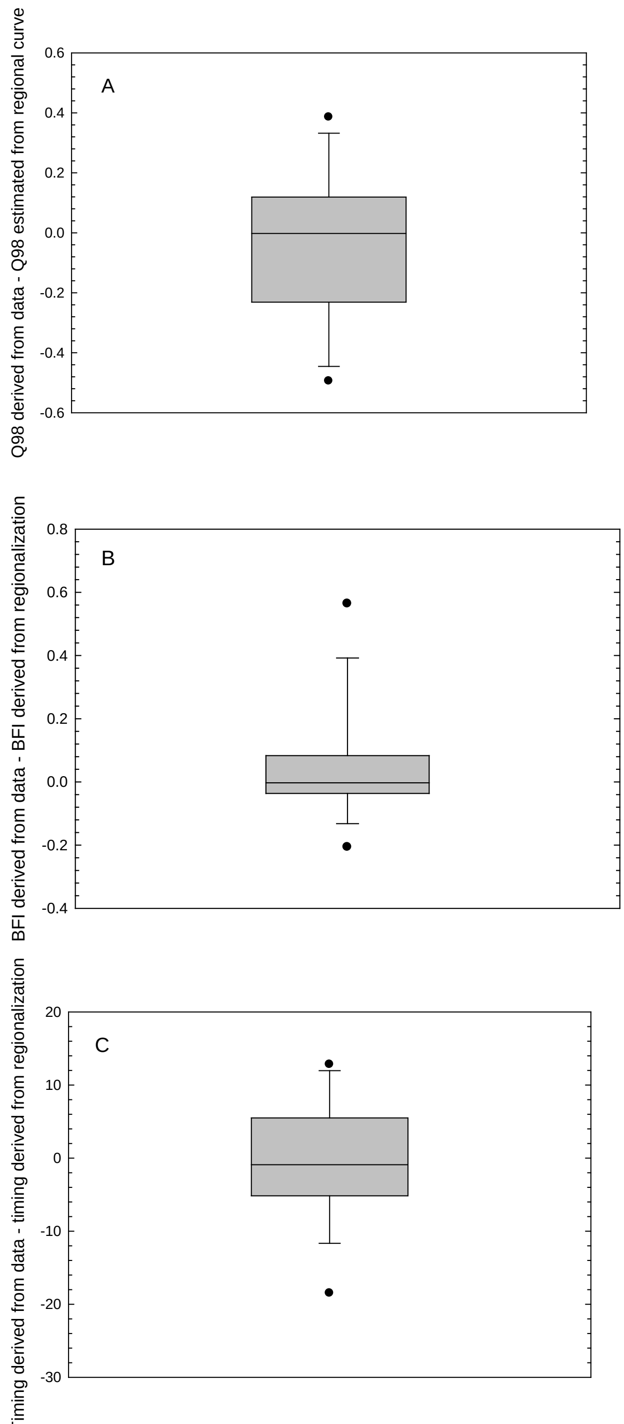

Figure 22. Cross-validation results for low-flow analysis (difference between metrics derived from regional and individual frequency curves for gaged sites). A. Q98 B. BFI C. Timing of onset of low flow.

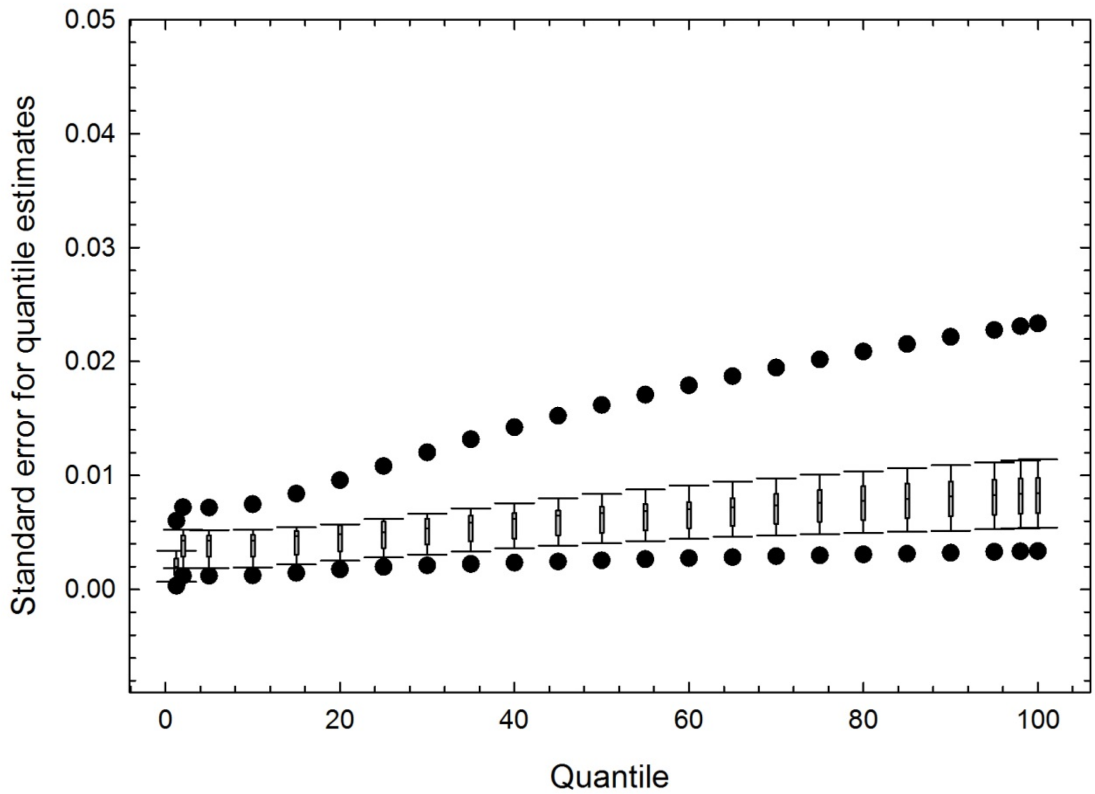

Figure 23. Standard errors for quantiles estimated for ungaged sites.

Appendix F Life Cycle Model for Spring Chinook Salmon in the Grande Ronde and Imnaha Rivers

March 2015

Robert Lessard, Columbia River Inter-Tribal Fish Commission

Introduction

A life cycle model was designed and built to reconstruct the population dynamics of spring Chinook salmon and to predict potential future dynamics under uncertain spawning, juvenile rearing, mainstem, and ocean survival conditions. The focal analysis of this project is on Catherine Creek and the Upper Grande Ronde, but since these populations share common life histories with neighboring populations (the other populations in the Grande Ronde/Imnaha Major Population Group (MPG) of the Snake River Evolutionarily Significant Unit (ESU)) we have expanded the life cycle analysis to include those populations in the reconstruction phase of the analysis. Including the additional populations improves the statistical power in population reconstruction and parameter estimation. The Grande Ronde/Imnaha MPG consists of the Grande Ronde River (GR), Catherine Creek (CC), Lostine/Wallowa (LOS), Minam (MIN), Wenaha (WEN), and Imnaha (IMN). Those six populations are modeled as separate spawning and rearing populations that share common aspects in their life histories, and are treated as independent samples of populations surviving common conditions outside of their natal streams. By including additional populations, we strengthen our statistical power when inferring survival downstream of spawning areas. In 2014, we focused on empirical validation of survival outmigrating juveniles and returning adults. We estimated survival of smolts through the hydro system and in the ocean in relation to environmental variables that describe inter-annual variation. Survival was modeled such that environmental variables influence the rate of survival. The degree of variation in survival in relation to each variable was estimated statistically. Model improvement efforts in 2014 provide an empirical basis for parameterizing the complete life cycle. The statistically estimated parameters provide the rates necessary to complete the prediction of survival and maturation from the smolt stage onward, whereas the spawning and rearing component predicts the spatial and temporal variation from the adult to smolt stage. The contents in this 2014 annual report section focus mainly the improvements to the empirical validation of the mainstem and ocean components.

Data

The life cycle model draws upon several sources of data. Adult and juvenile population data come from state and federal agencies. The adult data come from federal data sources. The Northwest Fisheries

Science Center of the National Marine Fisheries Service (NMFS) publishes salmon population summaries annually. These summaries include annual estimates of the number of spawners, the age compositions of spawners, and the fishery catches. The annual record can be used to account for the number of fish of each age from each spawning year (or brood year) that later return to spawn, including those that were caught in fisheries or collected for hatchery brood stock. We selected the time period for which all populations were monitored and environmental data were available, spanning the years 1964 to 2007, where 2007 is one of the most recent brood years with full recruitment of adults to the spawning grounds. Juvenile data (Favrot *et al*. 2012) come from Oregon Department of Fish and Wildlife, and are available for four of the six populations in the MPG: Catherine Creek, the Grande Ronde River, the Lostine/Wallowa and the Minam River.

Environmental data are used to predict mainstem and ocean survival rates. Ocean survival probabilities have been associated with indices of ocean conditions such as the Pacific Decadal Oscillation PDO (Mantua *et al*., 1997). Ocean survival has also been shown to vary with an upwelling (UPW) index indicative of primary production, and in-river survival has been shown to vary with water transit time (WTT), a variable that describes the rate of travel of water through the hydro system (Petrosky and Schaller 2010). Evidence has also shown that environmental conditions in the river affect the physical condition of out-migrating fish, and influence the rate of mortality after the fish enter the ocean (Petrosky *et al*. 2001; Budy *et al*. 2002). Petrosky and Schaller (2010) showed that the combined estuary/early ocean survival varied with PDO, upwelling and a variable describing juvenile interaction with powerhouses. An index of the effect of coming in contact with all powerhouses was created (termed NPH) where each powerhouse that fish come into contact with is discounted by the spill amount and spill efficiency. For example, a 50% spill can reduce a powerhouse contact from as high as 1.0 to as low as 0.5 (see Petrosky and Schaller (2010)). They found that the sum of the spill-adjusted powerhouse contact values (NPH) was negatively correlated with survival below BON and during the first year in the ocean. An empirical reconstruction of NPH from PIT tag detections (PITPH) is used in this analysis. PITPH looks at the detections from PIT tag data at each dam and estimates the likely number of juveniles that would have gone through the powerhouse based on spill and efficiency. PITPH is an empirically derived powerhouse contact rate. Any variation in PITPH with flow or WTT is implicit in the PIT tag detections.

Model

The model CRITFC is developing predicts the number of spawners, the number of eggs, the number of emerging fry, the number of juveniles rearing in different reaches of the river, the number of parr that migrate downstream in fall to overwinter, later migrating parr, the number of smolts, the number of fish in the ocean, and the number of returning adults. A simplified schematic of the detailed view of a single spatial unit of the freshwater spawning and rearing dynamics is shown in Figure 1. Fish rearing in the ocean are predicted to return to spawn as adults after a certain number years in the ocean. Throughout the life history, survival from one stage to the next is predicted with a Beverton-Holt survival function. Figure 2 shows a more detailed spatial view of the dynamics of spawning and rearing when spawner

straying and juvenile dispersal are considered. 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 rates from one stage to the next are predicted with a Beverton-Holt (BH) survival function. The basic formula for the BH survival function is $p/(1+pN/k)$, where N is the abundance, p is the density independent productivity and k is the carrying capacity term. When N approaches k/p, survival approaches $p/2$. All survival estimates by life stage use this assumption, though the values for p and k are not necessarily constant. Both p and k can vary with environmental conditions affecting any of the life stages described.

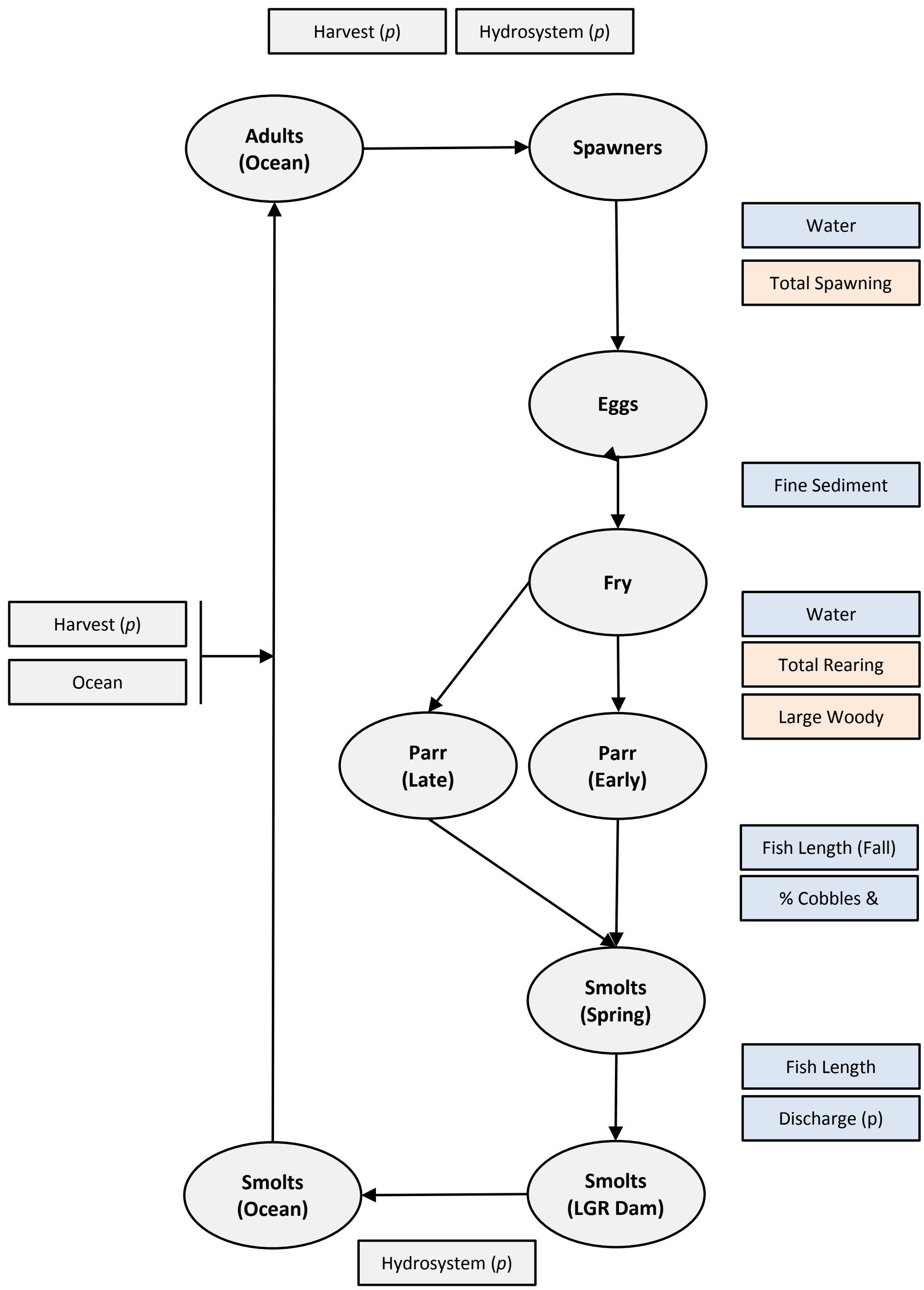

Figure 1 Life cycle diagram of single population, showing the freshwater spawning and rearing dynamics of a single freshwater spatial unit.

The model keeps track of environmental conditions at all stages and at all spawning and rearing sites, even if it is assumed that conditions are constant. Let $X_{i,j,k,t}$ 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. Let $Y_{j,k,t}$ be the environmental variable for the j^{th} stage, where j=1 is parr and j=2 is smolts, and the k^{th} variable in the t^{th} year. Let $Z_{j,k,t}$ be the k^{th} environmental variables for the j^{th} 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 such as X, Y, or Z variables, depending on which stage or spatial location the productivity calculation applies to. This form predicts a productivity on the order of (0,1), with a mean value of p^* when $\beta_0 = \ln(p^*/(1-p^*))$ and all other $\beta_n = 0$. Similarly, the capacity is calculated as follows:

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

where the mean is k^* when $\gamma_0 = \log(k^*)$ and all other $\gamma_n = 0$. 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 β_0 predict mean productivities between 0.05 and 0.95 and values on the range of (0,20) for γ_0 predict mean capacities between 1 and 485 million. For n>0, the scaling factors can take on any value, but a value of $\beta_0 = 0$ would predict mean of 0.5, so $\beta_1 = 1$ 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 γ_0.

The model predicts the number of adults returning in a given year and 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 allocate 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.

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 that strays 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.

The model assumes that the number of potential eggs produced is predicted by multiplying the number of spawners on a site by a fecundity (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.

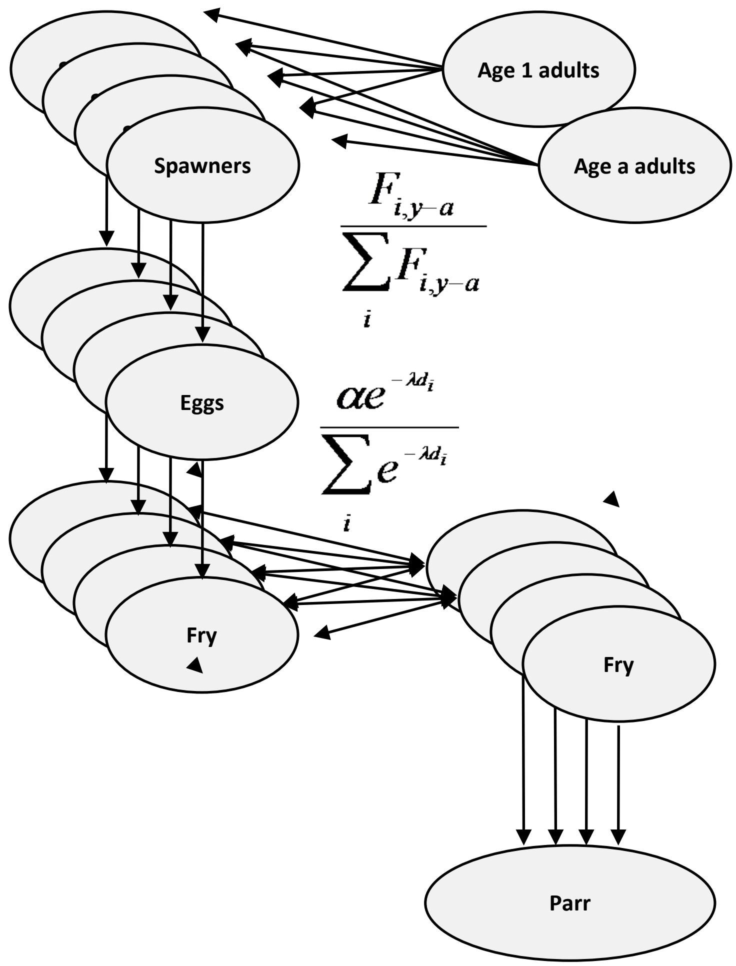

Figure 2 Spatial dynamics of spawning and rearing. Adults return to natal spawning areas in proportion to the number of fry that emerged the appropriate number of years prior to the age of maturity. Fry rearing and dispersal involves fry dispersing to spatial units other than the one from which they emerged from gravel. Illustration shows a distance scaled dispersal.

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.

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 to any given location upstream or downstream decays exponentially with distance of that point from the origin (as shown in Figure 2). The equation below shows the calculation of the distance scaled dispersal.

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

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

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 percentage 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.

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, water temperature, and percentage cobbles and boulders.

When smolts enter the mainstem, the dynamics through the hydro system uses a survival rate from an empirically derived estimate. The model estimates the relationship between the fraction of outmigrating smolts detected at Lower Granite Dam that are also detected as returning adults, and the anthropogenic and environmental effects (i.e., spill, PDO, and upwelling) will affect survival, as will transportation of fish on barges. The model explicitly estimates the relationship between survival and an index of spill and powerhouse contact, PDO, upwelling and the fraction of fish that are transported. The outmigrating population is divided into transported and untransported (in-river) migrant groups. Transported and in-river fish are treated as distinct for early ocean survival. 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 returns 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 age that do not return to spawn spend an additional year in the ocean. After the fourth year in the ocean, all fish return to spawn.

Mainstem and first-year ocean survivals are modeled in a slightly more complex manner than freshwater and later ocean survivals because of the distinction of transported and in-river migrants. The fraction of transported fish in year t ($trans_t$) was taken from the Comparative Survival Studies (Tuomikosky *et al*. 2013) annual report, which reports a statistical reconstruction of the fraction of transported fish that is derived from PIT tag detections at collection facilities of each hydro project. The survival rate of transported fish is assumed to be 98%. The survival rate of transported fish in the ocean is estimated in relation to PDO and UPW and is distinct from the effects of PDO and UPW on in-river migrating fish. The number of adults surviving to the end of the first year in the ocean (O) is predicted by O = 0.98transt sT M+ sR (1- transt) sH M, where sT, sR , sH, and M represent ocean survival of transported migrants, in-river survival, ocean survival of in-river migrants, and the number of smolts outmigrating two years after spawning occurs. sR, sT, and sH are calculated in relation to the environmental variables PITPH, WTT, PDO, and UPW using the logistic regressions. sR is calculated using

the relationship logit(sR) = αR + αPH PITPH + αW WTT. sH is calculated using the relationship logit(sH) = βH + βPDOPDO + βUPWUPW + βPHPITPH. sT is calculated using the relationship logit(sT) = βT + βPDOPDO + βUPWUPW. The 8 α's and β's are estimated parameters. Thus, in-river survival depends only on the powerhouse index and water travel speed, ocean survival of in-river migrants depends on PDO, UPW, and the powerhouse index, and ocean survival of transported juveniles depends on PDO and UPW, but not the powerhouse index. The magnitudes of the effects of variability in PDO and UPW on sH and sT are the same, but sH and sT have different base rates. Ocean survival in later years was fixed such that second- and third-year ocean survival were 0.6 and 0.7, respectively.

The mainstem and ocean dynamics of the life history of Catherine Creek and Upper Grande Ronde spring Chinook are empirically validated, whereas the complex spatial dynamics of freshwater straying and dispersal. For the purpose of establishing a baseline of model behavior and parameterization, we simplified the spatial aspects of freshwater dynamics and focused on estimating the rates that predict mainstem and ocean survival in relation to environmental conditions. For this effort, the freshwater aspects of the model were simplified such that no straying or dispersal were implemented. The simplified version of the model predicts outmigrating smolts from spawners for the six populations in the Grande Ronde/Imnaha MPG. The simplified multiple population model is shown in Figure 3. Using environmental conditions as the basis for calculating survival through the hydro system and in the ocean, predicted adult returns were compared to empirical values to find the parameters that predict the best fit to the data. A maximum likelihood approach was used to estimate the 8 α's and β's, and the Beverton-Holt *a*'s and *b*'s, and maturation rates at the end of each year in the ocean.

We implemented several statistical versions of the life cycle model. Each version was designed to focus on a particular bias in how the model used empirical data. A time series deviate model was implemented to examine how productivity in freshwater spawning and rearing varies over time as a purely statistical process. Unlike the mechanistic mainstem and ocean survival variation predicted by environmental variability, the deviate model merely attempts to explain how much annual productivity deviates from a mean value, and it assumes that some large scale deviation affects all six populations similarly. Another statistical implementation used was to assume that adult abundance data contain uncertainty. This observation uncertainty assumption relaxes the fitting procedure to place more confidence on predicted outcomes than on the data itself, attempting to predict each year's returns from previous predictions. Model fitting was performed by minimizing a negative log-likelihood composed of the aggregate deviates of predicted and observed smolt and adult return abundances. The assumed error structure for the deviates was log-normal.

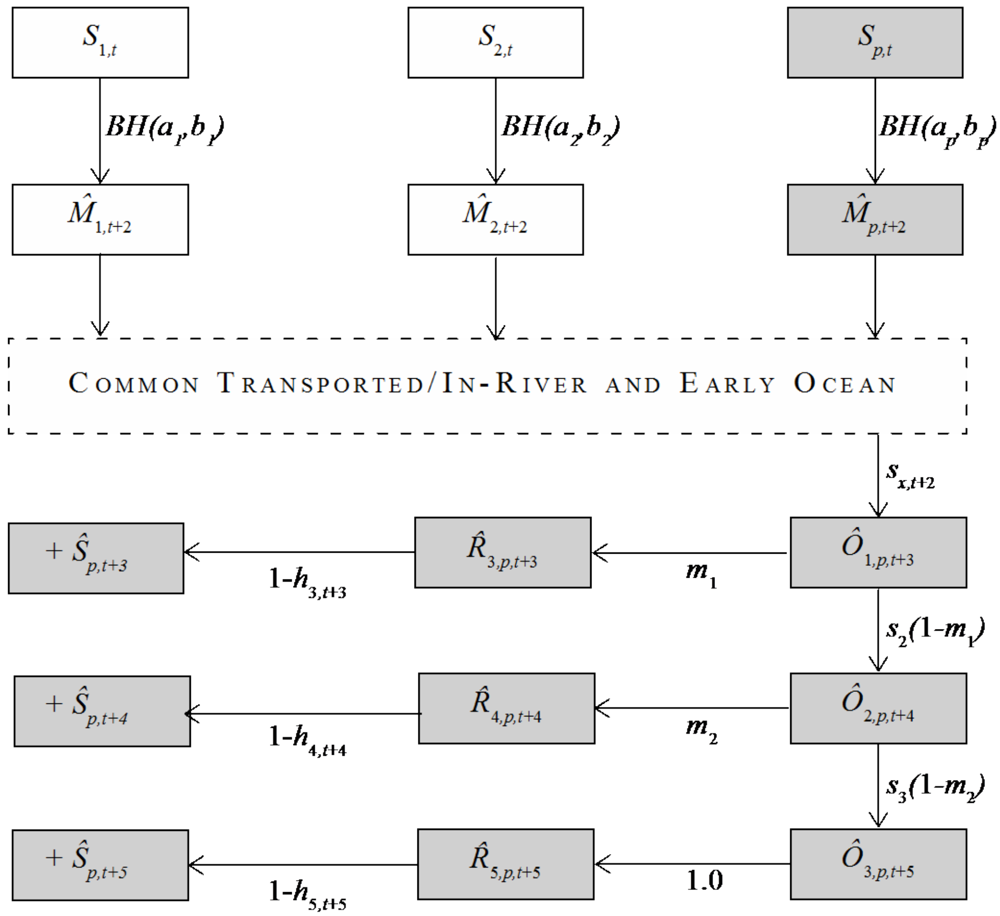

Figure 3. Diagram of model with simplified freshwater rearing. Multiple populations spawn and rear independently, but experience common mainstem and ocean dynamics.

Results

The maximum likelihood estimates of smolt productivities (Beverton Holt *a* parameters) for Catherine Creek and the Upper Grande Ronde were 166 and 1096 smolts per spawner at the origin when we assumed constant values of the productivity parameter. The value for the Upper Grande Ronde was very high when productivities were assumed to be constant, but when the deviation model was used, the rate averaged 156 smolts per spawner at the origin. The Catherine Creek deviation model productivity averaged 138 smolts per spawner at the origin. The maximum likelihood capacity estimates were 8,776 and 5,169 respectively for Catherine Creek and the Upper Grande Ronde.

The estimated in-river survival, ocean survival of transported fish, and ocean survival of in-river migrants are shown in Figure 4. We can see that ocean survival of transported migrants is lower than the ocean survival of in-river migrants, but the in-river migrants survive at a lower rate (~20-50%) than transported fish (98%) before they enter the ocean. The time series trend in Smolt-to-Adult rate is also shown along with the empirical data derived from PIT tag data. The estimated parameters for the prediction of in-river and transported migrants are shown in Table 1. The two positive effects are WTT and UPW, and are roughly the same magnitude. PITPH is estimated to be approximately as much of a negative effect on the in-river survival rate as it is on the survival rate in the ocean or approximately -0.8 to -0.88. PDO has a negative influence on survival in the ocean for both in-river migrants and transported migrants.

Plots of the fits of each population's returning abundances can be seen in Figure 5 along with observed data. We can see that there are periods of time where the model over predicts returning abundances, and other periods where the model under predicts. Most notably, Catherine Creek and the Upper Grande Ronde are both under-estimated in the early period of the model fitting, possibly owing to a pattern of declining survival for those two period.

Table 1 Estimated parameters for the prediction of the survival of in-river and transported migrants.

Parameter	Estimate
α_R in river	-0.77
α_{PH} in river	-0.8
α_{WTT} in river	0.3
β_T ocean survival of transported migrant	-2.89
β_R ocean survival of in river migrant	-1.65
β_{PDO} ocean survival both	-0.26
β_{UPW} ocean survival both	0.26
β_{PH} ocean survival in river migrant	-0.88

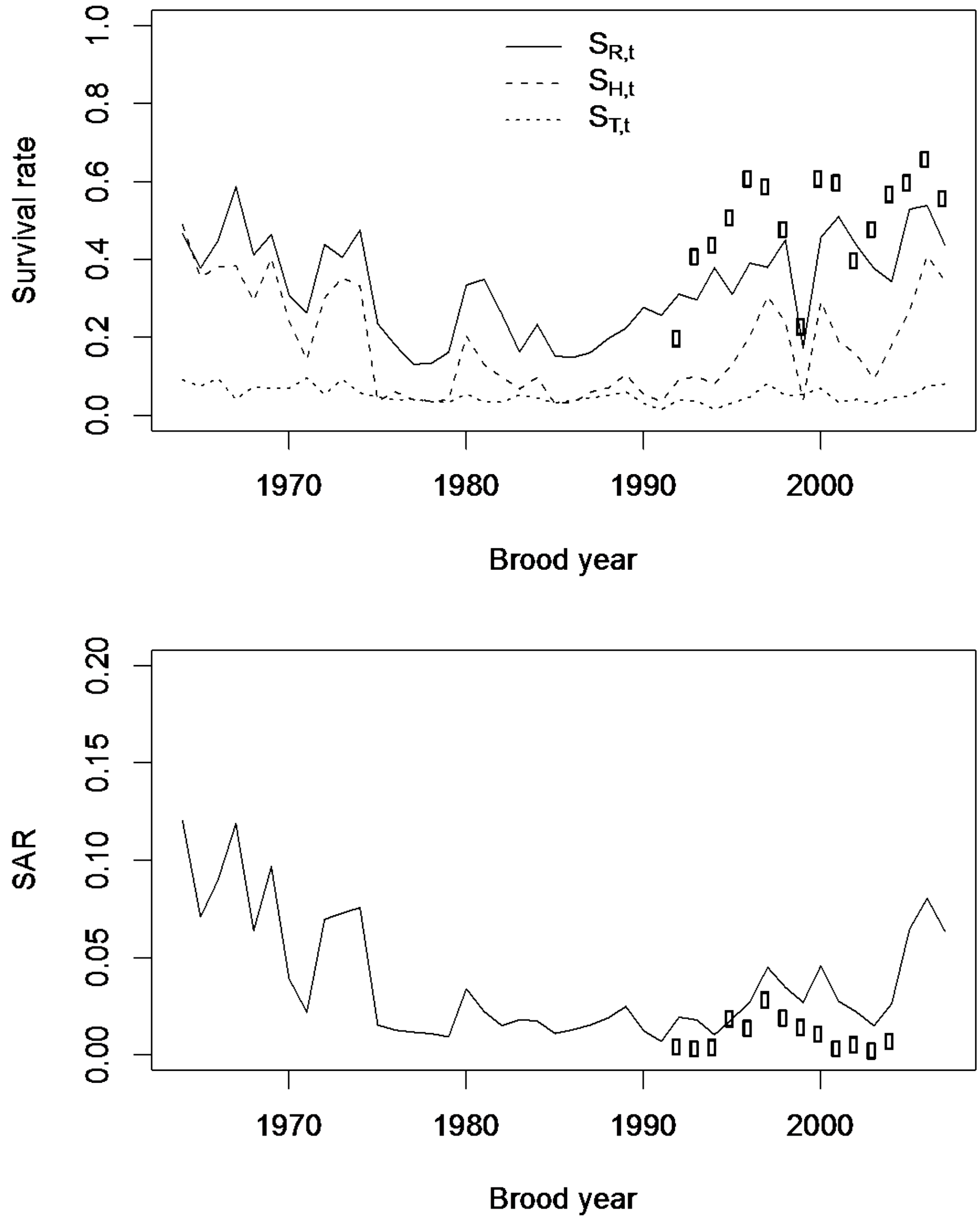

Figure 4 Upper panel shows observed in-river survival (circles) and predicted in-river and transported survival rates.

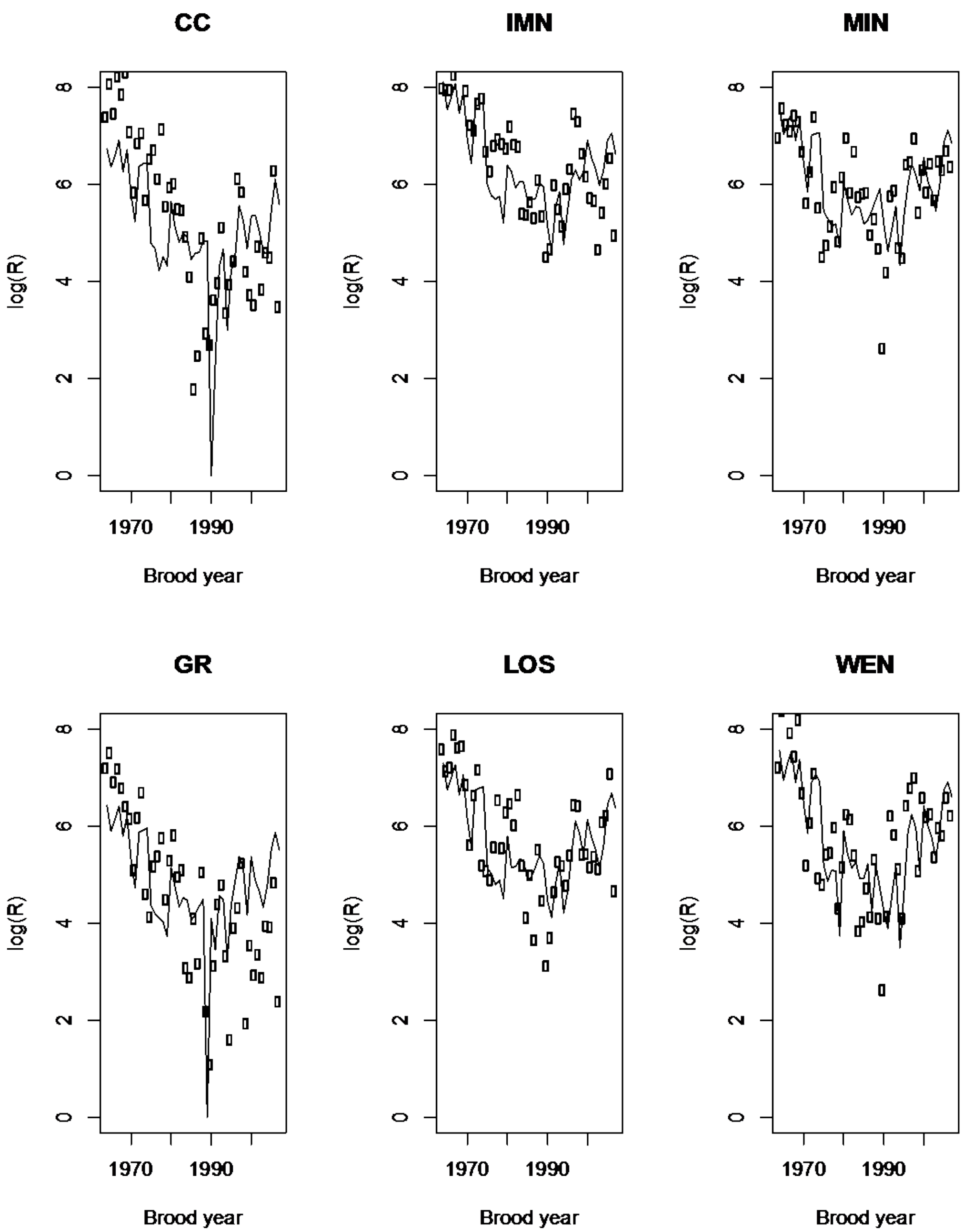

Figure 5 Time series plots of Grande Ronde/Imnaha predicted and observed abundances showing the logarithm of total return abundance to the spawning ground.

Discussion

Model development in 2014 focused mainly on providing the life cycle model with an empirical basis for parameterizing mainstem and early ocean survival. By including multiple populations into the parameter estimation phase of model development, statistical parameter estimation benefitted from additional sample size for the in-river and ocean survival portion of the life cycle model. Having established a rigorous statistical framework for estimating in-river and ocean survival, further effort can now be focused on freshwater and rearing dynamics. Six freshwater productivities and capacities were estimated in this model. This provided the ability to predict smolt production from spawning abundance, but assumed that the rates did not change over time in the way that survival in-river and in the ocean were allowed to vary in relation to environmental conditions. The next step in model development will involve formulating similar mechanisms for predicting freshwater rearing dynamics as those used in downstream dynamics.

We found that when we assumed that all six populations followed the same in-river and ocean dynamics, certain biases appeared in model fitting deviates. Particularly, Catherine Creek and Upper Grande Ronde appear to have experienced a downward trend in overall productivity. Because all dynamics following freshwater spawning and rearing are common to all populations, any differences in temporal pattern of deviates among populations implies that the pattern is driven by freshwater spawning and rearing dynamics. We conclude that Catherine Creek and the Upper Grande Ronde likely had higher than average freshwater production during the early period of the model fitting timeframe, and spawning or rearing productivity in those natal streams likely degraded over the course of approximately 10-15 years relative to the other four populations.

We see clear indication that survival can vary in relation to changes in environmental conditions. Life cycle model survival predictions in-river and in the ocean show a pattern that varies with several in-river and ocean conditions. Biases in overall adult abundance prediction deviates indicate that building a similar relationship for spawning and rearing capacity could further explain variation in predicted smolt production. On-going efforts to measure freshwater habitat conditions will be used to characterize a relationship between productivities and capacities, and conditions measured and monitored in natal streams. Several years of habitat data are now available for Catherine Creek and the Upper Grande Ronde (e.g., channel characteristics, pool densities, woody debris, temperature, flow metrics, etc.). Using recent historical averages of habitat metrics in each spatial unit of each natal stream, we will establish spatial baselines for these conditions and construct a relationship between habitat conditions and production parameters.

The ultimate goal of the life cycle modeling continues to be focused on building a relationship between habitat and freshwater spawning and rearing productivity and capacity for the purpose of monitoring and evaluating the effects of changes in habitat conditions. To achieve that goal, it is necessary to have an empirically based life cycle model, parameterized to predict all stage of life history. The estimation of parameters that predict in-river and ocean survival was a necessary step in that direction, and can now be used to make survival predictions downstream of spawning and rearing areas.