SOUTHEAST WASHINGTON INTENSIVELY MONITORED WATERSHED PROJECT IN ASOTIN CREEK:

YEAR 4 PRETREATMENT MONITORING SUMMARY REPORT

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EXECUTIVE SUMMARY

Introduction

- Asotin Creek in southeast Washington was chosen as a site to develop an Intensively Monitored Watershed Project (IMW) in 2008. The purpose of the IMW program is to implement stream restoration actions in an experimental framework to determine the effectiveness of restoration at increasing salmon and steelhead production and to identify casual mechanisms of the fish response to help guide restoration actions in other watersheds.
- Asotin Creek is designated a ***wild steelhead refuge and steelhead are the focus of the IMW***. The IMW is a multiagency cooperative project coordinated by the Snake River Salmon recovery Board (SRSRB) and monitoring activities are closely coordinated with the ongoing Washington Department of Fish and Wildlife (WDFW) Asotin Steelhead Assessment project.
- This report summarizes the first four years of pre-restoration IMW monitoring and infrastructure development. Restoration began in the summer of 2012 and be implemented in a hierarchical-staircase design (see below) in three tributaries to Asotin Creek over three consecutive years. Monitoring of the restoration effectiveness will continue until 2018.
- The IMW is being implemented in an adaptive management approach and as such we have revised the overall design and monitoring efforts in response to new information and ongoing analysis. There have also been several logistical and political issues that have required us to adapt the original IMW design. This report summarizes the design revisions and replaces all previous IMW plans.
- This report only presents an abbreviated version of the restoration plan. The complete restoration plan can be reviewed in a separate document (Wheaton et al. 2012).

Watershed Setting

- Asotin Creek is a small tributary that enters the Snake River directly at rKM 522.224 at the town of Asotin Washington. The watershed straddles the Columbia Plateau and Blue Mountains level III ecoregions. The terrain is steep with deep narrow canyons in a basalt dominated lithology, surrounded by semi-arid sagebrush steppe at lower elevations and open conifer dominated forests at higher elevations. An extensive watershed assessment in the early 1990's identified stream temperature, riparian condition, fine sediment, lack of large woody debris and pool habitat, and fecal coliforms as limiting factors. Extensive upland and management improvements and riparian fencing in the late 1990's and early 2000's are thought to have decreased sediments entering the streams. The IMW is being implemented in the lower 12 km of three tributaries to the mainstem Asotin Creek: Charley Creek, North Fork Asotin Creek, South Fork Asotin Creek (hereafter the study streams collectively and Charley Creek, North Fork, and South Fork individually).

Conceptual Models and Experimental Design

- The study streams consist primarily of highly homogenized and degraded habitats, which are thought to be limiting steelhead production. One of the primary limiting factors in the study streams is a lack of pool habitat and fish cover, which is thought to be directly correlated to the relatively low abundance, density and mean size of LWD compared to reference conditions and assumed historic recruitment levels. Therefore, LWD restoration treatments have been proposed for the Asotin IMW.
- We performed a power analysis of several experimental designs and monitoring schemes to assess our original IMW design. The analysis showed that under anticipated levels of variance in juvenile abundance and pool frequency all designs would be able to detect a 25% change in abundance after restoration. However, under "worst-case" levels of variance (i.e., upper 95% confidence levels) an alternative design in which restoration was implemented in all three study streams was more likely to detect changes compared to our original design of treating only one stream. Based on the power analysis results we revised our experimental design.
- The Asotin Creek IMW has a hierarchical-staircase experimental design where the lower 12 km of each study stream is divided into three 4 km long sections and one section of each creek will be treated (i.e., restoration applied) with the remaining sections acting as controls. Treatments will be staggered over three years with one section treated each year starting in 2012. A total of 12 km will be treated. The staggered implementation of the restoration (i.e., staircase design) provides explicit opportunities within the adaptive management plan to refine and adapt implementation and monitoring specifics as may be necessary.

Restoration Design

- The addition of LWD to streams to improve habitat complexity and quality is not a new restoration intervention. However, we argue that most projects place undue focus on the size and stability of LWD with frequent attempts to anchor LWD in place. From a system-wide perspective, we think that the low density of LWD is a much bigger problem than the size, and systems with healthy rates of LWD recruitment see much more dynamic behavior in their LWD (i.e., it moves occasionally). We seek to produce a population-level response in steelhead in the Asotin Creek Watershed by treating over 12 km of stream in three study streams with 500 – 600 LWD structures. We expect this to fundamentally alter the complexity of habitat at a system scale inducing an increase in steelhead production at the subbasin scale.
- To achieve the sort of LWD densities we are hoping to with traditional LWD treatment methods would be extremely expensive, highly disruptive to the existing riparian vegetation, and logistically infeasible to implement over the broad range of steelhead habitat in the Columbia Basin. Instead we, propose to test the effectiveness of a simple, unobtrusive, method of installing Dynamic Woody Structures (DWS), which are constructed of wood posts, driven into the streambed, and augmented with LWD cut to lengths that can be moved by hand.
- Dynamic Woody Structures are installed with a hand-carried hydraulic post-pounder by a crew of 2-4 people. Typical installation time is on the order of 1-2 hours per structure and material

costs are < $200. Thus, if the treatment method proves effective, this is potentially an easy and cost-effective method to implement in other watersheds.

- The DWS are designed to produce an immediate hydraulic response by constricting the flow width. Like natural LWD accumulations, this alteration of the flow field creates more hydraulic heterogeneity, providing shear zones for energy conservation for fish next to swift areas with high rates of invertebrate drift. Moreover, the convergent flow produced by the constriction is likely to scour and/or maintain pools at high flows, and divergent flow downstream of the DWS where the stream width expands, may promote active bars that provide good spawning habitat.

Monitoring Design

- To maximize our ability to understand the effectiveness of the restoration and the causal mechanisms of changes in steelhead production and habitat change we are building a multi-scalar Biophysical Framework using geo-referenced data in GIS. To build this framework we have acquired aerial and ground based LiDAR, aerial photography, and GIS layers on soils, geology, stream networks, topography, and are deriving landscape units, slope classes, and other products at multiple scales within the Asotin Creek watershed.
- To compliment these watershed scale biophysical data sources we are using existing and newly installed discharge and temperature monitoring stations throughout the Asotin and its tributaries, "fish-in, fish-out" monitoring at a WDFW adult weir and smolt trap, and historic redd counts and juvenile abundance estimates going back to the 1980s.
- We have developed a set of permanent fish (12) and habitat (36) monitoring sites across the three study streams to assess abundance, growth, survival, and production of juvenile steelhead. We use two pass mark-recapture and PIT tagging to assess fish and the Columbia Habitat Monitoring Protocol (CHaMP) to monitor stream habitat at the permanent sites. We also use mobile PIT tag surveys and rapid habitat assessments over the entire length of the study streams to compliment the site scale monitoring.
- To allow detection of adults and juveniles leaving and entering the watershed and the study streams and to estimate movement between study streams, we have established PIT tag interrogation sites in Asotin Creek at the mouth, upstream of George Creek on the Asotin Creek mainstem, and near the mouths of Charley Creek, North Fork, and South Fork.
- From these monitoring efforts we will calculate a variety of fish and habitat metrics to determine the biological and physical responses to restoration at the section of stream scale. Fish metrics we will calculate include smolts/spawner, juveniles/spawner, juvenile abundance (fish/m^2), growth (g/day), survival rates (season), and movement rates (m/day, season, year). Habitat metrics will include pool frequency, LWD count and volume, habitat unit density (i.e., number of units/100 m2), sediment budgets (deposition and erosion rates and volumes). Fish and habitat characteristics will be integrated into models of carrying capacity using temperature, flow, and topographic data to determine changes in the total carrying capacity of treatment and control areas.

Pre-Restoration Lessons Learned

- Estimates of smolt production and adult escapement are available from 2004-2005 respectively and watershed scale productivity estimates will be available for the pre and post period of the IMW (i.e., 2008-2012 and 2012-2018).
- Annually an average ~ 36,000 smolts have out-migrated and 654 adult steelhead have returned to Asotin Creek since 2004 and 2005 respectively.
- The majority of steelhead smolts are age 1 and 2, and the majority of returning adults spend one to two years in the ocean.
- WDFW have PIT tagged 15,324 juvenile steelhead at the smolt trap and an additional 12,512 juveniles have been PIT tagged at the fish sites within the study streams.
- Juvenile steelhead abundance, growth, movement, and survival have been estimated in the study streams using mark-recapture, interrogation site detections, and mobile PIT tag surveys. There is relatively high variability between population metrics across sites, streams, and years; however, control and treatment sites have similar trends across years which will improve detection of population changes due to restoration.
- On average South Fork had higher densities of juvenile steelhead, North Fork and South Fork had higher growth, all streams had minimal movement of juveniles within and between sites, and true survival was highest in Charley Creek and South Fork. Juvenile steelhead from the study streams (i.e., tributaries) are using the mainstem of Asotin Creek for up to a year to continue rearing before outmigrating.
- Total juvenile production averaged 12.1 g/ha/day (SD = 24.7, Min = -11.1, Max = 145.5) across all sites and also showed high variability between time periods, streams, and sites. Preliminary analysis found no strong correlations between production and common habitat metrics (e.g., frequency of pools and wood) though there was weak correlation with production and average daily sun hours at a site.
- Results from a trial restoration assessment are encouraging and suggest that the dynamic wood structures (DWS) we are proposing are a cost-effective and efficient way to generate habitat complexity using large wood. Geomorphic change detection indicates that scour pools, eddy bars, and undercuts are being generated by the DWS.
- Biophysical assessment of the study creeks is providing detailed, flow, temperature, and landscape level control information that will inform restoration planning and help interpret the effectiveness of the restoration structures and the response of fish populations and overall productivity.
- Future work will focus on generating juvenile productivity estimates for the study streams, further assessing the distribution of spawning and juvenile movement, and developing multivariate models to explain variation in steelhead juvenile and smolt production.

CONTENTS

LIST OF ABBREVIATIONS

ACCD - Asotin County Conservation District

DEM - Digital elevation model

DoD - DEM of difference

DOE - Washington State Department of Ecology

DWS - Dynamic woody structure (i.e., the proposed LWD restoration method)

ELR - Eco Logical Research Inc.

GCD - Geomorphic change detection

LWD - Large woody debris

NREI - Net rate of energy intake

NOAA - National Oceanic and Atmospheric Administration

NRCS - USDA Natural Resources Conservation Service

PCSRF - Pacific Coast Salmon Recovery

PTAGIS - PIT Tag Information System

RCO - Washington State Recreation and Conservation Office

RTT - Regional Technical Committee

SRSRB - Snake River Salmon Recovery Board

USFS - United States Forest Service

USGS - United States Geological Survey

WDFW - Washington Department of Fish and Wildlife

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1 INTRODUCTION

1.1 BACKGROUND

The Snake River Salmon Recovery Board (SRSRB) received funds in November 2007 to begin an Intensively Monitored Watershed project (IMW) in the Snake River Salmon Recovery Region of southeastern Washington. The SRSRB chose to implement an IMW in Asotin Creek after a comprehensive selection process (Bennett and Bouwes 2009). Intensively Monitored Watersheds are being implemented throughout the Pacific Northwest in an effort to determine how effective stream restoration is at increasing freshwater production of salmon and steelhead (Bilby et al. 2005). Past stream restoration efforts often had no associated effectiveness monitoring and were limited in scope (i.e., only a few structures or meters of habitat were restored at a location). The IMW program is attempting to increase our understanding of the effect of stream restoration on salmon and steelhead production by implementing restoration in an experimental framework with intensive monitoring of both fish and habitat responses to restoration. Restoration actions in an IMW are deliberately large in scale (i.e., stream or subbasin scale) in order to cause a population level response that is large enough to detect (i.e., signal) above the large amount of natural spatial and temporal variability (i.e., noise). The overall goal of the IMW program is to i) detect significant changes in salmon and steelhead production associated with restoration and ii) determine the casual mechanisms of the changes in production. The information gathered in individual IMWs will be used to inform restoration in other similar watersheds throughout the Pacific Northwest.

The Asotin IMW is a collaborative multi-agency initiative sponsored by the Snake River Salmon Recovery Board with agency support from the Regional Technical Team (RTT), Washington Department of Fish and Wildlife (WDFW), US Forest Service (USFS), Asotin County Conservation District (ACCD) and the Nez Perce Tribe (NPT). Funding for the primary research components of the IMW are from NOAA's PCSRF account. Those funds were used to fund the experimental design and initial habitat and fish data collection and analysis. A separate project funding by the Bonneville Power Administration (BPA) and implemented by the WDFW provides fish-in, fish-out monitoring for the Asotin watershed and compliments the NOAA funding (Crawford et al. 2012). In 2010, and anticipated for future years, BPA has committed to continue funding the fish in-fish out monitoring (adult weir and smolt trap). Funding for the restoration and protection actions will come from a myriad of sources including, but not limited to, Pacific Coast Salmon Recovery Fund (PCSRF) through the State of Washington's Salmon Recovery Funding Board (SRFB), BPA, Conservation Commission, USFS, and WDFW. Further, opportunities have been identified to support implementation actions including the Oregon Department of Transportation's I-5/Columbia River Crossing mitigation requirement, American Recovery and Reinvestment Act, National Fish and Wildlife Foundation's Community Salmon Fund, USDA's CREP (conservation reserve and enhancement program), USDA's EQIP (environmental quality incentive program) and others.

Assuming adequate funding levels and commitment from NOAA, it is estimated that the following tasks will be funded by the sources identified at the amounts estimated:

- NOAA ($200,00 per year for 10 years) - Experimental Design, Effectiveness Monitoring and Analysis plus IMW reports

- BPA ($200,000 per year for 10 years) Status and Trends Monitoring (fish-in, fish-out)
- PCSRF/BPA/USDA/etc. ($200,000 for 3 years) - Restoration and Protection Treatments

This partnership is durable and meaningful only if NOAA funding for the first set of tasks is funded. The restoration and protection treatments are highly likely to be funded, but these actions will not take place without sources of funding being available to conduct the monitoring necessary to determine the effectiveness of treatments as per the goals of the IMW.

The Asotin Creek IMW study area includes land that is owned by two private individuals and two government agencies (WDFW and USFS) and landowner commitment and support for the Asotin Creek IMW have been positive. Data essential to the IMW's success is collected in partnership with the Washington Department of Fish and Wildlife (WDFW).

A detailed Asotin IMW experimental design, monitoring plan, and work plan was developed using a phased approach. In 2007/08, Phase 1 of the IMW was implemented which included the identification of a suitable location for an IMW in southeast Washington, development of an experimental and monitoring design, assessment of restoration goals, and initiation of fish and habitat monitoring. Phase 1 was completed January 31, 2009. Phase 2 was initiated on April 15, 2009. The goals of Phase 2 were to refine the IMW experimental design developed in Phase 1, implement and assess the logistics of the monitoring design (including ground based LiDAR, aerial photography, bathymetry, fish, riparian, and stream habitat monitoring), install automated monitoring infrastructure, such as PIT tag antenna arrays, water gauges, and temperature probes, and develop databases to store, analyze, and share the monitoring data. Phase 2 was completed February 28, 2010.

Phase 3 included the third and fourth year of pre-treatment monitoring, and was initiated on July 15, 2010. The goals of Phase 3 were to continue pre-treatment monitoring, revise the experimental and monitoring designs, and finalize a restoration design and implementation plan. This report summarizes the results of the first four years of monitoring and reports on revisions to the experimental, restoration, and monitoring designs up to December 2011. This report details the experimental and monitoring designs developed to date. Future reports will only report on any changes to these designs and focus more on results and interpretation of restoration effectiveness. A stand-alone restoration design was also completed this year (Wheaton et al. 2012) and any future revisions of the restoration plan will also be detailed in brief updates. A summary of the restoration plan is provided in this report in section 5.

1.2 EVOLUTION OF ASOTIN IMW DESIGNS

This report builds off of previous work to select a location for an IMW in southeast Washington, assess the limiting factors, develop experimental, monitoring, and restoration designs, and implement the overall project (Bennett and Bouwes 2009 and Bennett et al. 2010). The development and implementation of the Asotin Creek IMW has been an iterative process starting with a pilot year in 2008 where a limited number of sample sites were established to test the logistical feasibility of the preliminary experimental and monitoring designs. Since 2008, we have continued to refine the designs as we have gathered and synthesized data. The most notable change to the IMW design took place in late 2010 when a detailed power analysis was completed that compared the statistical power of several alternative experimental and sampling designs to detect fish and habitat responses to the proposed restoration. Based on the power analysis results, we decided to revise the experimental and monitoring designs. We also implemented a trial restoration project in 2011 to test the feasibility of our proposed LWD restoration. Results of the trial restoration were evaluated this year and were used to modify the restoration design.

Appendix A provides a detailed list of the most significant changes to the original IMW design. For the remainder of this report we will only report on the revised IMW design. This revised design will supersede all previous versions and will be considered the ***current Asotin IMW Design***. Further revisions of the IMW design may be generated in an adaptive management approach as we collect more data on the scale and scope of fish and habitat responses to the proposed restoration (see Wheaton et al. 2012 for a detail of the Adaptive Management approach associated with the restoration implementation).

1.3 PROBLEM STATEMENT

Prior to the initiation of the IMW study in Asotin Creek, Ecosystem Diagnosis and Treatment (EDT) analysis was used to assess limiting factors for steelhead in Asotin Creek (SRSRB 2006). Common limiting factors that were identified in Asotin Creek included elevated sedimentation, substrate embeddedness, increased water temperature, decreased floodplain connectivity, decreased habitat diversity, low LWD, and low pool frequency and quality. Many of the limiting factors identified in Asotin Creek are directly or indirectly related to ***degraded riparian function***. Historical reconstructions (McAllister 2008) and vegetation modeling (LANDFIRE 2010) both suggest that the riparian habitat along Asotin Creek and its tributaries was likely more forested than it is at present, and that the riparian forest was composed of cottonwood trees bordered by stands of ponderosa pine and Douglas-fir. Riparian function was likely degraded by a combination of harvest, grazing, road building, and development.

Once degraded or removed, restoring riparian function can potentially take many years due to the length of time it takes native vegetation to grow to maturity in previously disturbed areas (e.g., over-grazed or harvested land). Currently, young alder and water birch dominate large portions of the riparian forests in Asotin Creek, especially along Charley Creek. Alder dominated riparian habitat likely provides adequate shading, organic and terrestrial invertebrate input, and bank stability. However, the alder trees are relatively small (i.e. < 30 cm diameter), tend to decay faster than other tree species, and are transported more quickly by fluvial processes from the reach (Beechie et al. 2000).

If the current riparian forests are not contributing sufficient amounts and sizes of LWD to the stream we would expect to observe fewer LWD pieces and pools in Asotin Creek than are predicted for streams in reference conditions (i.e. natural conditions unaltered by development). The results from our habitat analyses showed that overall LWD abundance, LWD > 30 cm diameter, and deep pools were all substantially lower than in reference streams in similar watershed settings (Bennett and Bouwes 2009).

Based on previous habitat assessments and the IMW habitat sampling conducted to date, we are making an explicit assumption that historical riparian forests along the study streams had larger trees dominated by cottonwood, with stands of ponderosa pine, and Douglas-fir bordering the riparian areas. Further, the removal of these large trees, and the subsequent replacement of these trees by alder dominated forests, is likely preventing the reestablishment of historic riparian conditions. The lack of a source of LWD has led to a decrease in the overall LWD entering the streams. This in turn has contributed to the development and maintenance of simple channel structure, low pool frequency, poor substrate sorting, and limited fish cover. Flooding has exacerbated these conditions especially events in the 1960s and 1990s (ACCD 1995, NRCS 2001).

1.4 ECOSYSTEM GOALS AND OBJECTIVES

The goals of the Asotin IMW are to test the effectiveness of restoration in increasing the productivity of wild steelhead in Asotin Creek and to determine the mechanisms that lead to increased production through intensive monitoring of fish and habitat at multiple spatial and temporal scales. An increased understanding of the relationship between LWD restoration effectiveness and steelhead population response gained from this IMW will then be applied to restoration efforts in similar watershed settings. **The ecosystem goal of the restoration treatments is to increase the productivity of wild steelhead in Asotin Creek.** Note, in this report the term *productivity* is synonymous with population growth rate which usually refers to a measure of the production of a population over the entire life cycle (McElhany et al. 2000). However, we will also use the term productivity to refer more specifically to the freshwater production portion of the steelhead life cycle (e.g., smolts or juveniles per spawner) as freshwater production is most likely to be influenced by stream restoration.

Limiting factors analysis and extensive assessments indicated that riparian function was the most significant limiting factor in the IMW study area (SRSRB 2006, Bennett and Bouwes 2009). The limiting factors analysis also indicated that there are less LWD and pools than were likely present during pre-European times. Due to these limiting factors the proposed restoration actions are to restore riparian function in the long-term and add large woody debris (LWD) in the short-term. The specific objectives of these treatments are to:

- Through grazing exclosure fencing and riparian planting, promote the passive recovery of the riparian corridor to encourage improvement in fish habitat, increase LWD recruitment and facilitation of fluvial processes with more regular lateral exchanges between the channel and riparian, and
- Through the addition of LWD and debris catching structures (i.e., dynamic woody post structures installed as veins) increase pool habitat, habitat complexity, sediment sorting, the production of dynamic bars and increase lateral exchange through fluvial processes with riparian habitat.

Riparian fencing and planting are expected to at least take several decades to have a significant effect on stream processes; therefore, the addition of LWD will be used to restore stream habitat complexity in the short-term. A separate riparian restoration plan will be developed at the end of the LWD treatment phase. We are waiting until the end of the LWD treatment phase to develop the riparian restoration plan because we are testing the effectiveness of LWD treatments not riparian restoration.

1.5 ADAPTIVE MANAGEMENT APPROACH

Adaptive management (Holling 1978) is frequently touted as an important part of the restoration process, but it is very rarely fully integrated into the restoration plan (Walters 1997). Adaptive management is an iterative process of learning by doing, which explicitly incorporates monitoring into the restoration process and provides opportunities for the information gleaned from the assessment and evaluation of monitoring activities to be explicitly incorporated into refining restoration actions to learn from. We have developed a detailed adaptive management process for the Asotin IMW, which consists of a series of adaptive management learning loops that will be revisited at least nine times over the next decade. The loops will provide continued opportunities to adapt the assessment of the limiting factors, restoration goals, conceptual models, and monitoring and restoration designs. The adaptive management approach is also outlined in the Restoration Plan, including steps to incorporate lessons learned from the restoration activities (Figure 1; Wheaton et al. 2012).

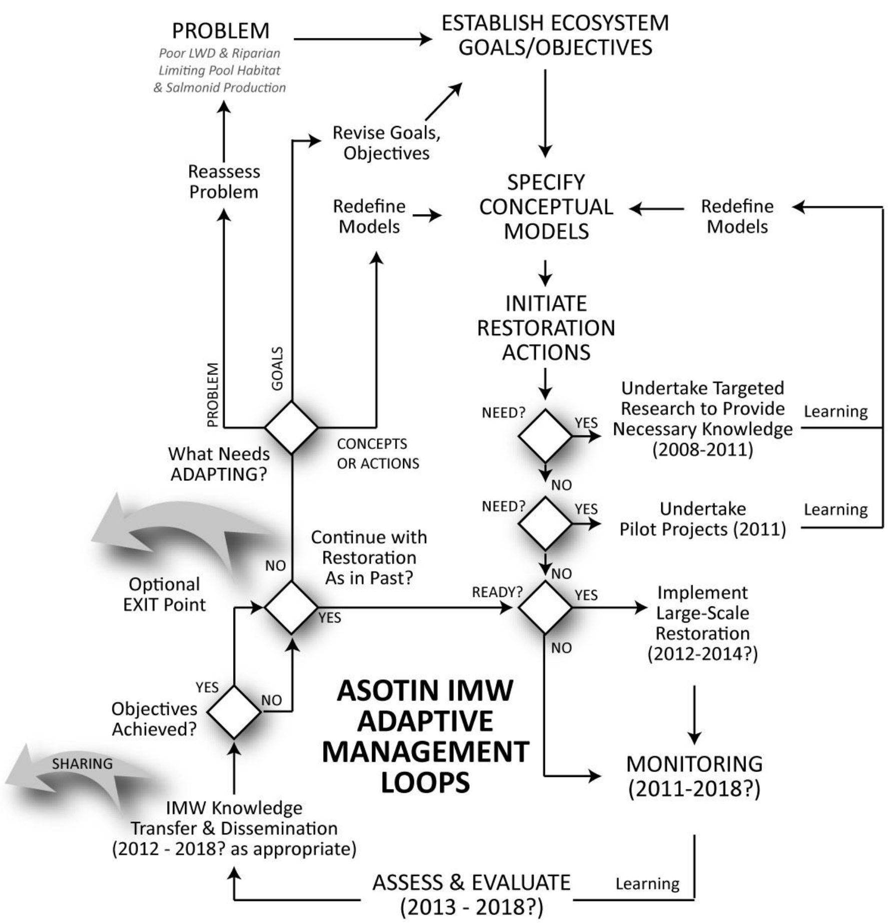


Figure 1. Asotin IMW Adaptive Management Aspects of Restoration Plan. Figure adapted from Kondolf (2000).

1.6 REPORT OUTLINE

This report summarizes the Asotin Creek IMW and changes made to the experimental, monitoring, and restoration designs. Justification for the goals and objectives of the IMW are detailed in the original IMW plan (Bennett and Bouwes 2009) and are only briefly reviewed in this report. Section 2 details the watershed setting with an emphasis on the hydrological and geomorphic setting of the Asotin watershed with specific reference to Charley Creek, North Fork Asotin Creek, and South Fork Asotin Creek (hereafter referred to as the “study streams” collectively and Charley Creek, North Fork, and South Fork individually). Section 3 briefly reviews the past habitat assessments and the IMW habitat assessment findings and outline both the current condition and potential future condition once the IMW restoration is complete. Section 4 details the revised experimental design, power analysis, and statistical issues relevant to the implementation and evaluation of the restoration responses. Section 5 summarizes the restoration design and implementation schedule. Due to the complexity of the project, we have created a stand-alone experimental design document that is also available for review (Wheaton et al. 2012). Section 6 reviews all the monitoring methods we are using to detect fish and habitat responses to the restoration action, the analyses that will be used to interpret the data collected, and schedule at which the data will be collected. Section 7 summarizes the results of all the monitoring efforts from 2008-2011. These results include a summary of the ongoing WDFW smolt trapping, adult weir, and redd counts that are collected under a separate project but are essential for the success of the IMW. Finally, Section 8 provides a discussion of the pre-treatment results and schedule for future monitoring and implementation of the restoration.

2 WATERSHED SETTING

2.1 STUDY AREA

Asotin Creek is a tributary of the Snake River, flowing through the town of Asotin, in southeast Washington (Figure 2). The area is semi-arid, with rainfall ranging from 115 cm at higher elevations (1800 m) to less than 30 cm at lower elevations (240 m). The most common land use is pasture/rangeland (43%), followed by forestland (30%), and cropland (27%; ACCD 2004). The Asotin Creek watershed is approximately 842 km^2 and is within the Columbia Plateau and Blue Mountains level III ecoregions. These ecoregions are dominated by deep narrow canyons cut into underlying basalt lithology and surrounded by semi-arid sagebrush steppe and grasslands at lower elevations and open conifer dominated forests at higher elevations (Omernik 1987, Clarke 1995, Omernik 1995).

The Asotin IMW plan identified three tributaries of Asotin Creek as candidates for implementation of the IMW: Charley Creek, North Fork, and South Fork. The study streams occupy the western half of the watershed and drain the headwaters of the Asotin Creek Watershed. Charley Creek is a left bank tributary to the mainstem Asotin Creek and its confluence is approximately 2 km downstream of the confluence of the South Fork and North Fork.

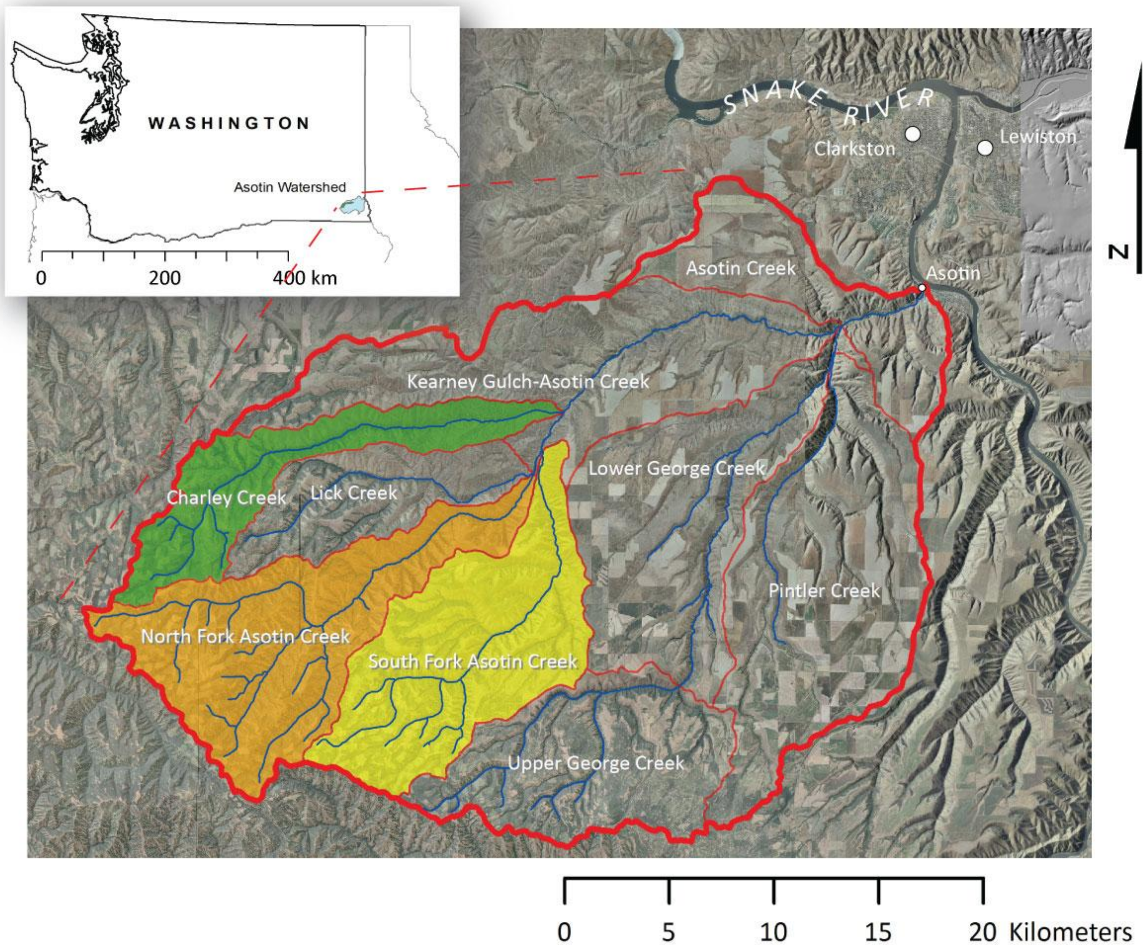


Figure 2. Location of Asotin Creek within Washington and the approximate location of the study stream watersheds within the Asotin Creek Watershed. Charley Creek is shown in green, North Fork Asotin Creek is in orange, and South Fork Asotin Creek is in yellow.

2.2 LANDOWNERSHIP

The focus of the Asotin IMW is within the lower 12 km of the three study streams. The WDFW and USFS own the majority of the land bordering North Fork and South Fork while Charley Creek landownership was predominately private in the lower 8 km with WDFW and USFS owning most of the upper watershed. However, one of the private landowners has recently sold some of their property bordering Charley Creek to WDFW and the other landowner has agreed to put their land bordering the stream into the Conservation Reserve Program (CRP). So despite a disruption in access to Charley Creek in late 2010 and 2011 we expect to have full access to the three study streams for the remainder of the IMW.

2.3 FISH SPECIES

Three species currently listed as threatened under the Endangered Species Act (ESA) are present in Asotin Creek: bull trout (*Salvelinus confluentus*), spring Chinook salmon (*O. thshawytcha*), and summer steelhead (ACCD 1995, Mayer et al. 2008, Crawford et al. 2012). Spring Chinook salmon are listed as extirpated, though small numbers of adults are spawning every year (Crawford et al. 2012). Recent genetic analysis suggests that the majority of Chinook entering Asotin Creek are of Tucannon River origin. Fall Chinook salmon are presumed to not have occurred in Asotin Creek. Bull trout spawning and rearing is mostly limited to the upper watershed. However, small numbers of adult bull trout use the lower reaches of Asotin Creek and its tributaries, and migrate between the Snake River and Asotin Creek. Some adult bull trout may even migrate into Asotin Creek to overwinter from other streams outside Asotin Creek.

Summer steelhead were selected as the ***target species*** for this IMW study by the local Snake River Regional Technical Team (RTT). Asotin steelhead are summer “A” run fish that generally migrate up the Columbia River and past Bonneville Dam before August 25 (ACCD 2004). Asotin Creek steelhead are part of the Snake River Evolutionary Significant Unit (ESU) based on genetic characteristics that distinguish the Snake River steelhead from other Columbia River Basin steelhead (ACCD 2004, SRSRB 2006). The Asotin Creek steelhead are further grouped into the Lower Snake Mainstem Tributaries Major Population Grouping (MPG) which includes the Tucannon River and nine small tributaries that flow directly into the Lower Snake River (SRSRB 2006). Asotin Creek and the following six tributaries are considered a ***subpopulation*** of the Lower Snake River MPG: Almota, Alpowa, Couse, Steptoe, Tenmile, and Wawawai Creeks. The Asotin Creek steelhead subpopulation is further divided into major spawning aggregations (MSA) and minor spawning aggregations (mSA) based on the intrinsic viability of spawning populations which is primarily determined based on the geographic complexity of spawning distributions and the number of discrete spawning populations within a watershed (ICTRT 2004). The Asotin Creek Watershed and Alpowa are considered MSAs because they are thought to have been able to support at least 500 spawners historically. All other tributaries within the Asotin Creek subpopulation of steelhead are considered mSAs, which indicates they historically supported between 50-500 spawners.

An average of 658 adult steelhead were estimated to return to spawn upstream of the WDFW adult weir trap on the mainstem of Asotin Creek between 2005-2011 (range 284-1411; Crawford et al. 2012). Adults begin to enter Asotin Creek in late fall to early December and peak spawning takes place in April and May. Asotin Creek was designated by WDFW as a natural production steelhead reserve after the discontinuation of a hatchery stocking program in 1987 (ACCD 2004). No marked hatchery steelhead are passed above the WDFW adult weir which is typically operated on the Asotin Creek mainstem 4-5 km upstream of the confluence with the Snake River. A detailed study of the steelhead run began in 2004. A 5 m rotary screw trap (smolt trap) is operated in the spring and fall to assess juvenile outmigration and an adult weir is operated from January to June to enumerate returning spawners (Mayer et al. 2008; See 6.3.1 for more details on this assessment program).

There are 16 other species of fish thought to occur within the Asotin Creek watershed (Table 1, ACCD 2004). Most of these species occur in the lower portion of the Asotin Creek watershed and 25% are non-native species. Lamprey are a species of concern in the State of Washington and current efforts are underway to reintroduce them to Asotin Creek.

Table 1. Indigenous and introduced fish species present in Asotin Creek Watershed and their approximate distribution.

Common Name	Genus Species	Indigenous	Distribution*
Bridgelip sucker	*Catostomas columbianus*	Yes	WS
Bull trout	*Salvelinus confluentus*	Yes	UW
Chinook salmon	*Oncorhynchus tshawytscha*	Yes	E
Largescale sucker	*Catostomas macrocheilus*	Yes	UNK
Longnose dace	*Rhinichthys cataractae*	Yes	UNK
Mountain whitefish	*Prosopium williamsoni*	Yes	UNK
Northern pikeminnow	*Ptychocheilus oregonensis*	Yes	UNK
Pacific lamprey	*Lampetra tridentata*	Yes	UNK
Paiute sculpin	*Cottus beldingi*	Yes	WS
Peamouth	*Mylocheilus caurinus*	Yes	NM
River lamprey	*Lampetra ayresi*	Yes	UNK
Speckled dace	*Rhinichthys osculus*	Yes	LW
Steelhead trout	*Oncorhynchus mykiss*	Yes	WS
Chiselmouth	*Acrocheilus alutaceus*	Yes	NM
Redside shiner	*Richardsonius balteatus*	Yes	UNK
Bluegill	*Lepomis macrochirus*	No	NM
Carp	*Cyprinus carpio*	No	LW
Channel catfish	*Ictaluris punctatus*	No	UNK
Crappie	*Pomoxis spp.*	No	NM
Smallmouth bass	*Micropterus dolomieui*	No	UNK

* E = extirpated, LW = lower watershed, NM = near mouth of major drainages, UNK = unknown, UW = upper watershed, WS = wide spread (Adapted from ACCD 2004).

2.4 GEOLOGY AND SOILS

The Asotin Creek watershed typifies many of the tributaries to the Snake River in southeast Washington and northeast Oregon in terms of its basic physiographic setting. Three broad geologic attributes set the character of the watershed: 1) the underlying basaltic lava flow bedrock (part of the Columbia River Basalt Group) that forms the broad plateau surfaces and uplands; 2) the Snake River Gorge, which sets the base-level control for tributaries like Asotin Creek, which 3) have dissected the Basalt flows with a network of streams draining to the Snake that have carved steep canyons, the larger of which have filled small valley bottoms with alluvium. The Columbia River Basalt Group (CRBG) is a thick sequence of flood basalts that spread throughout northern Oregon, eastern Washington and western Idaho during the Miocene between 6 and 17 million years ago. During the Pliocene (5.4 to 2.4 million years ago) these CRBG flows were uplifted, allowing the streams to form steep-sided canyon walls and hillslopes and formation of high plateaus (Gentry 1991). Many of these high plateaus are mantled by loess (wind-blown sediment) deposits. The Snake River Canyon, at the mouth of Asotin Creek, was subjected to the cataclysmic Bonneville flood some 14,000 to 15,000 years ago, associated with the rapid lowering of Lake Bonneville. Deposits from the Bonneville flood are overlaid by glaciofluvial deposits associated with outwash floods from Glacial Lake Missoula.

Figure 3 shows a generalized geology of the Asotin Watershed, with the Mv (Middle Miocene Andesites) making up the entirety of the Charley Creek and North Fork watersheds, and most of the South Fork watershed. The area has been mapped at a finer 1:100,000 scale by Schuster (1993), who shows that the Mv andesite shown in Figure 3 is indeed part of the CRBG and is comprised of several basalt/andesite flows ranging in age from 14.5 to 15.6 million years ago that make up three members of the Wanapum Basalt Formation. Two flows from the oldest member, the Eckler Mountain Member (Mv_{wem}), sliced across what is now the headwaters in a southeasterly direction. This was later overlaid by a much more expansive flow that comprises the Roza Member (Mv_{wr}) and covers the majority of the basin, and was later overlain in what is now the lower part of the basin by flows of the Priest Rapids Member (Mv_{wpr}). Most of these flows averaged 30-50 meters in thickness. What is mapped in Figure 3 as Qce (Pleistocene loesses) is underlain by the same flows, and represents the uplifted high plateaus that were mantled by much more recent fine grain loess deposits, which have supported the cultivation of cereal grains and other crops in the headwaters of portions of the South Fork watershed and much of George Creek watershed.

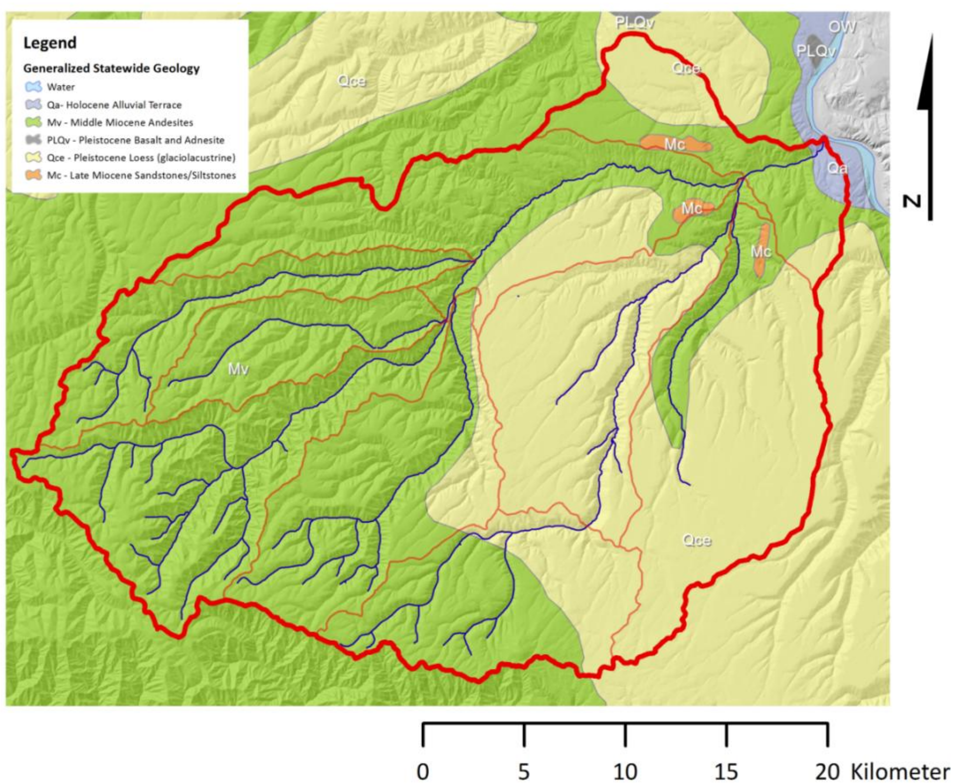


Figure 3. Generalized statewide Geology shown for Asotin Creek Watershed.

The geology of the Asotin Watershed summarized above is critical in constraining the character of streams that can exist in this basin and the range of habitats for salmonids they might support. Although the basaltic lithology is relatively porous rock, which is typically permeable and supports good aquifers, rates of runoff can be high. In Charley Creek for example, this aquifer supports numerous springs, which help maintain baseflows. The weathering of these rocks produces sediment that not only makes up the streambed, but also is the parent material for soil development. The development and distribution of soils is obviously a critical ingredient in supporting growth of forests in both the riparian and on the steep hillslopes of the canyons the study streams occupy. There are over 50 different kinds of soil in the watershed with a wide range in texture, depth, natural drainage, and other characteristics (Gentry 1991).

Most low elevation hillside soils do not support tree growth and are dominated by a mixture of native and cultivated rangeland grasses and forbs. The slopes that connect the upland plateaus and canyon/valley bottoms are steep (30-90 %) with numerous rock outcrops and cliffs. Upslope soils are typically shallow, coarse (very gravelly, cobbled, or stony), and well-drained, with north facing slopes having deeper soils and generally supporting stronger forests. Most upland soils mantling the plateaus are silt and clay loams formed from loess, colluvium, and slope alluvium erosion. All upslope soils are very susceptible to erosion (SCS 1984). Excessive erosion from upland farming is presumed to have been reduced in recent years due to the implementation of the Model Watershed Plan and associated restoration activities (ACCD 1995).

Aside from those fine grained soils formed in loess, the soils in the watershed are generally formed in colluvium (i.e., from sediment on hillslopes) derived from basalt parent material (Gentry 1991). The distribution of soil types is strongly aspect controlled. South-facing slopes in all three study streams are dominated by Gwinly-Mallory rock outcrop complexes comprising the staircase of cliffs leading up to the plateaus above, and Gwinly-Mallory very stony silt loams, making up the colluvial talus slopes below. The Gwinly and Malroy series soils both consist of well drained soils on canyon walls and shoulder slopes, with Gwinly soils being shallow and Malroy soils being moderately deep. By contrast, many of the north facing slopes are dominated by the Snell-Harlow DeMasters Complex and the north facing canyon walls by the Snell-Harlow rock outcrop complex.

Valley bottoms are dominated by soils formed in alluvium and occur on the floodplains bordering streams. There are only three soil types that are present along the study streams. In contrast to the soils that make up the hillslopes and canyon walls, the water erosion hazard of these soils is slight. Over 95% of the soils making up the riparian corridors of the South and North Forks are of the Bridgewater association, as are 70% of those in Charley Creek. The remaining soils in the riparian corridors are primarily of the Veazie-Veazie variant complex. All of these soils are capable of supporting various mixes of coniferous and hardwood riparian and upslope forests. The headwaters of these creeks are predominantly grand fir, subalpine-fir, and Douglas fir forests. Although the hillslopes throughout the lower portions of the study streams are largely devoid of tall trees, the valley bottoms likely supported forest corridor extending down and out of the headwaters, which would have been capable of supplying ample quantities of large woody debris to the channel. Douglas fir and ponderosa pine occur along the lower portions of study streams as single trees or in small stands usually on elevated terraces.

From an instream habitat perspective, the additional significance of the soils is that these have dictated both land-use and the fine fraction of sediment supply to the channel. Other than the loess mantled plateaus, which are used for arable agriculture and are generally confined to George Creek, the poor soils in Asotin Creek and steep canyons have meant that the land was poorly suited for arable agriculture and the primary land uses have been cattle grazing and logging in the headwaters. Despite the harsh, rugged setting defined by the basaltic geology and semi-arid climate, the riparian corridor along these streams would have been well shaded, full of a diversity of age and species of trees well suited for salmonids.

2.5 HYDROLOGY

The hydrology of the Asotin Creek watershed is strongly controlled by the semi-arid climate and geology described above. Mean annual precipitation in the watershed ranges from 53 cm per year in the eastern portion of the watershed, to 76 cm in the North Fork (Table 2). The majority of this precipitation takes place in the winter months as snow in higher elevations. However, the biggest floods are associated with either rain-on-snow events or highly localized, high intensity convective summer thunderstorms that may form over a small portion of the watershed, but produce a major flood downstream. These types of intense but relatively infrequent disturbance events are typical across the range of salmon and steelhead and can limit local survival for several years (Beechie et al. 2003, Waples et al. 2008). Although the rock and soils are well drained, the soils and rock-outcrops are susceptible to extremely high rates of runoff during such events via Hortonian overland flow (i.e. where rainfall rate exceeds infiltration rate).

Table 2. Basic watershed characteristics as summarized by the USGS Stream Stats tool for the three study stream watersheds, the Asotin watershed, and in contrast to the George Creek subwatershed in the eastern half of the Asotin Watershed (http://water.usgs.gov/osw/streamstats/index.html).

Parameter	Charley	North Fork	South Fork	Asotin	George
Basin Area- square km	5,835	16,490	10,383	84,083	33,151
Mean Basin Elevation in m	1,216	1,305	1,234	1,021	960
Min Basin Elevation in m	521	561	564	228	287
Max Basin Elevation in m	1,701	1,890	1,823	1,890	1,667
Max – Min elevation, in m	1,180	1,329	1,259	1,664	1,381
Mean basin slope in percent	34	40	29	24	15
% area slope > 30 percent	57	68	43	36	19
% area slope >30 percent and facing North	17	18	12	10	4
% area covered by forest	39	44	30	21	14
Mean annual precipitation, in cm	67	76	70	58	53

Streamflow is monitored by the United States Geological Service (USGS), Washington Department of Ecology (DOE), and SRSRB (Figure 4). The earliest discharge records and the longest continual monitoring were collected at Headgate dam on the mainstem Asotin Creek from 1928-1959. The next longest record of discharge is from a USGS gauge at Kearny Gulch on the mainstem upstream from Headgate Dam (1960-1995). Both of these mainstem gauges are no longer active. Active monitoring of discharge on the mainstem Asotin is now done at the mouth (USGS; not real time), just upstream of George Creek (DOE), and just downstream of the confluence of North Fork and South Fork (USGS; Figure 5). There is also a gauge on George Creek (DOE). On average, Asotin Creek has a typical snow melt dominated flow pattern with the peak runoff usually happening in late May (Figure 5).

Water level loggers were installed as part of the IMW infrastructure to gauge stream flows in Charley Creek and South Fork in 2009 and the mainstem Asotin Creek and North Fork in 2011 (Figure 4). The water level loggers measure water height every 2 hours and these measurements are combined with periodic field discharge measurements (usually 2-3 times a month) to develop stage discharge relationship for each logger site. A stage height relationship has been developed for the Charley and

South Fork stream gauges (Figure 6). Stage height relationships have not yet been developed for the water level gauges on the mainstem Asotin and at mouth of the North Fork.

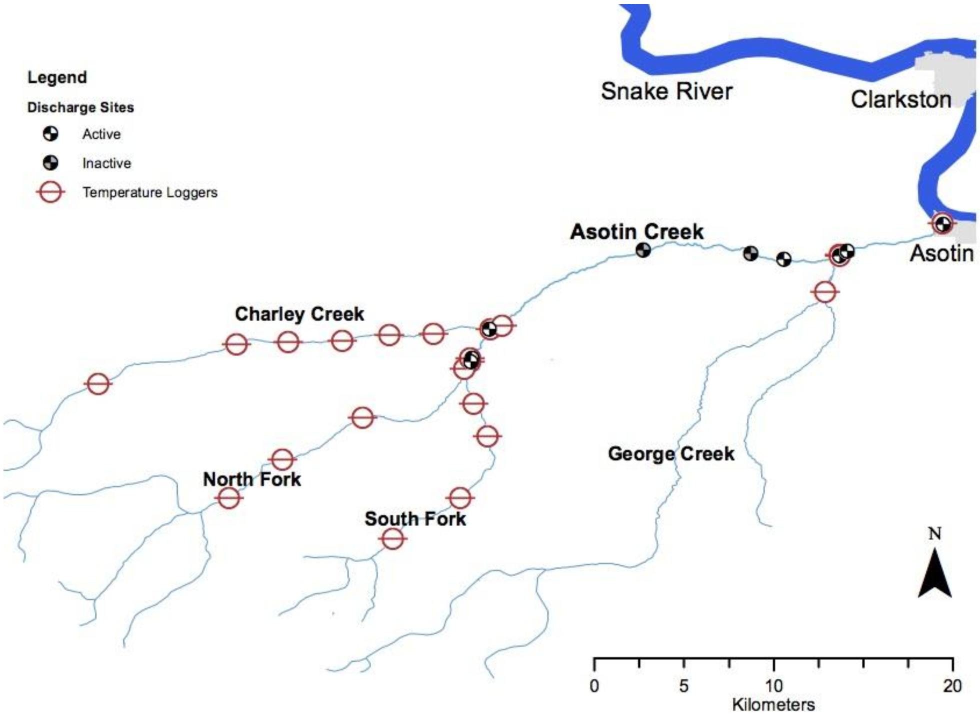


Figure 4. Location of stream temperature and discharge gauging stations (active and inactive) within the Asotin Watershed.

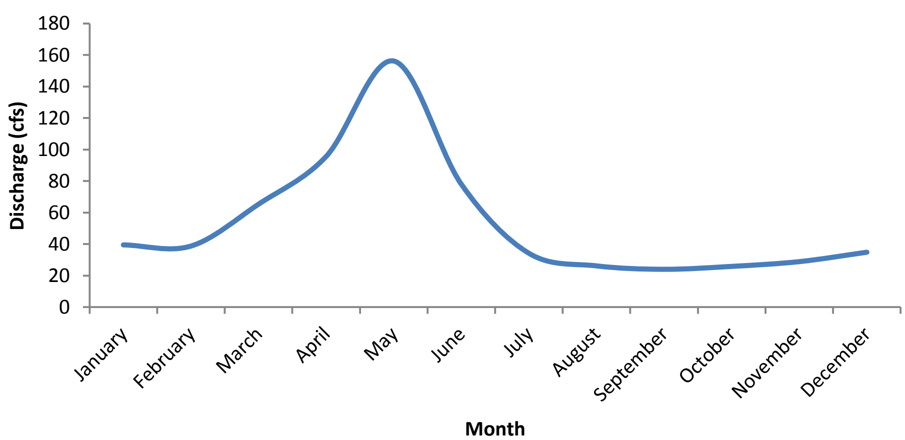


Figure 5. Average monthly discharge over the last 9 years (2001-2009) as measured at USGS gauge #13334450 approximately 200 m downstream from the confluence of North Fork and South Fork.

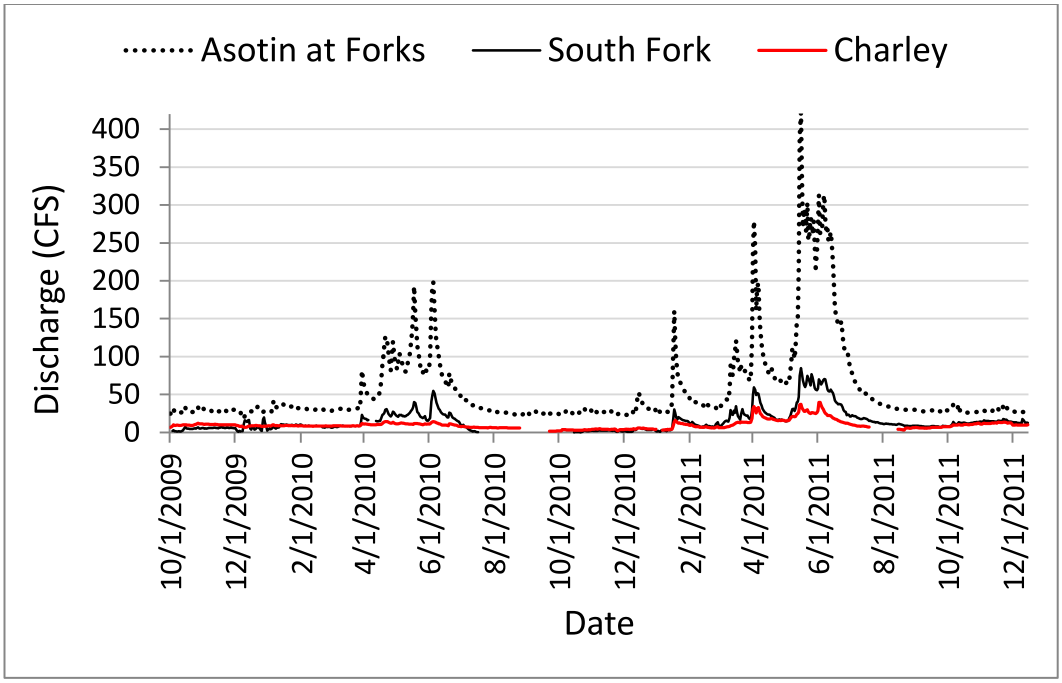


Figure 6. Average daily discharge of Charley and South Fork as measured with recently installed water level gauges compared to the discharge of Asotin Creek at the Forks USGS gauge #13334450.

The mean annual discharge of Asotin Creek is approximately 78 cfs (as interpreted from several mainstem gauge data sets). The North Fork's mean annual discharge is approximately 40 cfs (calculated by subtracting estimated South Fork discharge from the USGS gauge at the Forks), South Fork is 15.1 cfs, and Charley is 9.9 cfs (based on only 2 years of continuous discharge monitoring). The North Fork and South Fork discharges track each other closely based on a relatively predictable pattern of snow melt in the spring whereas the discharge from Charley Creek is dominated by spring-fed flows that give it a more consistent base flow (Figure 6). Although the South Fork is a larger stream and has a larger basin area, during the summer months Charley Creek can have greater flows than the South Fork due to the more consistent spring-fed dominated flows (Figure 6).

As long-term records only exist for the USGS gauges downstream on the mainstem of Asotin Creek, it is difficult to produce reliable estimates of flood flow frequency for the study streams. In the absence of a flow record of adequate duration, tools like the USGS Stream Stats application can be used to crudely estimate the magnitude of various return interval flows using regional regressions based on drainage area and watershed characteristics (Table 3). The absolute predictions from the Stream Stats analyses should be treated with some skepticism, but the relative differences between the subwatersheds are helpful for highlighting the relative differences between potential peak flows.

Table 3. Predicted flows based on gauge data and basin characteristics for the main basins within Asotin Creek watershed based on USGS Stream Stats tool (values = cfs).

Return Interval (Year)	Charley	George	North Fork	South Fork	Asotin
PK2	292	704	674	448	1490
PK10	866	2070	1740	1250	3880
PK25	1280	3050	2460	1810	5460
PK50	1660	3900	3100	2310	6820
PK100	2080	4860	3790	2870	8320
PK500	3300	7570	5730	4450	12400

Although intense summer thunderstorms and rain-on-snow events are relatively rare events, they are very significant geomorphically. The restoration project should be designed not just for the regular floods (e.g., 1.5 to 2 year return interval), but also for these major floods which have been shown to completely reshape the channel and riparian environments. The largest flow on record in the Asotin Creek was estimated at 5,050 cfs during the winter of 1996-97 resulting from a rain-on-snow event. Although the flood was documented at reducing the amount of riparian vegetation and pools along large sections of the mainstem (NRCS 2001), these floods present major opportunities to work with fluvial processes to reshape a more dynamic stream channel. A flood the size of the 1996-97 flood has a predicted return interval of approximately 25 years based on the USGS Stream Stats tool (Table 3).

Since there are no stream gauges on Asotin Creek with a long-term flow, we calculated an exceedence probability curve using a combination of annual peak flows from two gauge stations (one active and one inactive) with a combined flow record of 52 years (Figure 7). The exceedence curve predicts there is at least a 15% probability of flows exceeding 1000 cfs on the mainstem of Asotin Creek in any one year (Figure 7).

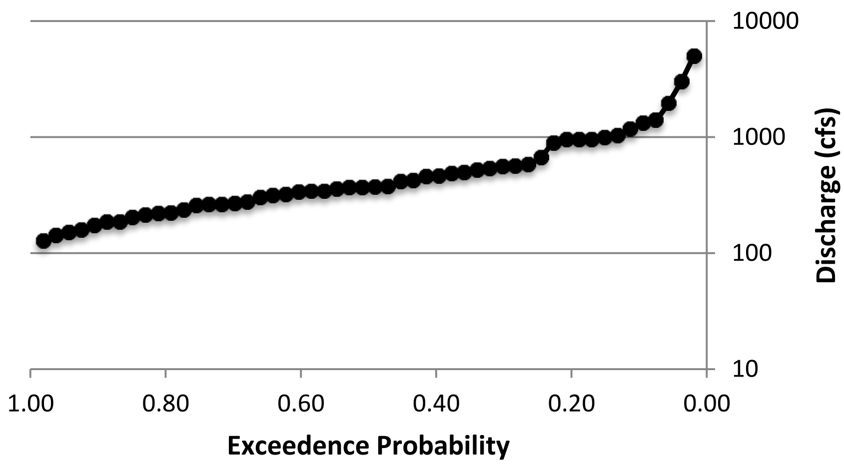


Figure 7. Log Pearson exceedence probability curve based on 52 years of combined peak discharge data from USGS flow gauges 13335050 and 13334500 on Asotin Creek.

2.6 STREAM MORPHOLOGY

We used existing PacFish/Infish Biological Opinion (PIBO) data sets to describe the study streams. Two years of PIBO data (Heitke et al. 2010) were summarized to compare the condition of each study stream. The study streams are small to medium sized with relatively simple channel form and have low sinuosity and bankfull widths that range from 5.1 – 9.3 m (Table 4). The study streams have coarse substrates dominated by cobble. Charley Creek has the finest sediments of the three study streams and the smallest average substrate size. All of the study streams have low frequencies of LWD and pools and, where pools are present, have a low average residual pool depth of < 0.4 m.

Table 4. Summary of stream characteristics for Charley Creek, North Fork, and South Fork in the Asotin Creek IMW project*.

Stream	Sinuosity	Gradient *(%)*	d50 *(mm)*	% fines <2 mm	% fines <6 mm	BFW *(m)*	W:D	Pools/ 100 m	RPD *(m)*	LWD/ 100 m
Charley	1.24	2.7	49.8	6.2	8.9	5.1	16.9	4.3	0.25	20.9
North Fork	1.29	1.9	96.1	2.1	2.9	9.3	21.2	2.3	0.38	13.7
South Fork	1.29	2.7	63.7	2.1	3.0	6.1	18.0	3.1	0.24	14.7

* All data summarized from sampling at 1-2 sites habitat sites per fish site using PIBO habitat protocol in 2008 and 2009 (Heitke et al. 2010) and CHaMP protocol in 2010 and 2011 (Bouwes et al. 2011). Grad = % slope; d50 based on Wolman pebble counts; % fines = pool tail fines; BFW = bankfull width; W:D = width to depth ratio; Pool Freq = number of pools/100 m; RPD= average residual pool depth; LWD Freq = number of large woody debris pieces >= 1.0 m long and >= 0.1 m in diameter/ 100 m. See Section 6 & 7 for more stream habitat monitoring methods and results.

The lower reaches of the study streams have a steep gradient and flow through narrow, u-shaped valleys with very steep side hills. The USDA Natural Resources Conservation Service (NRCS 2001) used the Rosgen (1996) stream classification approach to assess Asotin Creek and classify the common channel types in the study streams as Rosgen "G and B" (Charley and South Fork) and Rosgen "C" (North Fork). We used a provisional GIS layer developed for the entire Columbia Basin that predicts the historical channel pattern of mountain streams to classify the study streams and estimate potential reach breaks (Beechie and Imaki *in Press*). The Beechie and Imaki classification roughly captures the reach level floodplain dynamics of the study streams and provides an indication of the relative amount of lateral movement of the channel and age of floodplain surfaces. The primary geomorphological processes acting at the reach scale to produce lateral migration are erosion and deposition of sediment. This classification scheme uses common accepted terms to describe channel pattern but the GIS data layer developed by Beechie and Imaki (*In* Press) is provisional. However, we are using these data to roughly assess the reach types in the study streams prior to completion of our own more detailed description of reach types based on field data collection, extensive GIS resources (e.g., LiDAR and aerial imagery), and development of a biophysical framework (see Section 6.1).

Streams that are less than 8 m bankfull width are classified using the Montgomery and Buffington (1997) channel classification and streams with > 8 m bankfull width are classified using selected terms from the literature (Beechie et al. 2006). The dominant channel morphologies range from plane-bed to step-pool in Charley Creek and South Fork to straight and island braided in the North Fork (Figure 8 and Table 5).

Table 5. Definition of channel patterns as described by Montgomery and Buffington (1997) for streams less than 8 m bankfull width (BFW) and Beechie et al. (2006) for streams > 8 m BFW.

Channel Pattern	BFW Category	Definition
Cascade	< 8	Primarily single thread confined channel, dominated by boulder substrate, and fluvial, hillslope, and debris flow sediment sources
Plane bed	< 8	Primarily single thread variable channel, dominated by gravel and cobble substrate, and fluvial, bank failure, and debris flow sediment sources
Pool riffle	< 8	Multiple thread, unconfined channel, dominated by gravel substrate, and fluvial and bank failure sediment sources
Step pool	< 8	Primarily single thread confined channel, dominated by cobble and boulder substrate, and fluvial, bank failure, and debris flow sediment sources
Straight	> 8	Primarily single thread channel, sinuosity < 1.5
Meandering	> 8	Primarily single thread channel, sinuosity > 1.5
Island-braided	> 8	Multiple channels, mainly separated by vegetated islands
Braided	> 8	Multiple channels, mainly separated by unvegetated gravel bars

* confined channels = floodplain width to channel width ratio < 4; unconfined channels = floodplain width to channel width ratio > 4 (Beechie et al. 2006).

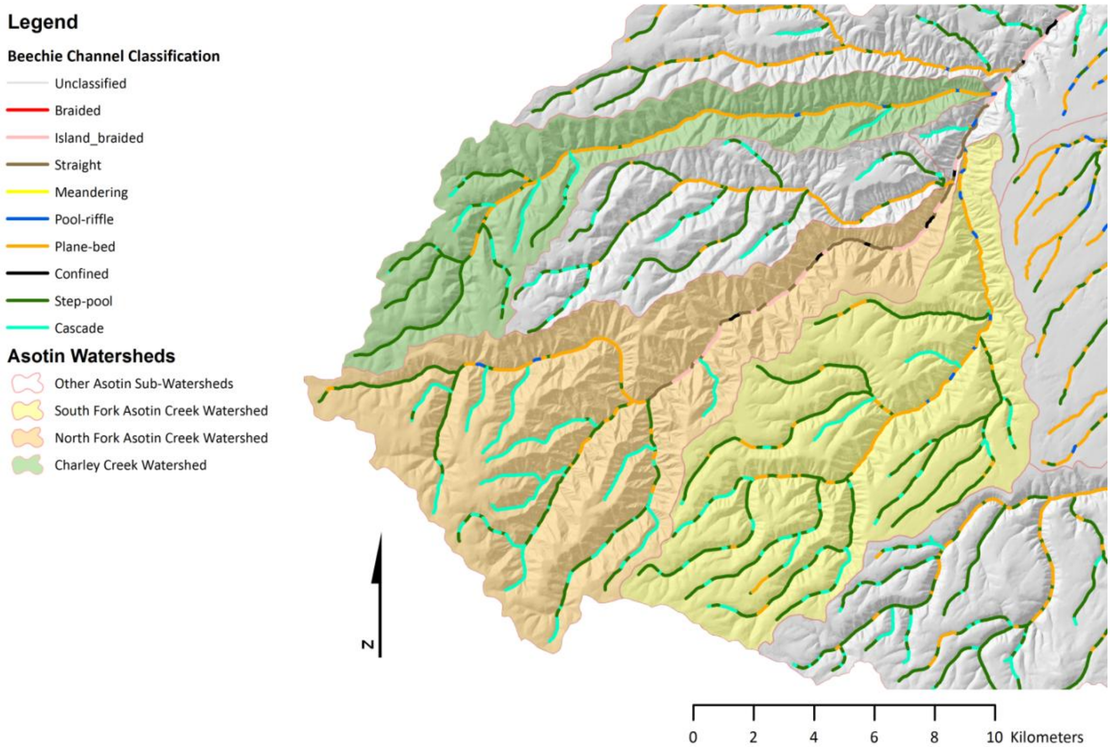


Figure 8. Assumed historic stream channel types in the Asotin Creek Intensively Monitored Watershed project area as classified by Beechie and Imaki (In Press).

2.7 HISTORICAL STREAM ASSESSMENTS

In 1995, a model watershed plan was developed for Asotin Creek by a landowner steering committee with support from state agencies and funding from BPA (ACCD 1995). The plan was one of the first attempts in Washington State to develop a watershed scale project to restore stream function and salmonid populations. The plan highlighted four key issues in the watershed: i) high stream temperature, ii) lack of resting and rearing pools containing large woody debris (LWD), iii) sediment deposition in spawning gravels, and iv) high fecal coliform counts. Since 1996, 581 fish habitat related projects have been implemented in the Asotin Creek watershed with the majority of projects focused on upland (60%) and riparian restoration (23.9%). Most of these projects were implemented in George Creek and its tributaries and in upper Asotin Creek between Headgate dam and the confluence of North Fork and South Fork. There was not an effectiveness monitoring plan established to assess these restoration activities; however, there was a reassessment of the condition of the stream habitat and riparian areas (retrospective analysis) and some focused fish surveys and temperature monitoring.

NRCS completed assessments of approximately 32 km prior to the implementation of the ACCD Model Watershed Plan and post restoration in 1993 and 2000 respectively. The assessment was conducted on the majority of mainstem Asotin Creek and the lower reaches of Charley Creek, North Fork, and South Fork. During the assessment period a large flood occurred in late 1996 and early 1997 that had a significant influence on stream channels in the Asotin watershed (NRCS 2001). The NRCS found that Asotin Creek and its tributaries had in general, become less braided, had a lower width to depth ratio, similar sinuosity, increased floodplain attachment, and decreased particle size and embeddedness. It was speculated that implementation of the plan resulted in reductions of sediment from upland sources, stabilization of stream banks, and increased habitat complexity (NRCS 2001). However, riparian function, channel, and bank conditions are still impaired in many areas, especially the lower reaches of Charley Creek on private land (NRCS 2001).

After a review of habitat changes in Asotin Creek mainstem, and the study streams between 1992 and 2001, local managers felt that more emphasis needed to be placed on adding LWD, especially conifers, to the stream instead of rock structures as natural and engineered LWD structures appeared to provide higher quality fish habitat, especially when they trapped natural debris (NRCS 2001, Bumgarner et al. 2003). It is unclear how the past projects may affect the IMW design, but based on the relatively even distribution of projects throughout the study area (ACCD 2004) and the length of time the projects have been in place (most completed prior to 2002), it is unlikely they will confound the assessment of the proposed treatments (see Wheaton et al. 2012 Restoration Design).

The majority of instream habitat structure projects involved meander reconstruction, channel reconstruction, bank stabilization, and placement of vortex log weirs and rock vanes. WDFW monitored fish populations at a number of these instream structures and control sites (with no structures) from 1999-2003 to determine their effectiveness and found higher densities of juvenile steelhead at restoration sites compared to controls sites (Bumgarner et al. 2003). These assessments were unable to relate increases in abundance of juvenile steelhead to increases in smolt production due to the limited scope of monitoring.

Riparian habitat is generally in better condition in North Fork and South Fork compared to Charley Creek because the lower North Fork and South Fork are entirely on lands managed by the WDFW and USFS, cattle grazing has been excluded, and riparian restoration planting of native species has been implemented as part of the Model Watershed Plan (ACCD 1995). Cattle grazing still continues on much of lower Charley Creek because it is mostly on private land.

3 CONCEPTUAL MODELS ARISING FROM ASSESSMENTS AND SURVEYS

There are at least two working conceptual models that arise from past assessments and our current surveys (Bennett and Bouwes 2009). One is a conceptual model of the current state of the study streams, which infers how this condition came to be, but more importantly focuses on what about the current condition is limiting geomorphic processes from sustaining better habitat conditions that could lead to increased fish production. The second is a conceptual model of how we think the system will function after the restoration treatments and explicitly articulates the attributes which will help support fish production and the physical mechanisms by which we hypothesize these conditions could be self-sustaining. We articulate both conceptual models here as they help transparently distinguish the things we know from that which we infer and create better opportunities for testing, learning, adapting treatments and refining these conceptual models through the IMW adaptive management process as the project continues (see Wheaton at l. 2012 for more detail on the Adaptive Management approach we are using).

3.1 CURRENT CONDITION

Our assessments and other regional assessments support the conclusion that there is less LWD in the stream channel of Asotin Creek and its tributaries than there was historically (ACCD 1995, NRCS 2001, ACCD 2004, SRSRB 2006, Bennett and Bouwes 2009). The lack of LWD, combined with a history of land use that has included extensive logging in the upper reaches of the study streams, over-grazing, channel straightening, and riparian degradation in the lower reaches has led to straighter, shallower, and more homogeneous channels with relatively few deep pools. A cursory inspection of riparian conditions along the study streams suggests a relatively healthy riparian corridor providing adequate cover and shading to help regulate stream temperatures. However, a closer inspection reveals that most of Charley, large stretches of the South Fork, and portions of the North Fork have a fairly stable and rather homogenous riparian age and species structure. This likely reflects a steady recovery following cessation and/or reduction in some of the previous land uses (e.g., logging, grazing) which were causing the most damage. Unfortunately, this recovery has taken place around a relatively homogenized channel and has acted to stabilize the degraded condition of the channel. There are encouraging exceptions and remnants (especially in the North Fork) of the feasibility of a more diverse age and species structure in the riparian corridor.

Our conceptual model for the current condition is that the majority of the study streams consist of homogenous instream habitat dominated by plane-bed runs and glides and characterized by a notable absence of large pools and large woody debris despite a riparian corridor that is well established and provides good cover. The current process regime supports the stability of this somewhat degraded state.

The ball and cup diagram on the left side of Figure 9 illustrates the fate of the current condition in the study streams. The system is stuck in a state of low channel complexity, whereby the system parameters are fixed and locked down by a combination of a stable riparian corridor, an armored bed, and relatively modest mean annual floods that lack the capacity to shift the system into a different state and/or to modify the system parameters. Even when rare big floods do occur, as noted by the historical discharge record of Asotin Creek, the system is quickly knocked back into its degraded condition. Despite this current condition, rapid habitat assessments of the lower 12 km of each study stream highlighted that the system is capable of promoting a higher degree of complexity. This seems largely related to the degree of hydraulic heterogeneity in flow width and flow patterns, which in turn are directly influenced by how much LWD is in this system (see Section 6.5 for a description of rapid habitat assessments).

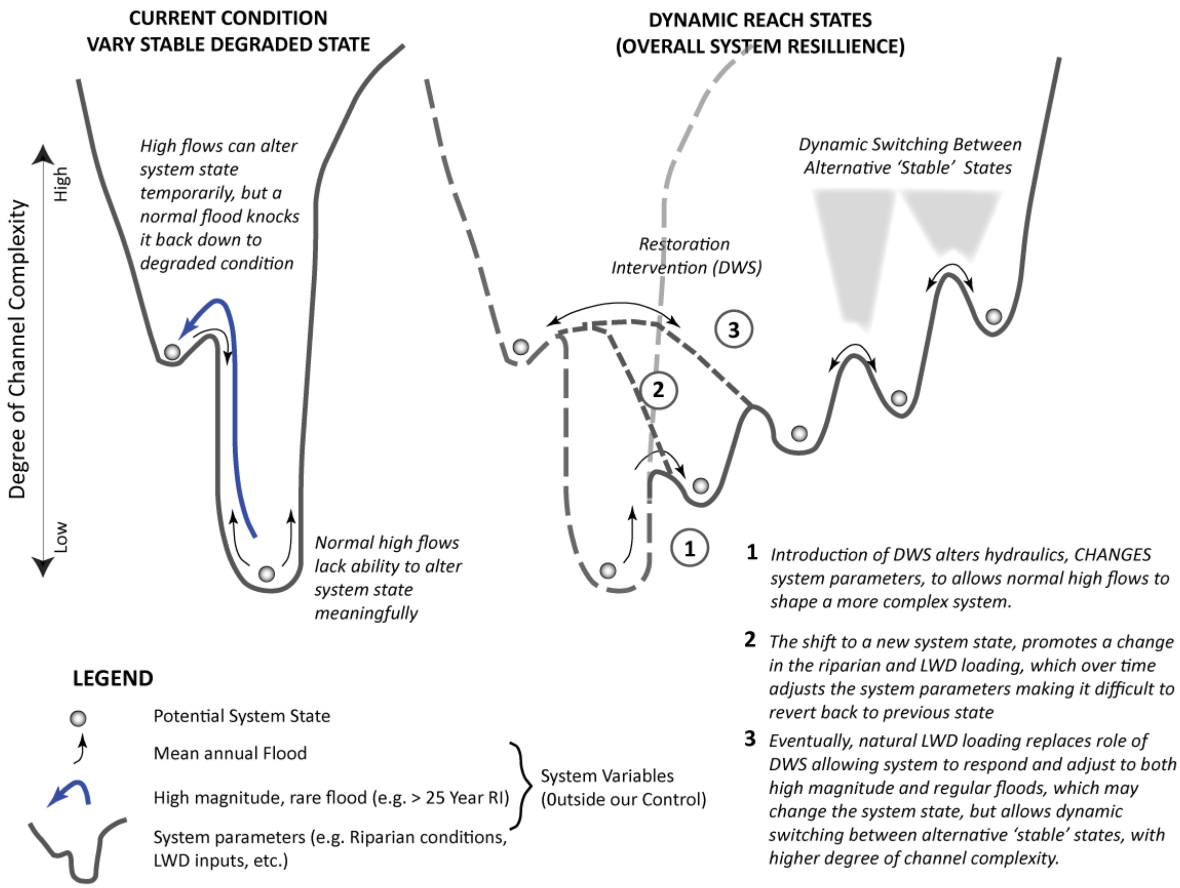


Figure 9. Conceptual model of current condition (left) and envisioned condition (right) post restoration in response to the introduction of dynamic woody structures (DWS). The system variables (e.g., hydrology) are fixed, but we can change the system parameters by increasing the loading of LWD, which we hypothesize will shift the system into a set of more complex system conditions that can dynamically switch between states.

3.2 ENVISIONED CONDITION

The vision for the treated sections of the three study streams is one of a dynamic and complex mix of habitat with a high concentration of naturally recruited LWD, active bars, small side-channels and a more regular exchange of wood, sediment, and water with adjacent riparian forests. In short, this envisioned condition is an expansion of the remnant pockets of historical conditions we found evidence for in the rapid habitat assessments over all treatment sections. Although the restoration intervention we propose to achieve this artificially increases the density of LWD in the short-term, the design is explicitly to rely on the stream's own fluvial and riparian processes to deliver LWD in the future. This design is intended to directly produce a hydraulic response, which is exacerbated at high flows and promotes fluvial processes of erosion and deposition to carve out and build more complex in-channel habitat as well as increase the exchange of materials with the riparian corridor. Figure 9 (right) illustrates the transition from active intervention to stream dynamic processes for creating desired changes. We start with the installation of dynamic woody structures (DWS), which act to change the system parameters, such that the stream can shift to a new (more complex) system state even in response to small floods (see Section 5 for more description of the restoration design). A larger flood would likely produce a more rapid and dramatic response. Through time, we hypothesize that the riparian will change such that LWD recruitment increases and density of roughness elements are maintained by natural recruitment and fluvial processes. At the local DWS scale, Figure 10 illustrates conceptually how a particular measurable metric (flow width) may be expected to change in response to the treatment. As with many metrics of potential interest, we are not necessarily looking for a shift in the mean value (difficult to detect), but rather a shift in the variability of that metric. We do not expect to see a physical response from the restoration outside of the three 4 km treatment sections (i.e., in the control sections) unless large amounts of LWD are transported from the treatment sections during high flows.

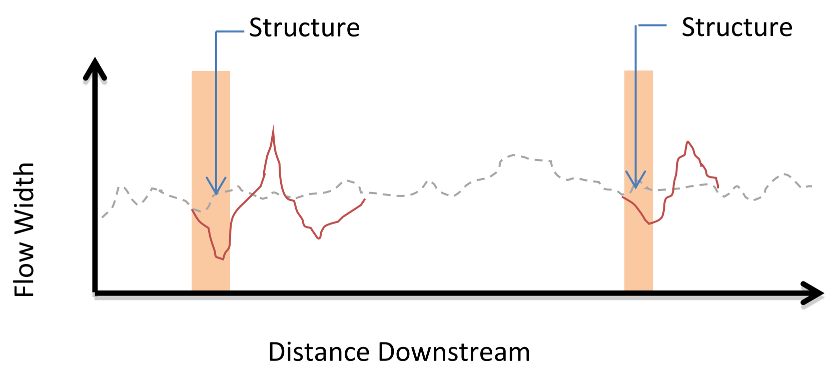


Figure 10. Conceptual diagram of the effect of LWD structures on stream width variation in the study streams. Grey dashed line represents existing stream width and the solid red line represents potential increase in stream width variation created by post structures.

4 EXPERIMENTAL DESIGN

The following section describes the need for implementing restoration within an experimental framework, reviews a set of alternative experimental designs we assessed, and proposes a set of characteristics that a powerful and robust design should have in situations where the effectiveness of restoration actions are being tested. We then report on the results of a power analysis we conducted to test the statistical power of our origin proposed experimental design compared to alternative designs. The details of our proposed design have changed since the IMW was initiated and this section reviews those changes and explicitly outlines the new design, experimental units, scope of the experiment, and potential fish response variables we will evaluate (section 4.4.2 and 4.5). For further description of the changes to the original experimental design, please refer to Appendix A.

4.1 NEED FOR LARGE-SCALE RESTORATION EXPERIMENTS

Past restoration efforts have rarely included effectiveness monitoring programs to determine if projects have increased salmon and steelhead freshwater productivity. Also, restoration efforts are often hampered by funding and political constraints (e.g., landowner cooperation and competing management objectives) and are rarely implemented over large contiguous areas with specific ecological and hydrological objectives (Katz et al. 2007, Fullerton et al. 2010). As such, despite the large expenditure on stream restoration, there is almost universal agreement for the need to better understand the linkages between restoration and fish population response which requires detailed implementation and effectiveness monitoring (Bernhardt et al. 2005, Katz et al. 2007).

Ecosystem scale experiments are a direct method for detecting a population or environmental response to management (Carpenter et al. 1995). Ecosystem scale experiments have contributed greatly to our understanding of ecological processes within watersheds, and results from many of these studies have led to changes in management strategies (Likens et al. 1970, Hartman et al. 1996). Watersheds are well suited for ecosystem experiments because they define natural boundaries of climatic conditions, nutrient cycling, sediment and water routing, and species migration and movement. Whole watershed experiments will likely have a far greater chance of detecting a population level response because they are more likely to trigger a population response that can be detected above the considerable natural variability of natural systems (Roni et al. 2010a). Also watershed scale restoration is implemented at the scale that species are typically managed at, unlike small and isolated restoration actions that are often difficult to evaluate in terms of management success (Fullerton et al. 2010, Roni et al. 2010).

However, there are limitations to watershed scale restoration actions and what can be learned from them when they are conducted in an experimental fashion. One of the most serious limitations of these large-scale experiments is that they are very difficult, if not impossible, to replicate. Replication is a fundamental component of many scientific experiments (Green 1979), but finding replicate watersheds is often impractical for logistical reasons (e.g., budgetary limits, land ownership, political boundaries, etc.) or ecologically infeasible (e.g., each watershed is likely to respond differently due to biological and geophysical differences).

Hence, historical evaluations of restoration, if conducted at all, have mostly been limited to site level evaluations. Site level evaluations have mostly produced equivocal results of their effectiveness because they have not accounted for other factors (Thompson 2006), have focused on local effects that may simply reflect a redistribution of individuals within a population rather than benefits to the population (Riley and Fausch 1995), are conducted at insufficient spatial and temporal scales to observe a population benefit, or have not used proper experimental approaches (Roni et al. 2010b).

However, there are some examples of restoration activities that have been implemented in an experimental setting that have provided data on fish responses (Cederholm et al. 1997, Solazzi et al. 2000). These examples provide some of the information that managers and funders of salmon habitat restoration are most interested in, namely (Roni et al. 2010):

- How many additional fish are produced by restoration,
- How much habitat needs to be restored to significantly increase fish abundance, and
- How much habitat needs to be restored to achieve recovery of threatened and endangered populations.

Restoration projects that have been able to provide information on their effect on salmonid production have had a direct influence on the availability of fish habitat (i.e., instream structures, floodplain reconnection, or elimination of fish migration barriers), and have intensive habitat and fish monitoring pre and post project (Roni et al. 2010b). However, there is an urgent need for a more coordinated approach to understanding the effectiveness of restoration actions.

One recent approach to evaluating restoration actions is the Intensively Monitored Watershed Program (Roni et al. 2002, Bilby et al. 2005, PNAMP 2005). Coordination at the regional scale has been initiated to develop a network of IMWs assessing a variety of actions, limiting factors, and watershed types. This coordination should lead to a better understanding of fish-habitat relationships and empirically based recommendations on how restoration should be prioritized and implemented as a recovery strategy. The goal of the IMW program is to improve our understanding of the relationship between fish and their habitat (Bilby et al. 2005, PNAMP 2005). Financial and logistical constraints make the IMW approach impractical for all restoration actions. Therefore, the IMW approach is being implemented in the framework of experimental management where the goals are to increase salmon and steelhead production while maximizing learning so that the results can be extrapolated to other situations (Walters et al. 1988). Generalization beyond a single system requires knowledge of mechanistic interactions or multiple ecosystem studies (Carpenter et. al. 1995). Directed research within an IMW may reveal the mechanisms by which the environment influences population performance of salmonids in a cost effective manner. In addition, the lessons learned from this network of IMWs will enable the region to implement further restoration with greater confidence without the rigorous effectiveness monitoring of the IMW approach.

Multiple experimental designs exist to assess the impacts of stream restoration efforts. Most of these designs were developed to evaluate the impact of some human perturbation on a resource (Box and Tiao 1975, Stewart-Oaten and Bence 2001a, Downes et al. 2002). Appropriate experimental designs precisely address how the impact is assessed and designate the proper statistical models required to analyze the data. Downes et al. (2002) suggest that it is incorrect to determine the proper statistical model for analysis after the data is collected. The experimental design is driven by the question and the statistical model is driven by the design. The statistical model requires sampling to occur in a certain fashion (e.g., random versus fixed assignments of treatments). The literature discussing these designs is confusing and often conflicting (Underwood 1994, Stewart-Oaten and Bence 2001b).

The most common design to evaluate the impacts of restoration actions is to apply a Before and After (BA) treatment comparison. In a Before and After design, samples are taken at various locations before and after a treatment. This occurs in the same reach or reaches impacted by restoration action, but in some situations are also measured in control areas, referred to as a before-after-treatment-control or BACI design. In most cases, the use of control(s) greatly increases the power of detecting impacts; however, poorly chosen control sites can decrease the power of detecting an impact (Korman and Higgins 1997).

The most common statistical models used to assess the impact of a human action on an ecological process is the family of general linear models such as analysis of variance (ANOVA) models and time-series analyses. The ANOVA approaches are flexible, robust and powerful hypothesis testing procedures (Downes et al. 2002). Intervention analyses (IA) are another family of models that have been widely used to assess environmental impacts (Stewart-Oaten and Murdoch 1986, Carpenter 1989). These models are based on time series analyses to estimate environmental impacts (Box and Tiao 1975). Intervention models use covariates to filter out natural variability rather than control sites.

4.2 ALTERNATIVE EXPERIMENTAL APPROACHES

A design that was first proposed by Walters et al. (1988) and referred to as a “staircase” design has been recommended as an alternative to standard BACI designs. A staircase design involves a modification to the typical BACI design whereby treatments are staggered in time within the treatment area (i.e., temporal contrast). Instead of a single treatment being initiated and compared to a control through time, the treatments are staggered so that treatment replicates are established in different time periods (Loughin 2006). There are several advantages to using a staircase design. First, the staggering of the treatments over time allows for the distinction between the random effects of year and year x treatment interactions. This prevents random initial environmental condition (e.g., drought or high water year) from having an overriding effect on the ability of the experiment to detect true treatment effects. Standard long-term experiments “fail to model both random environmental effects and their interactions with the treatments” which can lead to misleading results (Loughin et al. 2007). Second, by staggering treatments within the treatment area, treatment sections can be used as controls until they are treated, guarding against loss of other control areas. Third, it is uncertain to the degree restoration may impact downstream reaches. A comparison of multiple reaches within a single watershed may be more powerful because of a greater number of replicates and the ability to accurately describe a reach versus a watershed or subbasin; however, these sites may not be independent from each other. The independence of control sites will depend on how far fish move within and between streams, and on the degree to which physical impacts from treated reaches propagate into the surrounding reaches. Finally, implementing the full suite of treatments over an extended period can be a benefit logistically and economically because large areas do not have to be treated all within one year.

Another alternative design is a nested hierarchical approach. Underwood (1994) suggests a nested hierarchical approach when the scale of impact is unclear (i.e., does restoration at the site level influence habitat or fish populations at the reach or stream scale). The hierarchical design provides insight into the scale at which future restoration actions should be monitored and can better identify and describe the casual mechanisms of fish responses to restoration which often requires data from multiple spatial and temporal scales.

4.3 PROPERTIES OF POWERFUL AND ROBUST EXPERIMENTAL DESIGN

We identified a set of experimental design properties that may increase the likelihood of ecosystem (watershed) experiments determining the effectiveness of restoration at increasing salmon and steelhead production and understanding the casual mechanisms. These properties can be grouped into four categories: contrasts, treatment size, treatment and control properties, and logistics.

In order to detect a signal due to a restoration action, distinct contrasts in either time or space must be created that can be distinguished from background natural variability (i.e., noise). Both biological and physical processes are highly heterogeneous throughout stream systems such as between valley, geomorphic reaches or channel units. Biological and physical processes also exhibit a wide temporal variability such as within and between days, seasons, and years. This noise can make detection of a signal (i.e., response to restoration) very difficult unless the effect is extremely large. Thus, the larger treatment effects are, the more likely noise can be separated from the true treatment effect. Another approach is to replicate treatments either across space to account for a heterogeneous environment, or place treatments in very homogeneous sections of stream. The same approach could be used to distinguish the effects of time from treatment. However, replication across time and space is difficult with a large-scale experiment. Therefore, an ideal experiment for testing stream restoration would incorporate both time and space contrasts with a large treatment effect. This requires an understanding of the current and historical stream conditions and a proper identification of the limiting factors within the study watershed (Roni et al. 2010b).

Ideally treatment and control sites should be similar to each other prior to restoration. However, the absolute difference in a variable (e.g., fish density) over time in treatment and control sites can be large as long as the fluctuations over time are consistent (i.e., synchronous; Downes et al. 2002). Control and treatment sites should also be independent so, for example, fish movement between sites should be minimal. A balance between independence and similarity between treatment and controls is necessary because as sites are located further apart they are more likely to be less similar in terms of biological and physical characteristics (Downes et al. 2002).

Watershed experiments by their very nature are expensive. In order to implement large-scale restoration it may not be feasible with current funding levels for restoration. This may necessitate multiple treatments over several years.

4.4 ASOTIN IMW HYBRID HIERARCHICAL-STAIRCASE EXPERIMENTAL DESIGN

An experimental design that has the properties listed above can be achieved by a hybrid design that combines temporal contrast of the staircase design and the spatial contrast of the hierarchical design. We have been working with a statistician to assess the power of the hierarchical-staircase design compared to more traditional approaches to detect fish responses to restoration.

4.4.1 STATISTICAL MODELING AND POWER ANALYSIS

One of the main purposes of a monitoring program is to detect changes in a particular variable of interest over time. Serious concerns have been raised about the ability of many fish and stream habitat monitoring programs to detect biologically meaningful changes due to confounding factors such as high natural variability in many ecological variables, poorly designed monitoring programs, inconsistent monitoring protocols, and low statistical power (Larsen et al. 2004, Roni et al. 2008). Preliminary power analysis of the original experimental design suggested that we had an 80% chance to detect a 50% increase in juvenile steelhead abundance after one restoration treatment; however, this was a very basic analysis and it did not compare alternative designs, or include estimates of the range of variances likely to occur over time (e.g., annual variation) and space (e.g., between sites, sections, and streams).

We worked with a statistician familiar with staircase designs to evaluate the statistical power of a traditional BACI experimental design and two forms of the hierarchical-staircase design. The purpose of this comparison was to determine if combining a hierarchical and staircase design was indeed more powerful at detecting responses, and to compare alternative forms of the hierarchical-staircase design both in terms of where the restoration was implemented and how we decide to distribute our sample sites. The two hierarchical-staircase designs we tested were a situation where one large restoration treatment was implemented in Charley Creek (the original design) and a situation where the restoration treatment was divided up between all three study streams (Loughin 2010). See Loughin 2010 for the complete report on the power analysis.

We originally planned to conduct one large restoration in Charley Creek because we wanted to make sure that the restoration action was large enough to produce a detectable fish response at the population level (i.e., demonstrate that juvenile steelhead production had increased in Charley Creek as a result of stream restoration). This would be a more powerful design if the combination of several restoration treatments would act to increase the response of fish or habitat (i.e., synergism). However, if the restoration actions do not have a synergistic effect on the fish and habitat responses, then having the restoration divided among the three study streams would be more powerful.

We used a combination of data collected by WDFW between 1986 and 2006 and the IMW monitoring program between 2008 and 2009 to estimate the variance of juvenile steelhead abundance and pool frequency between sites, streams, and years. The variance estimate and 95% confidence intervals were used in the power analysis to determine the best case (lower CI), expected (estimate), and worst case (upper CI) scenarios for detecting changes in juvenile abundance and pool frequency.

We also varied the sampling design during the power analysis to determine how to allocate fish sample sites and habitat sample sites. See Section 4.4.2 for a description of experimental design units (e.g., treatment and control ***sections***, ***fish sites, habitat sites***). For pool counts, seven different sampling plans within habitat sites were considered (Loughin 2010). For juvenile abundance, five different sampling plans within fish sites were considered:

a) "1-per-stream", in which one fish site was chosen at random from the middle section of each stream and measured in each year. This represents the barest minimum measurement that could take place in a BACI-type study, and was used only with the 1-time experimental design.
b) "1-per-section", in which one fish site was randomly chosen from each section of each stream and measured in each year. This represents a minimum sampling plan design in which all three designs can be run and compared.
c) "Planned", which consists of the same measurements as in 1-per-section, plus a second fish site in each section in Charley Creek (originally the treatment stream).
d) "Alternative", which follows the same spirit of the Planned sampling, but matches the extra measured fish site with the treated sections from the Alt design.
e) "Full", in which two fish sites are measured in each section (twice as much measurement as in 1-per-section, 50% more than Planned).

Under the best case for variability, all designs and sampling plans have 100% detection of the 25% increase in juvenile abundance. Even under the estimated variability, all designs and sampling plans have at least 95% power to detect the treatment effect except the BACI combination, 1-per-stream sampling with a 1-time design, which has just over 70% power (Figure 11a). Once measurements are made in each section, confidence interval lengths do not change much with additional subsampling within the sections (Figure 11b). The alt design has the shortest intervals, while the 1-time design has the longest. Under the worst-case variability, greater differences among the methods begin to emerge (Figure 12). The 1-time and current designs have very similar powers and lengths regardless of the sub sampling intensity (Figure 12a). However, the alt design distinguishes itself in terms of both power and length of confidence interval. Powers range between 60-70%, compared to 25-35% for the other designs. Confidence interval lengths are roughly 2/3 those of the other designs (Figure 12b). The power to detect changes in pool frequency was similar between designs (Loughin 2010).

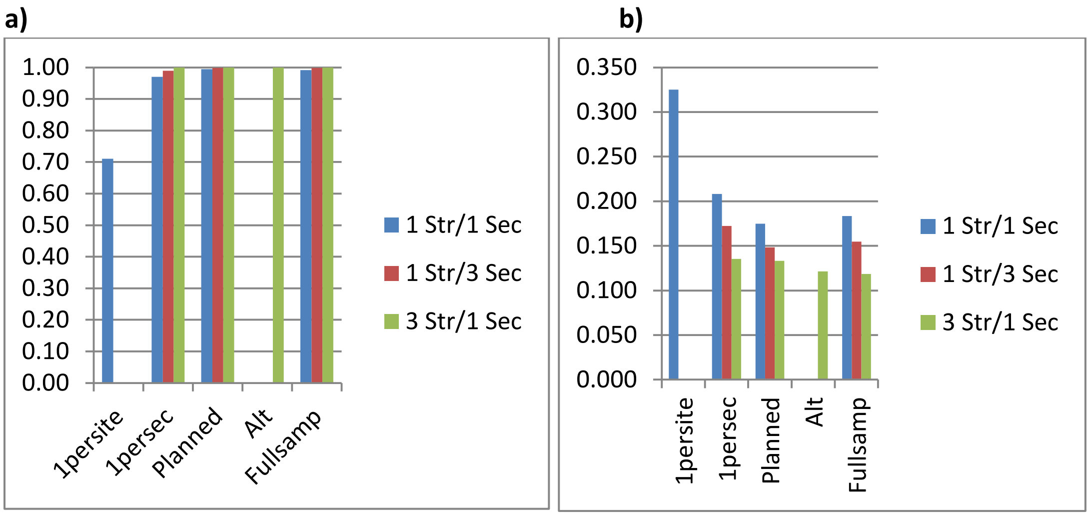


Figure 11, a) Estimated power of designs and sampling plans for log-Abundance under expected variability and b) estimated confidence interval length for designs and sampling plans for log-Abundance under expected variability.

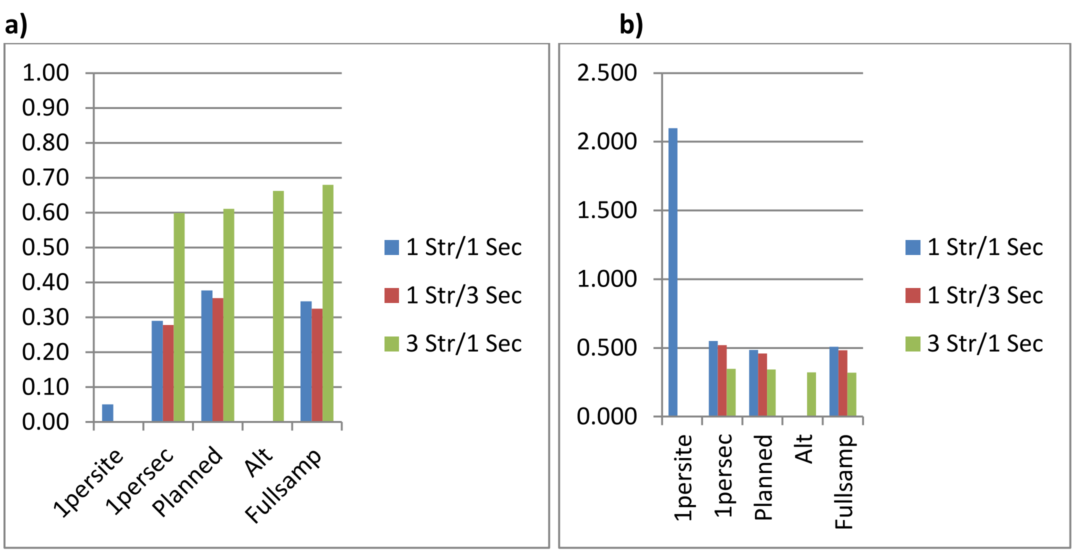


Figure 12. a) Estimated power of designs and sampling plans for log-Abundance under worst case variability and b) estimated confidence interval length for designs and sampling plans for log-Abundance under worst case variability.

4.4.2 REVISED EXPERIMENTAL DESIGN AND EXPERIMENTAL UNITS

Based on the above reviews and power analysis we are proposing to implement the alternative experimental design whereby restoration will be implemented in all three Asotin IMW study streams: Charley Creek, North Fork Asotin Creek, and South Fork Asotin Creek. Figure 13 shows the experimental and monitoring layout for the IMW. Table 6 defines some design terms that we will use throughout this report. The lower 12 km of each stream are divided into three 4 km sections that we will refer to as treatment and control ***sections***. Each stream will have two control sections where no restoration is implemented and one treatment section where the entire 4 km will be restored. The location and timing of restoration sections was selected randomly without replacement so that each section of creek (lower, mid, or upper section) was included in the design to specifically test if the response to restoration will vary depending on the distance upstream. Four years of pre-treatment monitoring has taken place since 2008 and the first treatment will be implemented in the South Fork in 2012. Charley Creek will be treated in 2013 and the North Fork will be treated in 2014. Post-treatment monitoring will continue until 2018. If the preliminary results of fish response to the restoration are very weak or undetectable, we will consider treating more sections within one stream. Control sites will be maintained in each study stream throughout the IMW project.

Fish and habitat responses to the restoration will be primarily monitored at permanent fish and habitat surveys sites nested within the experimental design (Figure 14). There are four fish sites in each creek, two in each treatment section and one in each control section for a total of 12 fish sites. Each fish site is 300-600 m long and was systematically located within a section, centered either 1 km or 3 km upstream from the bottom of the section. This was done to ensure that there was independence between fish sites both within a treatment section and between treatment sections and control sections. The location of fish sites within the sections was selected randomly whereas each treatment section always has a fish site at the 1 and 3 km location. Stream habitat is sampled within every fish site with three consecutive habitat surveys. Two types of habitat surveys are used: a detailed topographic survey approach (i.e., CHaMP; see Section 6.5) and rapid surveys of a few key habitat variables (e.g., LWD, pool habitat and forcing mechanisms, etc.; see Section 6.5.1.3).

Many other types of data are being collected to monitor fish and habitat at various scales such as PIT tag arrays, mobile PIT tag surveys, fluvial audits, aerial photography, and LiDAR. Some of these data are not collected annually and will be used as ancillary data to help explain casual mechanisms and linkages between habitat change and fish responses. A summary of the monitoring plan is provided in Section 6.

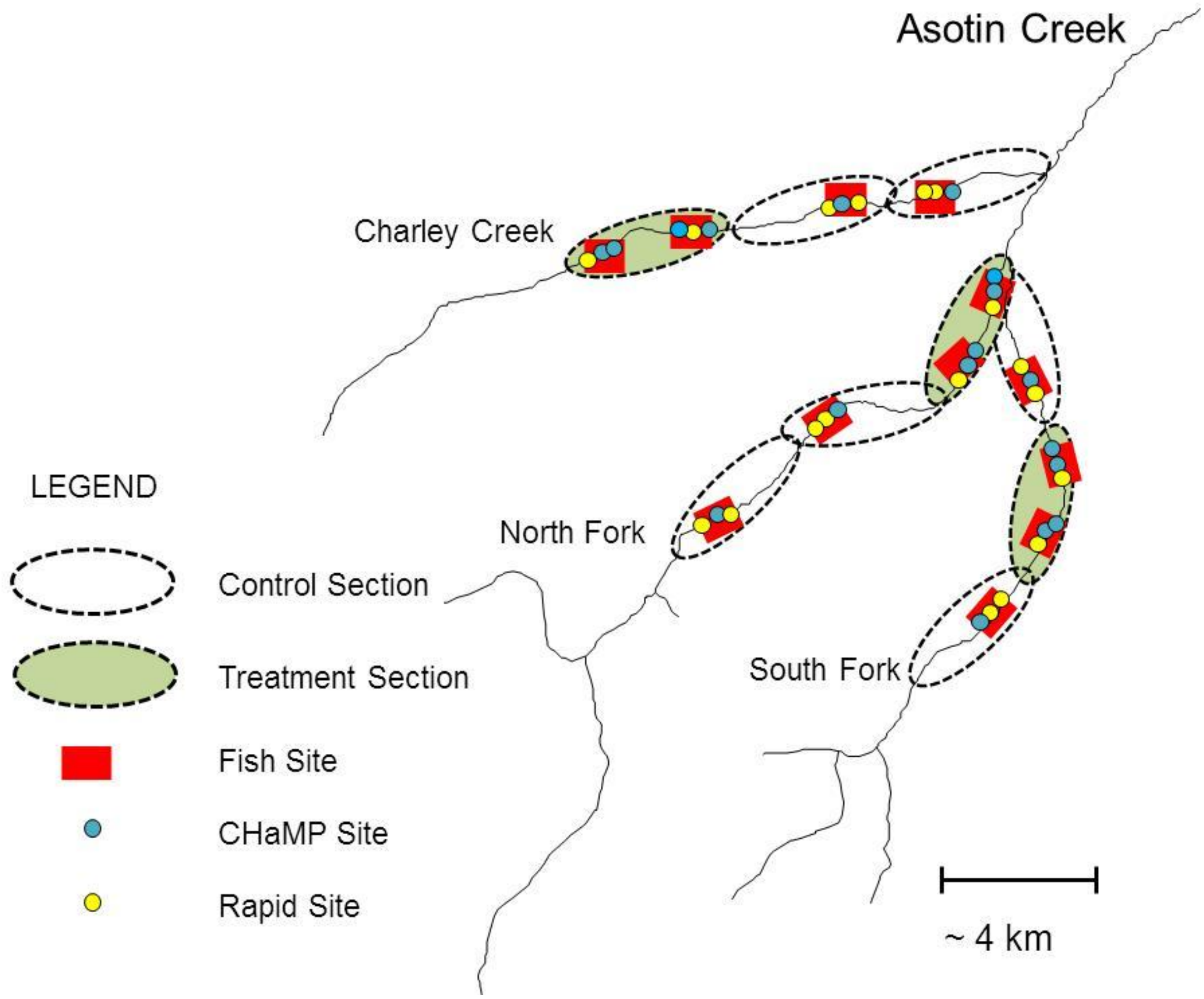


Figure 13. Experimental and monitoring design layout. South Fork treatment section will be restored in 2012, Charley Creek treatment section will be restored in 2013 treatment, and North Fork treatment section will be restored in 2014. All sections not colored will be controls throughout the project.

Table 6. The hierarchy of sample design terms going from the most basic (element) to the most general (Target Population). Adapted from Thompson et al. (1998).

Increasing Unit Size --->

Design Term	Elements	Sample Unit	Treatment Unit	Sample Population (Sample Size)	Sample Frame	Target Population (Scope of Inference)
Fish Example	Individual Fish	Fish Survey Site (300-600 m)	4 km treatment or control section (3 sections per creek)	Number of Sites Surveyed (12 fish sites)	All 500 m sample reaches in lower 12 km of study streams (72 possible sites)	All juvenile steelhead in lower 12 km of study streams
Habitat Example	Habitat Unit (pool, piece of LWD)	Habitat Survey Site (160 m)	4 km treatment or control section (3 sections per creek)	Number of Sites Surveyed (36 habitat sites)	All 160 m sample reaches in lower 12 km of study streams (225 possible sites)	All habitat units in the lower 12 km of study streams

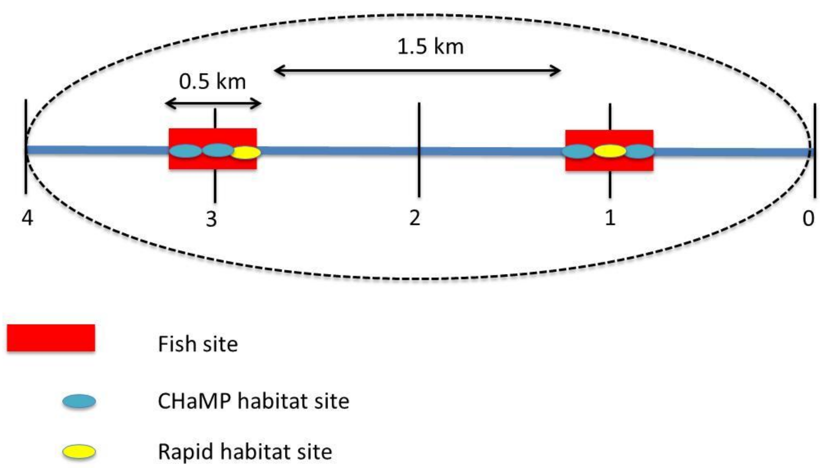


Figure 14. A detail of the location of annual fish and habitat monitoring sites within a treatment section of the Asotin IMW experimental and monitoring design. Fish sites were located systematically at either the 1 km or 3 km from the downstream end of a section to keep a minimum of 1.5 km between any two sites. Control sections have only one fish site randomly located at either the 1 or 3 km location.

4.4.3 DEFINING THE IMW SCOPE

We used a series of questions to refine broad management goals into specific hypotheses which dictate the experimental and monitoring designs (Marmorek et al. 2006). The responses to these questions help to determine what, where, when, how, and the duration different comparisons will be made and how the sampling design will allow for such comparisons. Examples of questions we used include:

- What are the species, including life-history type and gender, of interest?
- What is the spatial boundary of the population for which inferences will be made?
- What is the population response variable(s) that will be evaluated treatment effectiveness?
- What is the reference or final condition that the restoration is trying to achieve?
- What is the size of change in population response that can be detected?
- Over what time period(s) do you want to describe the population response?
- Are there surrogate measures of population response?
- Are there other factors that can be attributed to the observed population response?
- What tradeoffs between uncertainty, errors, and costs are acceptable (i.e., Type I and Type II statistical errors)?

Based on the question clarification approach above we have proposed the following scope of the Asotin Creek IMW:

Focal species – wild, summer run steelhead

Life history group – focus on juvenile survival and production (g/ha/day), but will also evaluate the number of juveniles and smolts/redds or spawners where possible.

Scope *(boundary of inference)* – primarily the lower 12 km of Charley Creek, North Fork, and South Fork in the upper Asotin Creek Watershed.

Final restoration condition – increase in LWD and pool abundance, pool quality and volume, and riparian conditions (long-term) in the study streams to within a range of reference conditions found in similar streams (i.e. target 75th percentile of reference condition distributions for LWD and pools (Fox and Bolton 2007).

Effect size – want to detect a minimum of 25% increase in fish and habitat attributes (LWD and pools).

Factors to attribute population response – increase in habitat complexity (width and depth variability, pool abundance/volume, residual pool depth) which results in increased winter survival of juvenile steelhead due to increased winter habitat capacity.

Type I and II errors – will use $\alpha = 0.1$ (10% probability of a Type I error) and $\beta = 0.8$ (20% probability of Type II error) for all analyses.

We propose to use a variety of response variables to evaluate whether fish are responding to changes in habitat as expected (Table 7). We will focus on productivity as measured by the number of juvenile steelhead produced (i.e., emigrating from each study stream and Asotin Creek) relative to the number of redds or adults from each year. We will also look at population parameters such as abundance, growth, and survival, which together can be used to measure the total biomass produced per time and unit area within treatment and control sections. We will also use the information gathered from PIT tag detections and recaptures of PIT tagged juvenile and adult steelhead to assess movement and changes in life history characteristics (i.e., time spent rearing in tributaries versus mainstem) to help explain possible mechanisms of overall changes in production (both smolt numbers and biomass). We define explicit hypotheses we will be testing for both habitat change and fish responses in Section 5.6.

Table 7. Potential response variables to be used to detect the effects of stream restoration on steelhead populations in the Asotin IMW study area.

Population Performance	Response variable	Description	Data types
Abundance	Population Abundance	Number of fish per unit area or length (redds/km)	Mark-recapture, depletion estimates, spawner survey
Productivity	Growth and Size	Growth rates by age class and season, size at out-migration	Length and/or weight at two time periods
	Juvenile Survival	Measure of freshwater production (e.g., egg to smolt); seasonal survival (% survival from summer to fall)	PIT tagging, Mark-recapture, program MARK modeling
	Migratory Timing	Date of out-migration, age at out-migration, age at spawning	Smolt trap captures, scale analysis
	Recruiting adults (R/S)	Number of returning adults from a spawner. Population production. Can also get maximum production and carrying capacity based on Ricker, Beverton-Holt, etc.	Yearly escapement, harvest, marine survival
	Smolt to adult return ratio (SAR)	Measure of out-of-basin survival; number of adults return from number of smolts leaving subbasin, Bonneville Dam, etc.	Adult escapement and juvenile out-migration estimates
	Smolts/Redd or Spawner	Measure of freshwater survival which would be the number of smolts per spawner	Redd counts, eggs per redd, spawners per redd, smolt out-migration
Spatial Structure	Distribution	% of available habitat occupied, changes in relative density by location within distribution	Presence/absence surveys, relative abundance surveys
	Species composition	changes in relative abundance of salmonid and non-salmonid fish species	Relative abundance surveys

5 RESTORATION DESIGN

In the following sections, we provide a summary of the scope of the restoration, proposed restoration treatments, methods of construction, and design criteria. A stand-alone restoration plan has been drafted for the Asotin IMW and is currently being reviewed by the RTT and interested parties. A trial of the proposed restoration was initiated in August 2011 to assess the logistical feasibility of the proposed restoration technique and to assess the performance of the structures. We demonstrated the logistical feasibility of the proposed restoration and have performed geomorphic change detection analyses at the trial structures after high flows in the spring of 2012. Please refer to the full restoration plan for more details on the proposed restoration actions and methods (Wheaton et al. 2012).

5.1 SCOPE OF RESTORATION PLAN

The ultimate goal of the Asotin IMW is to initiate riparian restoration over a large area of the study streams (minimum of 12 km of instream length). It is presumed that riparian restoration will lead to development of mature riparian forests that over time will provide a source of large (> 30-40 cm diameter) trees that will fall into the stream and lead to more historic levels of wood recruitment. However, in the short-term LWD will be added to the study streams in an effort to mimic wood recruitment that is currently lacking. We recognize that stream restoration needs to be thought of in the context of the watershed. Adding wood to a stream that has chronic oversupply of sediment from road building or logging is ill advised. A basic assumption that we are making for this project is that restoration efforts and changes in management strategies that were implemented in the late 1980's and early 1990's in the Asotin have stabilized the streams enough that instream restoration is justified.

We estimate that approximately 53 pieces of LWD/km would need to be added to each study stream to equal the mean reference conditions (Table 8). This equates to approximately 211 pieces of LWD for each 4 km proposed restoration section. The exact number of structures has not been determined, but we expect approximately 200 structures/section to be installed with an average of two 2-3 m pieces of LWD per structure (we are using short pieces of LWD to allow hand placement of the structures). The spacing between structures will average 20-40 m apart depending on the stream. We propose to install 85-90% of the structures as dynamic woody structures (see below) and 10-15% of the structures as whole trees or very large complexes of LWD.

Table 8. Number of LWD by size class to be added per km and restoration treatment section in the Asotin Creek treatment streams. The negative value for LWD pieces <=30 cm reflects that there were more small pieces in the study streams than found in references conditions.

LWD Diameter Size Class (cm)	LWD to add/km	LWD to add/ 4 km section
<=30	-1.4	-5.8
30-40	24.8	99.1
40-50	18.0	71.9
>50	11.5	45.8
TOTAL	52.8	211.1

5.2 RESTORATION PHILOSOPHY AND RESPONSE UNCERTAINTY

The basic philosophy we bring to this restoration plan is that restoration actions should be implemented in a way to maximize learning and that the treatments are intended to kick-start natural fluvial processes that will eventually restore high quality salmon and steelhead habitat to be self-sustaining through time. When it comes to the role of LWD in streams, it is clear that both size and density matter. However, the vast majority of past restoration efforts that have used LWD focused just on size and placed a relatively small number of pieces of larger LWD in a relatively small number of locations (Roni et al. 2008). While we recognize that size of LWD does matter, we hypothesize that the density of in-channel LWD is more important in terms of promoting habitat complexity and conditions for fish over the scale of the entire stream. Another way of conceptualizing the role of LWD is as roughness elements. The current conditions in Asotin Creek are very much like the gutter of a bowling alley - there is very little variation in width or depth and there are virtually no roughness elements to change the speed or course of the bowling ball (i.e., floods carrying water, sediment and LWD). Virtually anywhere on the study streams where there is some variation in width, depth and large-scale roughness (i.e., LWD and boulders), we observed temporary storage of sediment in bars, persistent pools and more complex habitat. This suggests that the bowling balls (i.e., floods) are carrying useful material with them for constructing and maintaining such habitats. There simply are not enough places where the flow field varies enough to promote higher residence time of the material (sediment and LWD) and exchange with the riparian corridor. We postulate that a high density of LWD and/or debris catching structures, will help 'kick start natural fluvial processes' that through time can maintain themselves and recruit more LWD from adjacent riparian and hillslope areas. Although it is possible to place structures in a way to induce specific hydraulic and geomorphic responses, we only use these techniques to initiate the desired responses. The specific effect of any one structure, or its persistence, is less important than the overall effect of all the structures in fundamentally altering channel roughness and habitat complexity over the scale of restoration treatment (i.e., several km).

If an isolated structure 'fails' and washes out, the consequences of such an event are relatively insignificant. The cost of that structure in terms of raw materials is less than $200, including materials and labor. The hydraulic and geomorphic influence of the structure may be lost, which under a worst-case scenario would result in the stream returning to its pre-treatment condition. However, if the structure is instead part of a complex network of 100's of structures in series with each other, the consequences of a failure are actually part of a natural progression. The materials (wooden fence posts) and LWD that might have been part of that structure is likely to end up moving downstream to the next structure and becoming tangled up in that roughness element as a debris jam. Debris jams come and go, inducing a consistent and roughly predictable cast of associated features that are sculpted and built by the fluvial processes they induce. If there are enough debris jams, the transitory nature of the structures and the attributes associated with them are simply part of the overall character of the stream. By contrast, if there are only one or two mega-features, their failure leads to the diffusion and dispersal of the material that built them into generally less effective forms.

5.3 RESTORATION GOALS AND OBJECTIVES

The restoration goals can be split into long-term and short-term actions. In the long-term, we hope to restore riparian function by promoting the development and maintenance of a healthy riparian zone that resembles historic conditions. This forest will be dominated by native species, have a diversity of seral stages appropriate to the natural disturbance regime of the vegetation and ecosystem types they represent, and provide a suite of attributes that will benefit the streams they border. Many of these goals will require coordination with landowners and management agencies and will likely take many decades to fully realize. However, the IMW project will attempt to initiate the process of riparian restoration with a series of activities designed to remove immediate stressors and promote long-term recovery. The main tools at our disposal to start this process are fencing, planting of native species, control of introduced species, and thinning of existing alder forests to promote conifer and cottonwood regeneration.

The specifics of the riparian restoration design have not been completed for three main reasons: 1) riparian restoration is not the focus of the IMW effectiveness monitoring, 2) we have only recently acquired aerial imagery of the entire study area to aid in a full assessment of the riparian condition, and 3) the ownership and status of the riparian areas of Charley Creek have been in a state of flux. We expect to be able to provide a more detailed restoration plan once the aerial imagery has been assessed and the ownership status of Charley Creek is resolved (Note: WDFW recently negotiated the purchase of some private property along Charley Creek and other portions of private property in Charley Creek will be enrolled in the Conservation Reserve Enhancement Program which will influence the development of a riparian restoration plan).

The specific objectives of the riparian restoration actions of fencing, planting, weed control, and thinning are to:

1. Remove grazing activity from the riparian area to allow natural recovery,
2. Speed up recovery by planting native species,
3. Remove competing non-native species to allow natural recovery, and
4. Create gaps in the alder forest to allow the re-establishment of conifers and cottonwood trees that will eventually contribute to the LWD in streams.

In the short-term we propose to add LWD in a 4 km section in each of the study streams to simulate natural wood loading densities that would have been provided by a properly functioning riparian forest. The goals of the LWD additions are to learn how LWD additions change the hydrologic and geomorphic conditions in the study streams. Ultimately, we want to cause a positive population response in wild steelhead as a result of the LWD additions and understand what the mechanisms are that lead to the response. A secondary goal is to develop an inexpensive, low impact, and widely applicable LWD restoration method that can be used in many small to medium-sized tributaries to increase habitat complexity. We also want this restoration method to be more dynamic than traditional restoration approaches whereby we let the LWD be more mobile thus allowing the river to rearrange the LWD we add to build more dynamic and natural debris piles and to create more diverse hydrologic conditions and geomorphic features. Therefore, we propose to build dynamic woody structures (DWS) using wooden posts driven into the substrate supplemented with LWD and with additions of whole trees.

The specific objectives of the DWS and whole tree structures are to:

1. Increase channel width variability
2. Increase instream habitat diversity (e.g., fish cover, pool frequency and depth)
3. Promote mobilization of and sorting of sediment by encouraging bar development, bed scour, bank erosion, and substrate sorting (e.g., Figure 15).

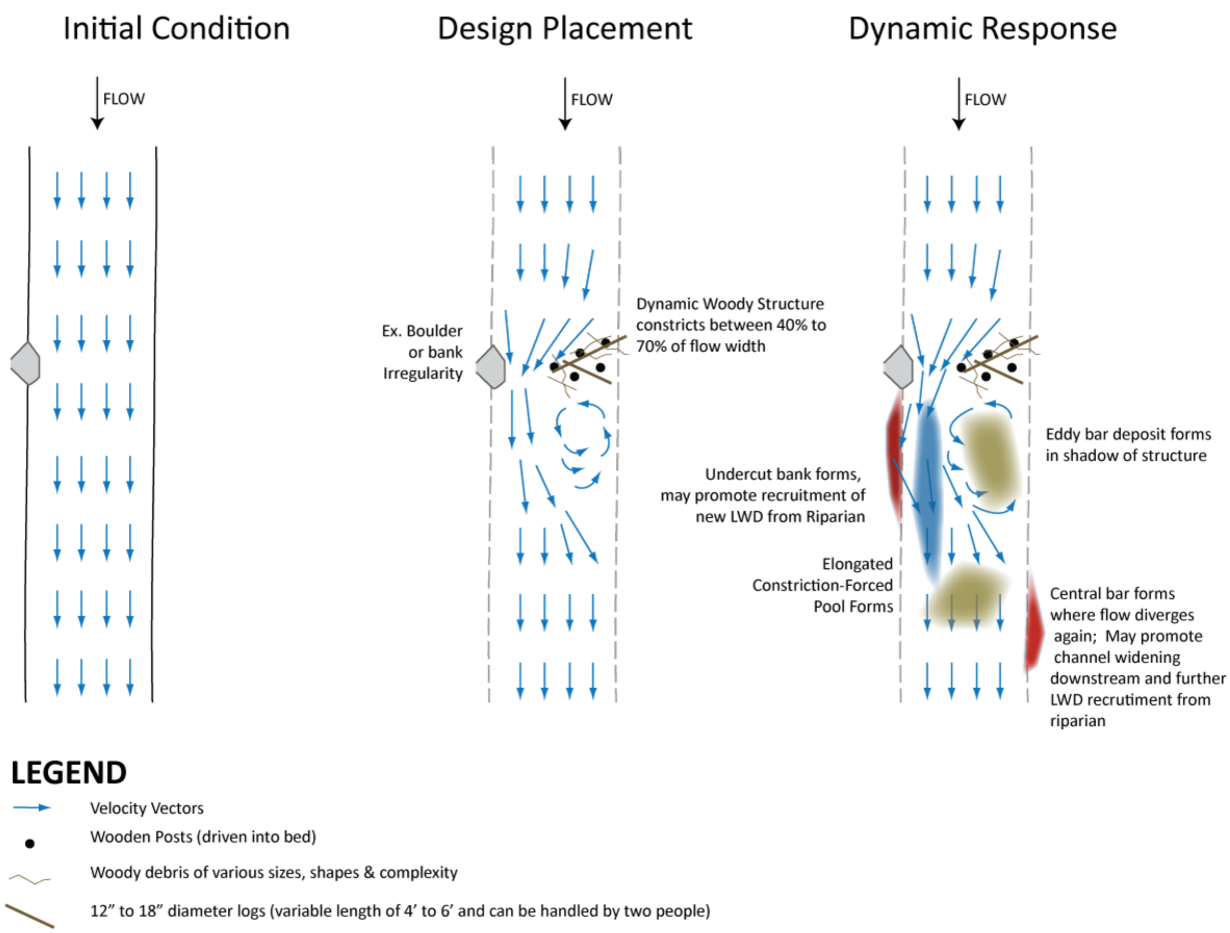


Figure 15. Schematic of the potential response to post deflectors or whole trees added to a relatively simple plane bed channel to constrict the flow. The constrictions in flow will be created by either dynamic woody structures (DWS), DWS with LWD added to increase their complexity (pictured above), or whole trees.

5.4 RIPARIAN RESTORATION TREATMENTS

The primary riparian restoration treatment is one of passive recovery, which will be facilitated by more regular exchange between the channel and the riparian environment as promoted by the more active restoration intervention of adding LWD to the channel. Opperman and Merenlender (2004) showed that riparian restoration can be an effective means of restoring instream fish habitat, promoting LWD recruitment and encouraging fluvial processes to 'do the work of restoration.' The passive treatments will be either direct fencing exclosures, or removal of grazing, depending on land ownership and management agencies' requirements. An extensive amount of local knowledge for fencing riparian areas already exists as large portions of the mainstem Asotin Creek have been fenced (ACCD 1995, ACCD 2004). We would draw on this knowledge to inform any fencing activity in the study streams.

The design of the fencing exclosure(s) should use the following design criteria:

- Only use a fence if absolutely necessary as they are expensive and can have unintended consequences. Reasonable alternatives include i) locating off-stream water troughs in areas easily accessible to the herds that deter them from needing to enter the stream, ii) effective management of herds (e.g. lower densities and use of riders)
- The fencing should be designed to keep domestic ungulates (cattle and sheep) out of the riparian corridor, but should not have the unintended consequence of keeping them trapped in the riparian
- The layout of the fencing should be such that it does not segment the riparian corridor and become an unintended barrier to wildlife migration
- A fence design that keeps both calves and adults out, one that affords calves opportunities to get through the fence means mom will find a way through…
- Access gates should be provided to allow wildlife free passage when domestic ungulates are not present, as well as providing access for monitoring crews
- In areas where invasive plant species are or prove to be a major concern, the 'exclosure fencing' may be used as short-term, targeted, high-intensity 'enclosures' for using ungulates to help knock back invasive plants at critical times of year. Thus, access gates may be desirable.

Once the immediate stressors of grazing and/or land disturbance within riparian areas are removed, more active restoration activities will be initiated. These activities will include planting, non-native species control, and riparian thinning. In areas devoid of vegetation planting will be the most effective treatment if it is matched with measures designed to prevent wildlife damage to the seedlings during the first few seasons of growth and potentially watering or fertilizing to promote rapid establishment. Again, there is extensive knowledge of these treatments within the watershed from previous work on the Model Watershed Plan and we will draw heavily from this past work (ACCD 1995, ACCD 2004).

There are some extensive areas of scotch thistle invasion along Charley Creek. The USFS has already begun a control program and has donated time and money to this issue. We will continue to work with the USFS, WDFW, Asotin County, and private landowners to develop and implement an invasive weed control program, especially where it relates to riparian vegetation reestablishment.

A final active treatment action that we are proposing is riparian thinning. We have noted that there are many areas of all of the study streams that have a well-established riparian community. However, a substantial amount of these established riparian zones are dominated by alder trees of 3-10 m in height. These alder forest are providing excellent shade and allochthonous inputs to the streams but may be preventing reestablishment of other tree species that would historically have been native to the riparian zones (e.g., cottonwood, Douglas fir, spruce, and ponderosa pine). Selective thinning (i.e., opening small gaps in the existing forest) of the predominantly alder riparian community could allow for more diverse riparian vegetation and trees species such as cottonwood to establish. This is analogous to gap theory in forest ecology and is well supported in the literature (Hartshorn 1989, Lertzman 1992). The purpose of thinning is to disturb the currently stable and homogenous corridor without robbing it of its important structure and function and to create opportunities for the riparian corridor to diversify both in terms of species composition and age structure. The thinning could also dove-tail with the post defector and LWD additions we are proposing by becoming a source for small and large woody debris onsite. This proposed treatment will require discussions with local foresters to develop a more detailed prescription and significant permitting challenges that we will pursue if possible.

5.5 INSTREAM RESTORATION TREATMENTS

To improve instream habitat in the short-term, we propose to add LWD in the form of three types of structures: Dynamic Woody Structures (DWS), DWS with LWD added, and whole trees. All three designs are expected to constrict the flow locally and induce the creation of active bars, scour pools, and undercut banks (Figure 15). The exact location of the structures will be determined in the field by a professional geomorphologist who flags each structure location ahead of the installation team, and uses a proforma to record critical placement elements and instructions to the installation team. The structure locations will be flagged, GPS'd, photographed, and a decision will be made in the field on placement details. This will take place approximately 1-4 weeks ahead of the installation effort as to allow adequate time to prepare and stage the installations. Although a detailed design of every structure is possible, a critical element of this IMW and treatment approach is to test to what extent a simple in-the-field design procedure can be successfully implemented. Detailed designs are very expensive, and the extent to which we can demonstrate that a simpler/cheaper design process is possible will help in the eventual transferability of results from this IMW. We believe that undue focus on a specific structure misses the point of this restoration project. While we can likely predict the plausible range of responses explicitly for each structure, the behavior around an individual structure is not as important as how all these structures will function together. The instructions for placement summarized in the professional geomorphologist's proforma will include approximate guidelines on:

- Which side of the channel to hinge the DWS off of
- Rough angle of DWS (i.e. 90° vs. 120°)
- Rough percentage of flow width to constrict
- Highlight any critical features to work with (e.g., anchoring off of an existing boulder or root wad; directing flow at a bank with excellent alluvial source material to supply downstream bar development; directing flow at good potentially recruitable LWD/trees).

5.5.1 DYNAMIC WOODY STRUCTURES (WOODEN POSTS ONLY)

We will build dynamic woody structures (DWS) by driving wooden fence posts into the stream substrate with a hydraulic post driver. These DWS are similar to post deflectors and log deflectors that have been used in several restoration projects to induce meanders (Zeedyk and Clothier 2009), reduce channel incision by trapping sediment and promoting inset floodplain development (Pollock et al. 2011), create overwinter habitat for salmonids (Cederholm et al. 1997), create scour pools (Koski 1992), and create

LWD debris complexes (Slaney and Zaldokas 1997). In this restoration plan, we are proposing the use of DWS to act primarily as surrogates for high concentrations of LWD and/or as temporary anchors for LWD. Their overall functional roll at the section scale is to act as large-scale roughness elements that increase the variability of width in the stream, and promote higher degrees of habitat complexity. At the local scale they are designed to induce an immediate influence on the hydraulic flow field that forces otherwise uniform flow paths into convergent flow past the structure itself and then expands into divergent flow paths downstream of the structure (Figure 15 and Figure 16). This is expected to be exacerbated at high flows to the point that it promotes a geomorphic response in terms of bed scour and/or bank erosion where flows are concentrated, and deposition of sediment and construction of bars where flows are divergent. Also at high flows, we expect woody debris of various sizes to collect on the structure itself and hopefully get stuck. This will further accentuate the hydraulic response. The geomorphic response is intended to increase the variability in channel width and depth and promote and sustain more complex habitat development and evolution. These structures are termed ‘dynamic’ because we fully expect them to evolve, blow-out, migrate, become part of other structures, or reform in their own natural debris jams after being moved during high flow events.

The basic design calls for non-treated, wooden fence posts (10 cm diameter and 1.8 – 2.0 m long) to be driven into the stream bed approximately 30 cm apart to effectively narrow the width of the stream and act as woody debris catchers (Figure 16). The posts are driven in at least 60-90 cm when possible with a hydraulic post driver and aligned at 90-120 degrees to the stream flow. The depth is to ensure that the posts last long enough to withstand low-flow hydraulic forces, and promote the likelihood of debris being caught up on the structures. The posts are to be installed in a staggered pattern to create a rougher surface more likely to act as a trap for complicated pieces of wood, as opposed to a straight wall that could potentially deflect floating debris. Once the posts are driven into the stream substrate, the posts are cut to a height 10-20% above the mean annual flood height as determined by evidence of flood activity and other bankfull indicators. Leaving the posts too high might produce too much pressure on the posts if material builds up against the posts. This could cause the posts to lay over in a downstream direction and potentially wash out. While this would not be catastrophic, we would like the posts to last long enough to act as a catcher for debris and kick start geomorphic responses.

This installation method is designed to be possible with mostly hand tools and hand labor. A crew of 2-3 people hand carrying the materials will stockpile the posts and LWD near the installation areas beforehand. The LWD will be donated by the USFS from blow-down and beetle killed trees within the Asotin Creek watershed. The LWD will be cut into 6-10 foot lengths that can be loaded by 2-4 people onto a trailer and transported to the restoration sites. The only equipment required for installation is a hydraulic post driver to drive the posts into the stream bottom and a chainsaw to trim the posts.

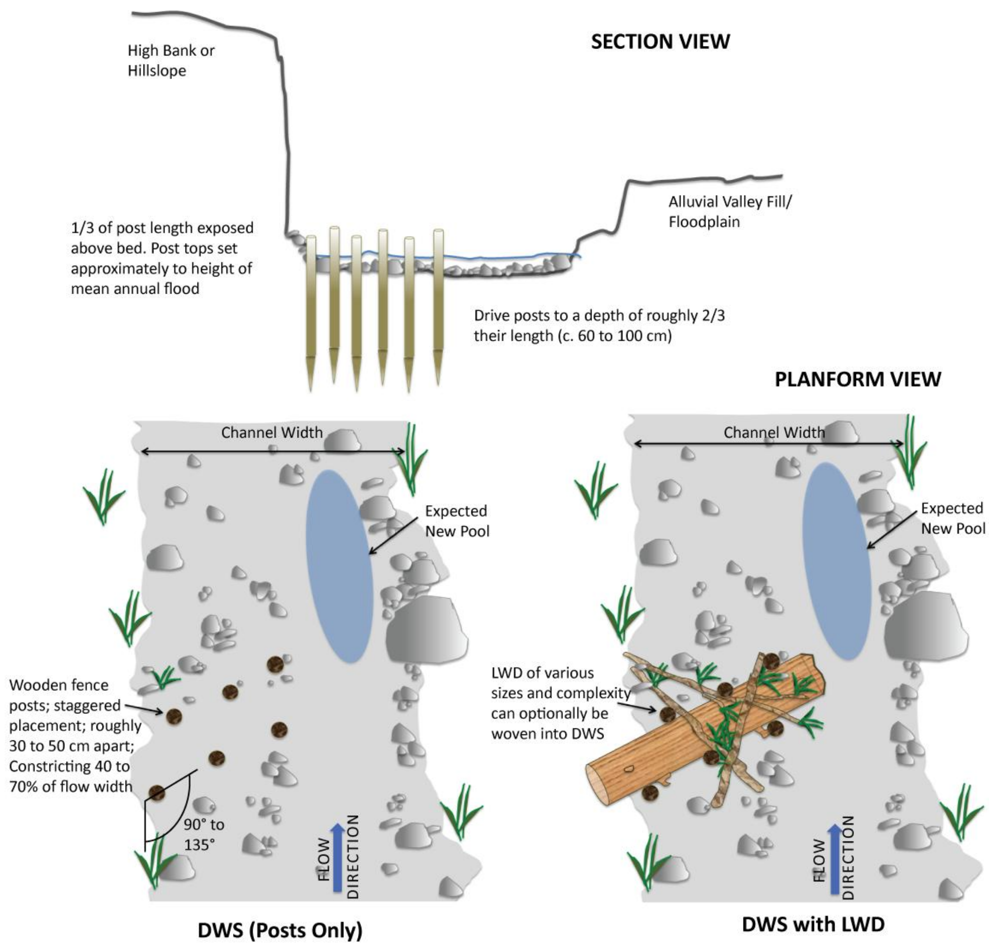


Figure 16. Basic design of an individual dynamic woody structure (DWS) using posts driven into the stream bed with a hydraulic driver.

5.5.2 DYNAMIC WOODY STRUCTURES WITH LARGE WOODY DEBRIS

The DWS with large woody debris is the same design as the DWS (posts only) design except we propose to add LWD to the structure (Figure 16). The addition of wood will produce a more pronounced hydraulic response immediately, and promote faster debris accumulation at high flow, increase the structural complexity of the structures, increase fish cover, and increase the amount of scour and bar development associated with the structure. When possible, branches will be kept on the LWD and/or branches will be added to the structure to simulate natural LWD. We will also align the LWD to "lock" in place on the post deflectors (i.e., cross several pieces within the spaces between the posts) to aid in securing the LWD in place temporarily. The intent is not to permanently anchor the LWD (as is frequently done with cables), but instead to promote the likelihood that the LWD and structure stay there long enough to produce a geomorphic response at high flows. We will use pieces of LWD that can be hand set in place with 1-3 people to limit the disturbance to existing riparian vegetation.

5.5.3 WHOLE TREES

Whole trees are being used as a restoration treatment throughout the Snake River Salmon Recovery Region (snakeriverboard.org). We will use whole trees as a part of the restoration where feasible without causing significant damage to the existing riparian vegetation (i.e. avoid impacts of heavy equipment on riparian areas). Elsewhere, we may opportunistically harvest whole trees from thick areas of the riparian and use them in the stream as close to the location of harvest as possible. In some cases, trees may be felled from the riparian directly into the channel, in other areas they may be dragged by a crew of three to four laborers into the riparian. We do not intend to use heavy machinery to do this work, and instead will rely on hand work by crews. The same basic criteria will be used to select sites to add whole trees once the criteria of protecting the riparian habitat are met. It is anticipated that the whole trees will be less mobile than the post and LWD structures because they will be anchored by large portions of the tree being on the bank, interlocked with existing riparian trees, and/or the overall irregularity in the shape of the tree.

5.6 DESIGN HYPOTHESES AND EXPECTED RESPONSES

The following design hypotheses all directly or indirectly stem from the conceptual model of the current conditions we derived from reviewing past assessments and our ongoing habitat sampling (see Section 3). From this understanding of the current system, we generated a vision of the restored condition that we then used to form specific, testable hypotheses and a monitoring program to test those hypotheses.

5.6.1 RIPARIAN HYPOTHESES AND EXPECTED RESPONSES

We do not expect significant increases in LWD from riparian due to the length of time it will take for fir and cottonwood trees to establish and mature, and the limited length of the IMW (i.e., expected completion of monitoring in 2018). The most immediate response may come from planting forb and shrub species in areas with little vegetation cover, and weed control actions. Specifically, we expect:

- Little or no increase in LWD from riparian areas due to “natural” tree fall; however, if significant bank avulsions or lateral shifts in the channel occur due to DWS, this could cause significant input of mature alder trees into the stream.
- No change in summer water temperature as most sites are well shaded, and at sites with no shading, revegetation will not be fast enough to alter stream temperature during the IMW.
- No changes in fine sediments from hillslope and anthropogenic sources (e.g., roads) because these sediment sources do not appear to be a significant problem and most riparian habitat is intact enough to act as a buffer to these sources.

5.6.2 INSTREAM HABITAT HYPOTHESES AND RESPONSES

We recognize two important plausible “responses” of the DWS additions: i) some structures will fail (i.e., be swept downstream, or the channel will move around the structure possibly leaving them outside the active channel), and/or ii) some structures will have limited immediate effect (i.e., create only a limited number of all the possible responses). Rivers are dynamic and we fully expect both outcomes to occur at some structures. However, the density of structures and dynamic nature of the structures (i.e., temporary nature of the posts and non-secured LWD) are explicitly designed with these plausible outcomes in mind. Our monitoring program is also designed to learn how structures function and to show what characteristics of the channel and installation create positive responses.

It is generally recognized that the addition of LWD into streams can increase pool habitat, sediment storage and sorting, and fish cover (Roni et al. 2008); however, the long-term effectiveness of this restoration approach has rarely been evaluated beyond determining a structures durability (Roper et al. 1998). This IMW has the unique ability to track the function of DWS over several years and document how those functions change over time. The individual DWS are designed to produce an immediate hydraulic response by constricting the flow width, followed by changes in erosion and deposition and ultimately, increases in habitat diversity. These expected changes are also summarized graphically in Figure 15. Here we summarize the general instream habitat responses we expect to occur at the structure scale and reach scale over the short-term:

We expect that the DWS will cause the following:

- Alter the hydraulics (i.e., flow width constriction and conversion flows)
- Increase erosion and deposition processes
- Increase channel width variability

We expect that reaches with greater variability in channel width will:

- Increase connectivity with inset surfaces and terraces
- Increase diversity of flow conditions (i.e. shear zones, fast and slow)
- Increase diversity of residence time for sediments
- Increase diversity of substrate size (i.e. better sorting)
- Habitat heterogeneity and structural cover
- Reaches with more structures will increase trap efficiency of recruitable wood

5.6.3 FISH HYPOTHESES AND EXPECTED RESPONSES

The ecosystem goal of the restoration treatments is to increase the productivity of wild steelhead in Asotin Creek**.** We are most interested in the production of juveniles (pre-smolts) and smolts (presumed out-migrants) at the fish site, treatment/control section, subbasin scale, and watershed scale (referred to as “productivity” hereafter). Although there are interesting patterns of habitat utilization at the individual-structure scale that we could study, most of our hypotheses are going to focus on processes and phenomena more commensurate with our fish sampling design at the fish site and subbasin scale and the ecosystem goals of the project. Measuring the juvenile and smolt productivity is an indirect measure of the survival of egg-fry, fry-juvenile, and juvenile to smolt life history stages which are the stages stream restoration activities are trying to benefit (Horton et al. 2009). We will also asses biomass production to measure the effectiveness of restoration. Unlike estimating productivity (i.e., numbers of smolts produced per spawner), biomass production is the result of three key population parameters: abundance, growth, and survival which together can measure population yield in biomass per unit area over time (Waters 1999, Almodóvar et al. 2006).

In streams west of the Cascades where steelhead coexist with coho salmon (*O. kisutch*), steelhead do not appear to respond to the addition of LWD during the summer, but do respond positively during the winter by both increased winter abundance of juveniles and increased smolt productivity from treated sites (Solazzi et al. 2000, Roni and Quinn 2001). By contrast, in early studies in Asotin Creek, steelhead abundance increased in the summer after the addition of boulders and LWD but winter abundance and smolt production were not measured (Viola et al. 1998). Asotin Creek is on the east side of the Cascades, and east side streams are more likely to have low flows during the winter due to cold temperatures and more precipitation in the form of snow (although infrequent, but large flows can result from rain-on-snow events). Assessments of the effectiveness of LWD treatments suggest that the response of steelhead may vary depending on the stream type and the presence of other salmonid species. For example, steelhead are known to select riffle habitat in the summer and pool habitat in the winter when coexisting with coho (Hartman 1965, Bustard and Narver 1975, Bisson et al. 1982) which may explain the differences in study results in Asotin Creek where coho are absent.

To add to the complexity of predicting how productivity and biomass production will be affected by the proposed restoration, there are multiple pathways by which changes in habitat conditions (predicted in previous section) can influence these measures of fish response (Figure 17). Though our fish and habitat monitoring programs may help to elucidate some of these relationships, we may not be able to fully describe all of these pathways.

Below we propose a set of specific fish response hypotheses that directly relate to the hypothesized habitat responses above. The Adaptive Management Plan we have initiated and our ongoing monitoring will help refine these hypotheses further (Wheaton et al. 2012). In comparison to the predicted habitat responses, the fish responses are more appropriately differentiated by life stage and the spatial scale of our fish monitoring.

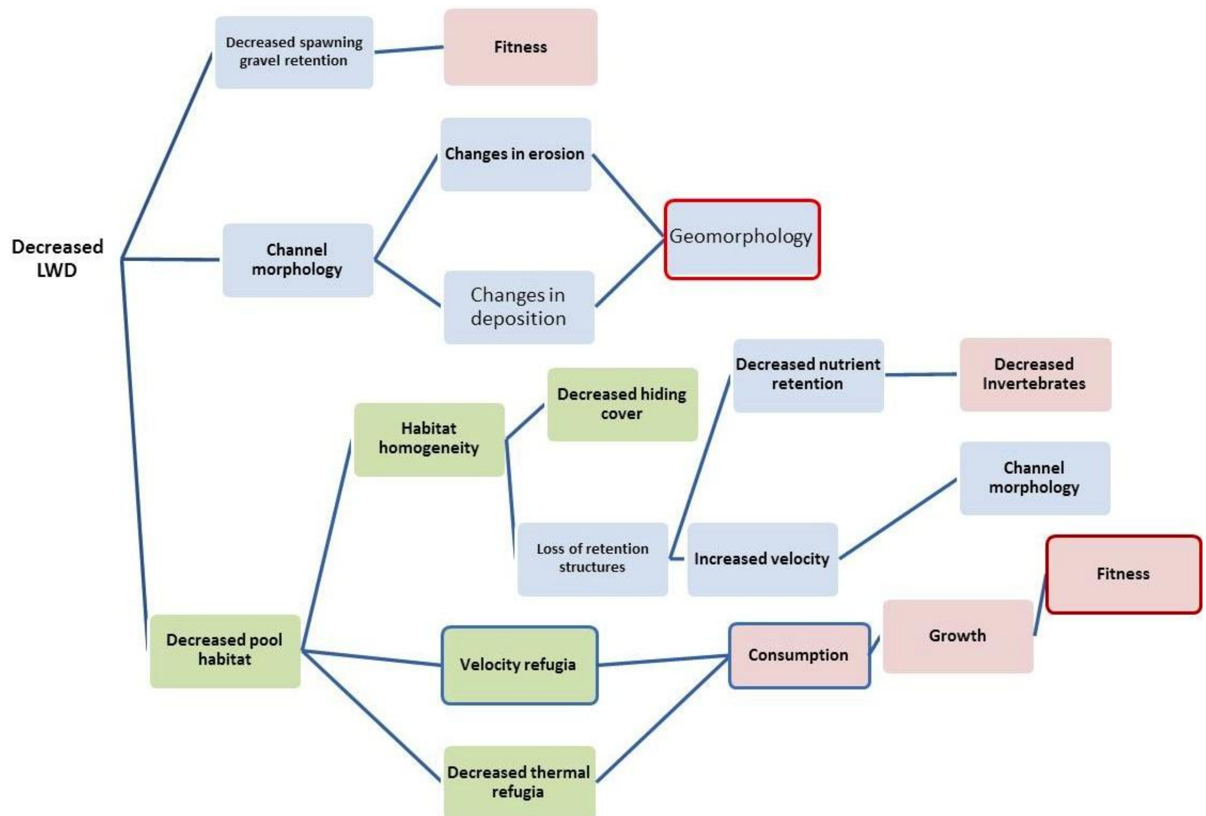


Figure 17. Consequences of decreased LWD supply on stream process and habitat types thought to be critical determinants of individual and population fitness and ultimately production. Reversing the effects of decreased LWD by installing dynamic woody structures can increase population fitness and production through multiple pathways and synergistic interactions. Colors of boxes equate to geomorphic/hydrologic changes (blue), fish habitat changes (green), biological changes (red).

5.6.3.1 HYPOTHESIZED FISH SITE AND SUBBASIN RESPONSES

The majority of our fish sampling occurs at the 12 permanent fish sites (Figure 13). At these sites, we are estimating juvenile age and abundance, growth, and survival by cohort (i.e., total biomass/period) over all summer and fall seasons, and estimates of adults or redds within each study stream. However, due to the complex interaction between stream conditions, adult escapement, and density-dependence, it is difficult to determine which of these population parameters are most likely to change. For example, juvenile abundance could decrease, but if the mean growth of individuals and their survival increases, the net production may increase. Therefore, we provide hypotheses that apply both to the productivity of juvenile and smolt steelhead and to the overall site biomass production as measured by any combination of abundance, growth, and survival (Table 9). We hypothesize that at the scale of the fish site and treatment/control section juvenile production (pre-smolt) will increase. We expect that winter and spring increases in abundance, growth, and survival will have a more significant effect on production than during other times of the year. Increases in growth and/or survival will result from i) an increase in shear zone refugia that enhances feeding efficiency, and/or ii) increases in fish cover that will increase survival due to decreased predation threat and increase refugia during high flow events. The increase in shear zone refugia, cover, and habitat diversity will lead to an overall increase in the carrying capacity of the treated sections. Based on observed increases in fish abundance from similar LWD treatments, we predict that production could increase 25%-50% relative to the control sections after controlling for the number of spawners and other changes in habitat not accounted for by using the control watersheds (Viola et al. 1989, Roni et al. 2001). The positive increase in juvenile production should lead directly to an increase in smolt production as the survival and overall production from the juvenile to smolt stage should also increase as a result of juvenile production.

Table 9. Hypothesized responses in juvenile and adult population parameters and the associated causal mechanisms and habitat changes from the installation of dynamic woody debris structures in the Asotin Creek IMW.

		Response				
Parameter	**Units**	**summer/ fall**	**winter/ spring**	**Mechanism**	**Habitat Change**	**Monitoring Method**
Age @ Migration	time	?	?	+ growth	+ shear zones	MR, PIT
Abundance (A)	fish/m2	+	++	- predation, +survival	+ pools, cover	MR
Growth (G)	g/g/d	++	++	+ feeding efficiency	+ shear zones	MR
Survival (S)	%	+	++	- predation,+G	+ pools, cover	MR, PIT
Movement	m	-	-	- searching micro-habitats	+habitat diversity	MR, PIT
Production (Pj)	g/m2/month	+	++	+ A,G,S	+ carrying capacity	NREI modeling
Production (Ps)	recruits/spawner	+	++	+ Pj	+ carrying capacity	WT, MR, PIT, SS
Adults/Redds	count	N/A	++	+local hydraulics	+ bars, sediment sorting	WT, PIT, SS

* Responses are trending positive (+), significantly positive (++), trending negative (-), significantly negative (--), unknown (?); Pj = juvenile production (pre-smolt), Ps = smolt production; Monitoring methods are MR = mark-recapture, PIT = PIT tag detections due to capture, mobile surveys, and traps, SS = spawning surveys, WT = adult weir and smolt trap.

6 MONITORING DESIGN AND SAMPLE METHODS

The monitoring design is composed of four components: fish, stream habitat, riparian habitat, and stream channel/floodplain monitoring. We are using a set of monitoring protocols for these components that are either regionally recognized protocols or well supported monitoring methods from the literature. This will allow for efficient and precise data collection, data sharing between various agencies, and the detection of biologically and geomorphologically significant changes due to restoration actions. Most monitoring activities are focused on the three study streams: Charley Creek, North Fork, and South Fork (Figure 2). All monitoring activities will be integrated with ongoing WDFW's Asotin Creek Assessment Project (Crawford et al. 2012).

An important goal of IMW projects is to test and develop the most effective monitoring tools for change detection. Although the Asotin IMW is using the most accepted protocols for fish and habitat monitoring, recent reviews of a variety of stream protocols have demonstrated that several attributes are not measured consistently between observers or with enough precision to detect moderate responses (Olsen et al. 2005, Whitacre et al. 2007, Roper et al. 2010). It is also important to note that it is not always clear how the specific metrics used to monitor stream habitat are related to the habitat requirements of fish, which is often an unstated assumption of the monitoring program. For example, substrate size distribution is often measured with pebble counts because research has shown that increased fine sediments can negatively impact salmonid redds (Quinn 2005). However, fine sediments are often underestimated in pebble counts or the location of pebble counts are not stratified by habitat type so that percent fines represent an average across several habitat types (Bunte and Abt 2001). Due to the difficulty of measuring stream habitats, we will continually review the monitoring protocols that are used in an effort to use those protocols that focus best on metrics that are precisely measured, strongly correlated with the truth, and are related to fish production.

6.1 BIOPHYSICALLY FRAMED MULTI-SCALAR GEO-SPATIAL DATA MANAGEMENT

Considerations of fish and habitat responses to restoration activities will be most informative if appraised within the appropriate spatio-temporal context of their natural and impacted environments (e.g., Wohl et al. 2005, Hemstad and Newman 2006). This requires the collection, analysis and presentation of geospatial data describing baseline and changed environmental conditions as well as some conceptual model within which biological and physical relationships are appraised. While extensive GIS data are available through various sources, they are not readily applicable to this specific purpose, (i.e. they typically require intermediate to advanced GIS skills to prepare for application specific analyses). To support this end, we are in the process of developing the Biophysical Framework for Asotin Creek (Figure 18). The Biophysical Framework is an ArcGIS based geo-database, customized map document, and geo-processing toolbox, which can be used to identify, describe and explain the biophysical context for any location in the Columbia River Basin. Development of this framework and its application are based on the River Styles Framework (Brierley and Fryirs 2005) which provides both the conceptual model that places streams into location specific, biophysical context and a set of procedures that can be followed to develop geo-spatial data describing this context for a given reach.

River Styles is a geomorphological framework comprising an integrative conceptual model and a set of guidelines, procedures and tasks that walk users through the framing of reaches into their biophysical context. These procedures are grouped into four sequential stages, each resulting in a relevant component of this context (Brierley and Fryirs 2000, Brierley and Fryirs 2005). The first stage conducts a catchment-wide baseline survey of river character and behavior, essentially classifying reaches into types to support the comparison of like with like in setting the baseline biophysical context, by relating manifested reach structure to multi-scalar environmental processes. Implementing this stage within GIS can be viewed as a more comprehensive, in-depth and finer resolution application of Beechie's (Beechie et al. 2006, Hiroo Imaki 2008) work in the CRB, which we have been using to provide context for IMW's until this framework is developed. The primary difference between River Styles and Beechie's approach is that the former is better refined in terms of hierarchical patterns and relationships, as it implements both top-down *and* bottom-up metrics by incorporating the assemblage of geomorphic units in the delineation of reach types. The higher resolution and precision is also important to relate IMW sampling to finer than the reach scales. In addition to scalar issues, implementing River Styles results in descriptions of the range of natural variability for each reach type and appraisals of catchment-wide downstream patterns. This sets up further analyses in distinguishing differing reach types from differing reach conditions and identification of catchment scale controls on recovery potential. Condition assessment is the second stage, which steps through the assessment of geomorphic river condition in terms of that expected and river evolution. Analysis of recovery potential is conducted in the third stage, via procedures to predict the likelihood of future condition based on location specific controls and constraints. Finally, the results from each of these stages are appraised and summarized in the fourth stage, in terms of implications for river management activities.

Several aspects of the River Styles Framework and its implementation within a GIS are especially relevant in supporting IMWs, especially the multi-scalar, hierarchical and spatially explicit perspectives. The causal mechanisms and responses are likely to be operating at multiple scales and can be revealed and appraised within this framework. The multi-dimensionality of rivers is also incorporated to support classification and change analyses in terms of channel-hyporheic-floodplain relationships. The temporal dimension (including frequency and duration of disturbance events and responses) and timeframes of evolutionary adjustments are represented in time series geo-database formats, which can be associated with longitudinal, vertical, and lateral spatial dimensions at multiple scales.

Incorporating local scale IMW's into the River Styles' catchment wide framework provides two important advantages. Firstly, while local scale habitat is a key relationship between biota and physical structures/processes within channels and floodplains, habitat is a function of landscape wide processes that can best be understood from a catchment wide perspective (Zalewski and Welcomme 2001). Secondly, identifying the scalar and positional attributes that are relevant to habitat and fish requires the ability to relate features to each other across the catchment. This allows identification of the natural range in the character and behavior of a reach type and provides insight to expected versus existing reach condition. This catchment wide perspective is represented in GIS by datasets describing catchment position and channel network. These feature datasets and attributes are related within a hydrologically informed geodatabase model to describe the conveyance channel components in terms of process zone (sediment source, transfer or accumulation) and connectivity. This information is vital to extract catchment level metrics used to evaluate relationships between fish assemblage, local habitat variables, and position along stream networks (Smith and Kraft 2005).

Implementing River Styles within GIS involves storing, exploring and analyzing geo-spatial data within a framework that makes these insights intuitive. IMW habitat monitoring data are built into the framework as spatially explicit features (e.g., polygons, lines, points, raster) and time-series attributes as they are collected. Once the physical component of the framework is built, biogeochemistry, vegetation, fish, invertebrates and other ecological components are incorporated at relevant scales. Users can apply the framework in various ways: visualizing relationships between datasets describing forms and processes (represented by data organizational structure in ArcCatalog and ArcMap); conducting spatial analyses (data query, export to statistical packages and/or ArcToolbox geo-processing); or creating maps for presentation of results as well as questions at hand. This framework will provide a coherent template for ongoing development and sharing in line with adaptive management objectives (Brierley J. and Fryirs 2008).

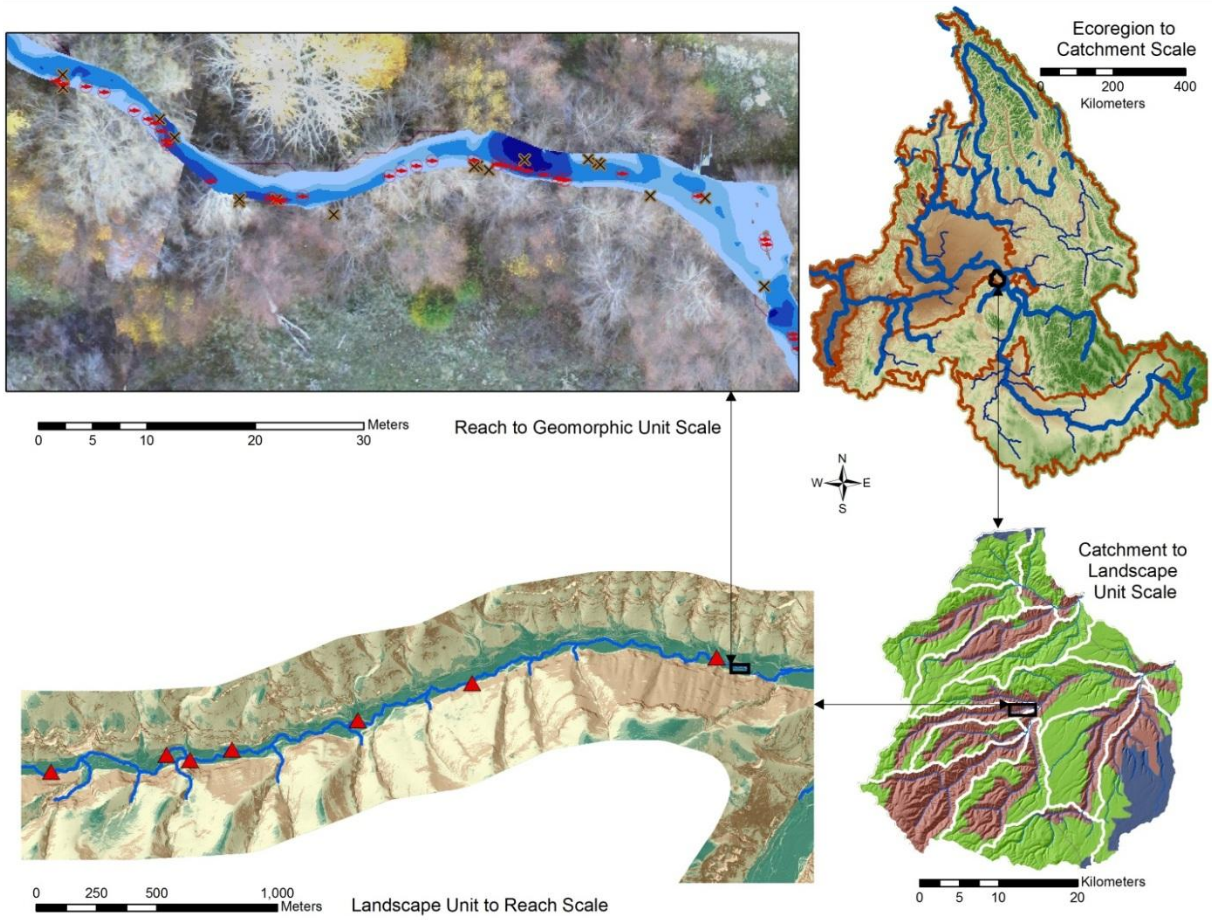


Figure 18. Example of the Biophysical Framework we are developing to provide multi-scalar context for the Asotin IMW project. The four panels depict the major scales from the Columbia River Basin, Ecoregion, Landscape, Reach, and Geomorphic unit scales. Red triangles at the reach scale are reach breaks and brown X's and red dots at the unit scale are locations of LWD and PIT tagged fish all identified during rapid field surveys.

6.2 MONITORING INFRASTRUCTURE

We have developed a monitoring infrastructure based on the experimental design and project objectives. The restoration treatments will be implemented in the study streams and therefore most of our sampling effort is directed to the lower 12 km of the study streams. The monitoring infrastructure has been developed from preexisting monitoring programs (e.g., WDFW Asotin Program, USGS gauges) and new installations, such as new juvenile steelhead and habitat sampling sites, PIT tag arrays, temperature probes, and water levels gauges (Figure 4 and Figure 19). This base infrastructure will allow us to relate responses of fish populations to hydrologic attributes (i.e., discharge and water temperature) and specific stream habitat attributes at the site/reach, stream, subbasin, and watershed scale.

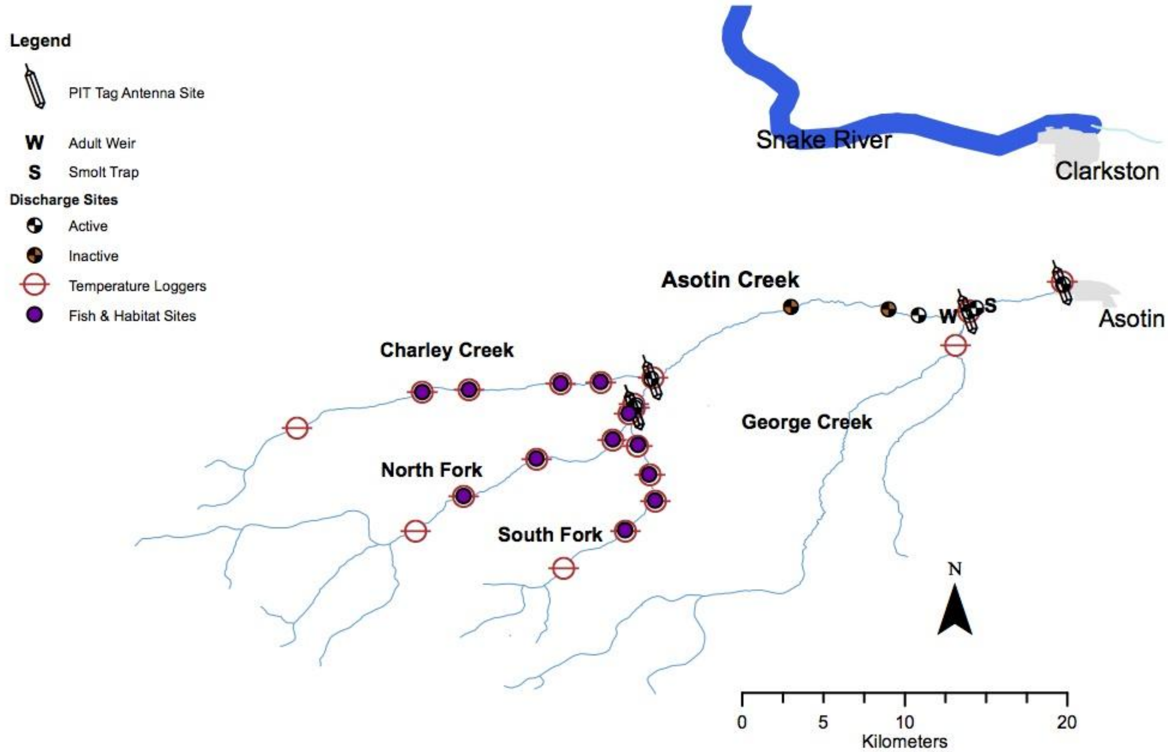


Figure 19. Monitoring infrastructure for the Asotin Creek IMW including PIT tag arrays, adult and smolt migration traps, discharge gauges, temperature loggers, and fish and habitat sites. Note that fish/habitat sample sites have been rearranged since the 2009 IMW design based on changes in the experimental due to power analysis results and logistical constraints.

6.2.1 ADULT WEIR AND SMOLT TRAP

The WDFW has been conducting a detailed assessment of the steelhead population in Asotin Creek since 2004 (see below for more description of the WDFW project; Crawford et al. 2012). One of the primary goals of the WDFW assessment is to estimate the life stage survival rates of the steelhead population. To accomplish this goal WDFW operates a smolt trap and adult weir on the mainstem Asotin Creek. The smolt trap is operated for several months in the spring and fall to capture outmigrating steelhead smolts. An adult weir is operated from January to June to capture returning adults to Asotin Creek. Redd surveys are also conducted on approximately 20% of available spawning areas.

6.2.2 IMW SAMPLE SITES

We established permanent fish and habitat monitoring sites in each of the control/treatment sections within the study streams in 2008 and 2009 (Figure 13). Due to changes in private landowner access and refinement of the experimental design we will be shifting two sample sites from Charley Creek (CC-F1 and CC-F4) to treatment sections in the North Fork and South Fork (NF-F2 and SF-F4; Appendix A). There are four fish sites in each creek, two in each treatment section and one in each control section for a total of 12 fish sites. Each fish site is 300-600 m long and was systematically located within a section so that they were centered either 1 km or 3 km upstream from the bottom of the section. This was done to ensure that there was independence between fish sites both within a treatment section and between treatment sections and control sections. The location of fish sites within the sections was selected randomly whereas each treatment section always has a fish site at the 1 and 3 km location. We periodically sample "upper" sites for fish which are sites 5-7 km upstream of the IMW study area. These sites are used to assess the boundary between anadromous and resident *O. mykiss*. Stream habitat is sampled at three sites located within every fish site. One habitat site is sampled every year with the CHaMP protocol (CHaMP 2012) and the other two sites are sampled with a rapid habitat survey.

Many other types of data are being collected to monitor fish and habitat at various scales such as PIT tag arrays, mobile PIT tag surveys, fluvial audits, aerial photography, and LiDAR. Some of these data are not collected annually and will be used as ancillary data to help explain casual mechanisms and linkages between habitat change and fish responses.

6.2.3 PIT TAG ARRAYS

We installed PIT tag antennas at three sites in 2009 and at one site in 2011 to monitor PIT tagged fish entering and leaving the Asotin mainstem, Charley Creek, North Fork, and South Fork (Figure 19). We refer to these PIT tag antenna sites hereafter as *interrogation sites*. Each interrogation site has a three-letter code assigned to it by PTAGIS. The interrogation sites are located at the Highway 129 bridge crossing at the town of Asotin (ACM), the Cloverland Bridge crossing approximately 5 km from the mouth of Asotin Creek (ACB), in Charley Creek 0.5 km upstream from the mouth (CCA), and at the confluence of the North and South Forks of Asotin Creek (AFC). All of the sites except ACB provide directional information in that at least two banks of antennas cross the stream so that fish moving downstream will cross the antennas at different times and allow their direction of travel to be determined. We define an antenna array (hereafter an *array*) as one or more antennas spanning the stream at a single cross section as per Zydlewski et al. (2006) and Connolly et al. (2008). At the four interrogation sites in Asotin Creek there are a total of eight arrays (Table 10). Appendix B provides a detailed summary of the location, operation, and antenna arrangement of each interrogation site.

Table 10. Location of interrogation sites, arrays, and the number of antennas per array within Asotin Creek for monitoring PIT tagged fish.

Interrogation Site	Array Number	Location/Stream	Number of Antennas
ACM	1	Mouth/Asotin Cr	2
ACM*	2	Mouth/Asotin Cr	2
ACB	3	Cloverland Bridge/Asotin Cr	5
CCA	4	0.5 km from mouth/Charley Cr	1
CCA	5	0.5 km from mouth/Charley Cr	1
AFC	6	Confluence of NF and SF/Asotin Cr	3
AFC	7	Mouth/North Fork	2
AFC	8	Mouth/South Fork	1

* another array with two antennas was added to ACM in the summer of 2012 during maintenance and repair of this interrogation site.

The interrogation sites are all run with a Biomark FS1001M multiplexing reader that operates at a frequency of 134.2 kHz. Each reader can auto tune and read up to six antennas but the antennas can be no further than 30 m from the reader to function properly. Each antenna was constructed by the WDFW in Wenatchee, WA using 10 cm diameter pvc pipe. In 2011, each array was outfitted with a Campbell Scientific data logger, modem, and telephone line to allow for remote access to the PIT tag data and array diagnostic information. The data at all sites except ACM are now downloaded automatically every 12 hours and uploaded to PTAGIS via a cooperative agreement with Quantitative Consultants Inc. (QCI) that provides this service for all ISEMP interrogation sites and many WDFW interrogation sites in the Columbia Basin (*ACM is downloaded manually due to interference from the phone line). The function of each interrogation site (current, noise, test tag firing, data upload, and voltage) is monitored daily and warning alarms are sent from QCI if any of the sites critical functions are detected to be below user defined thresholds (i.e., drops in voltage could indicate a power failure and an alarm is sent via email). If necessary, the antennas are manually tuned during the field inspections if noise levels are above 10%.

6.2.3.1 ANTENNA AND ARRAY EFFICIENCY

There are between two and six antennas at each interrogation site ranging between 2-7 m long. The read range of all antennas has ranged from 25-50 cm during regular checks with test tags. The arrangement of each set of antennas at an array is designed to cover as much of the bankfull width as possible to maintain high detection efficiency. At most of our sites we estimate the antennas cover to be > 90-95% of the bankfull width (BFW); however, the South Fork array only covers 60% of the BFW under high flow conditions but the thawleg continues to flow directly over the antenna. Field checks of the detection efficiency of each antenna are performed regularly by floating a plastic PIT tagged fish across the antenna 10 times and recording the number of detections. During each field check we recorded the total depth of water, height of water above the antenna, and height above the antenna at which the test tag is first read to estimate the read range of each antenna.

We assessed the detection efficiencies of arrays using an indirect method described by Connelly et al. (2008) where the number of detections of PIT tagged fish at two or more arrays at the same interrogation site are compared (i.e., were fish detected at both upstream and downstream arrays at the same site). To perform this comparison we first classified all the fish that have been detected by an array as either a downstream migrating juvenile or an upstream migrating adult spawner. We classified the age and direction fish were moving using our PIT tag database (i.e., records of all our PIT tagged fish), queries of the PTAGIS database, and by determining the first time a fish was detected at each array. If a fish was detected by only one array we used its last known location from IMW fish capture events to help determine its direction. Adults were either sorted out by information provided by the adult weir operated by WDFW, or from the fish's most recent data uploaded on PTAGIS. Connelly et al. (2008) established a set of criteria which we adopted to select fish passage events that were suitable for estimating efficiency. In addition to these criteria, we also removed all tagged species except steelhead from the data. The criteria we used to include a PIT tag as a detection event were:

1. If the fish was captured, tagged, and released > 50 m away from any array;

2. When a fish is detected at only one array, assume that it passed all arrays but was not detected by the others.
3. Include PIT tags if the time between crossing two arrays does not exceed the 90th percentile of all times recorded to cross the arrays.
4. If the direction of movement can be reasonably determined from previous or later detections.
5. If a fish-detection event meets all of the criteria above, treat it as a fish-passage event.
6. Do not use a fish-passage event if the same fish is detected on any antenna 12 hours before or after this event.

In order to better understand how our arrays perform throughout the year, we calculated efficiency during spring runoff in 2010 and 2011 when the water height over the arrays is at its highest. We used data from nearby USGS and WDOE stream gauges as well as our own height gauges at each site. There was not a stream gauge installed at the mouth of North Fork during this time, so we used the correlation between the South Fork gauge and a USGS gauge 200 m downstream of the South Fork and North Fork confluence. We estimated efficiency over the entire year from 1/1/2010 to 1/1/2011, and from 4/1 to 6/30 in 2010 and 2011 at each array. We also estimated the combined efficiency of each pair of arrays leading to the study streams. The combined efficiency is the probability of detecting a tagged fish by at least one of the arrays involved in the estimate.

Other studies have used this method with two or more arrays (Connelly et al. 2008; Zydlewski et al. 2006). We estimated the efficiency of each array in pairs as 2x1, 2x2 or 2x3 systems, meaning two arrays consisting of 1, 2, or 3 antennas. There have not been enough detections at the new interrogation site at the mouth of Asotin Creek (ACM), so we have not estimated the detection efficiency for this site, but expect to in the future.

The calculations require at least two pairs of arrays with one downstream from the other. We selected arrays that allowed us to calculate efficiency for tagged fish moving in and out of the study streams (Table 11). To calculate the efficiency of our 2 x 2 and 2 x 1 PIT tag interrogation systems, we used the calculations described by Connelly et al. (2008). This calculation has two assumptions:

1) The probability of a tagged fish being detected by one array is independent of a tagged fish being detected by any other array, and
2) The tagged fish detected at the first array continues to move in the direction of the next array.

Table 11. Arrays used to calculate detection efficiency from 2010 to 2011 in Asotin Creek. We were able to calculate efficiency by pairing arrays leading to the major tributaries of Asotin Creek.

Stream	Site	Arrays
South Fork	AFC	6 and 8
North Fork	AFC	6 and 7
Charley Creek	CCA	4 and 5
Asotin Creek	ACB	3, 4, and 6

The criteria we used to determine a fish detection event ensures that we follow the assumptions. We defined the arrays in each system as A and B from downstream to upstream. The efficiency of each array in a system is described as:

PA = NA/(NA+UA)

Where
NA = Fish detected on array A
UA = Fish undetected on array A

To calculate UA, the number of fish undetected on array A, we used the formula:

UA = (NA x NB)/NAB

Where
NA = Fish detected on array A
NB = Fish detected on array B
NAB = Fish detected on array A and B

The overall efficiency, or detection probability, of the system is then calculated as:
P = 1 – [(1-PA) x (1-PB)]

6.2.4 WATER LEVEL GAUGES AND TEMPERATURE PROBES

Stream discharge and water temperature are two key variables we are recording throughout Asotin Creek. The size and frequency of discharge can have a large effect on all aspects of a salmonid's life history. Extreme low flow can limit adults from accessing spawning grounds, allow the buildup of fine sediments, and limit the amount of habitat available to juveniles. Temperature controls all physiological processes of fish and high temperatures can lead to increased stress, disease, and death in both adult and juvenile salmonids. Discharge and temperature can fluctuate over relatively small scales due to local conditions like anchor ice, bedrock formations, riparian conditions, substrate size and fine sediment, and the presence of groundwater springs. Therefore, we have developed a watershed wide discharge and temperature monitoring infrastructure incorporating existing monitoring stations and new sites (Figure 4).

Both the US Geologic Service (USGS) and the Washington State Department of Ecology (DOE) operate stream discharge monitoring sites within Asotin Creek. The longest discharge record exists for two gauges that are no longer operating at Kerney Gulch and Headgate Dam. We installed two TRU Track water height loggers in September 2010 (http://www.trutrack.com). One water height logger has been placed near the Charley Creek antenna array and the other is at the mouth of the South Fork of Asotin Creek. Both sites are setup to record the water level, air temperature and water temperature every two hours. We periodically measure the velocity at these sites by hand using a flow probe. Using a linear regression model we created a stage-discharge relationship to produce discharge at each site in cubic feet per second (cfs). The DOE maintains a flow gauge on the mainstem of Asotin Creek upstream of the confluence with George Creek and on George Creek. There is also a flow gauge maintained by the USGS just downstream of the confluence of South Fork and North Fork Asotin Creeks (Figure 4). We installed pressure transducers at each PIT tag interrogation site that record water temperature and water pressure (Table 12). We have not developed stage-discharge relationships for these new sites, but are collecting the data to do so in the future.

Table 12. Location and installation date of Asotin IMW water gauge stations.

Site	Logger Type	Date Installed
Charley Creek	TruTrack WT-HR	9/29/2009
South Fork	TruTrack WT-HR	9/29/2009
Charley Creek	Pressure Transducer	12/7/2011
North Fork	Pressure Transducer	8/25/2011
Asotin Creek at Cloverland Bridge	Pressure Transducer	8/25/2011
Asotin Creek near mouth	Pressure Transducer	9/7/2011

Water temperature is monitored at all of the discharge sites and at 22 temperature logger sites that we have established as part of the Asotin IMW (Figure 4). The majority of the temperature monitoring sites are within fish sample sites in the three study streams. We are using HOBO Pendant® temperature loggers to collect water temperature every 15 minutes. The temperature loggers are secured to the bottom of the stream with wire cable and checked a minimum of twice a year to download data, replace batteries and check they are still secured. We have also placed temperature loggers at the upper elevation sites, all of our PIT tag array locations, and along the mainstem of Asotin Creek and George Creek to characterize water temperatures outside the study streams.

6.3 FISH MONITORING

Our fish monitoring program is primarily focused on juvenile steelhead capture, PIT tagging, and recapturing or resighting of fish within the study streams. We are focusing on this proportion of the population because it will provide the best measure of freshwater production that is most directly influenced by stream habitat conditions and restoration actions. These fish monitoring efforts will be supported by WDFW monitoring of outmigrating smolts and returning adults with the mainstem smolt trap and adult weir respectively. Spawning surveys will also be conducted by WDFW and IMW staff as stream conditions permit. Below we describe the fish monitoring programs in detail.

6.3.1 WDFW MAINSTEM STEELHEAD MONITORING

One of the reasons that Asotin Creek was chosen as a site for an IMW was that the steelhead population has been monitored continually since 1984, it was designated a wild steelhead refuge in 1997, and it is currently conducting a detailed assessment of steelhead abundance, productivity, and distribution (Mayer et al. 2008, Crawford et al. 2012). The IMW relies on both historic and current WDFW monitoring in Asotin Creek. The historic fish monitoring data were used to determine the status and trend of the population and were useful in estimating population variance over time (annually) and within and between tributaries (on a reach and stream wide scale). We also used the historic data to determine the correlation of juvenile and adult abundances between study streams, as the utility of control sites in different tributaries relies on the synchronicity of these populations (Downes et al. 2002). The historic data for Asotin Creek includes juvenile abundance estimates, juvenile tagging, juvenile and adult trapping, and redd counts in the mainstem and tributaries of Asotin Creek.

6.3.1.1 ASOTIN CREEK STEELHEAD ASSESSMENT

Currently the WDFW are conducting a detailed assessment of the steelhead and Chinook populations in Asotin Creek by operating a smolt trap and adult weir and conducting redd counts throughout the watershed (Crawford et al. 2012). The smolt trap and adult weir efforts began in 2004 and 2005 respectively. The goals of the Asotin Creek Steelhead Assessment are to "… determine the abundance and current productivity of the Asotin Creek steelhead population and to estimate life stage survival rates in the mainstem of Asotin Creek" (Crawford et al. 2012). The combination of the smolt trap and adult weir data can help interpret the results of the Asotin IMW because these data can be used to calculate key metrics of production such as: watershed smolt production, adult escapement, smolt to adult return rate (SAR), and recruits per spawner (i.e., progeny to parent ratio). With these measures the changes in production within the IMW study streams can be compared to annual changes in smolt production at the watershed scale. Calculation of SAR at the watershed scale will also allow us to compare the rate pre and post restoration and help to put the IMW results in context compared with out-of-basin factors that influence abundance and productivity. In 2010, the WDFW began tagging adult steelhead at the weir trap that will also allow us to determine the movement of adults within Asotin Creek when adults are detected by the PIT tag arrays.

We briefly review the methods used at the smolt trap and adult weir here, but for more details see Mayer et al. (2008) and Crawford et al. (2012). A 1.52 m rotary screw trap (referred hereafter as a smolt trap) is used to capture smolts outmigrating in the spring and fall. Length and weight of all smolts is recorded and smolts are scanned for the presence of tags (i.e., outmigrating smolts could have been tagged as juveniles during IMW tagging (see below). A proportion of the captured smolts are tagged with PIT tags and scale samples are collected to age the smolts. Trap efficiencies are calculated once to twice weekly by releasing PIT tagged fish approximately 200 m upstream of the trap.

Returning adults are captured using a resistance board floating weir from January to June each year. General biometric measurements are made of all adults including sex, length, weight, and scale samples for aging. Fish are checked for the presence of tags or marks, and the fish's origin is identified where possible. Hatchery origin fish are not passed above the weir. Starting in 2010, all unmarked wild fish were PIT tagged in the dorsal fin sinus so that their movement within Asotin Creek could be monitored by the IMW array infrastructure. Adults are also tagged with colored anchor tags that are recorded during spawning surveys to estimate the weir efficiency.

6.3.2 JUVENILE CAPTURE AND TAGGING IN THE STUDY STREAMS

To assess the direct effects of stream restoration we are capturing and PIT tagging juvenile steelhead within the treatment and control sections of the study streams. Juvenile tagging in the study streams will allow us to determine juvenile abundance, growth, movement, and survival pre and post restoration. We started tagging juvenile steelhead in 2008 (a pilot year) where we captured and PIT tagged juveniles at three fish sites in each study stream (i.e., nine sites total; Table 13). All fish in this study are PIT tagged with 12 mm BioMark TX1411SST or Allflex HPT12-BIO12.B.03V1 high performance tags (134.2 kHz FDXB). In 2009, we expanded the tagging efforts to 12 sites based on the experimental design and restoration design that was proposed to conduct all the restoration in Charley Creek (see Appendix A for summary of IMW design changes). The current tagging program still calls for 12 sites to be sampled but the arrangement of the sites has changed to four fish sites in each study stream to ensure replication of sample sites within the treatment sections. Each fish site is visited twice a year during a summer tagging session (June to July) and a fall tagging session (September to October). The two tagging sessions allow us to calculate the population parameters over shorter time periods (i.e., summer to fall and fall to the following summer; Table 14). We may also initiate a winter capture session to allow us to calculate abundance and growth over the winter period. Sites 5-7 km upstream of the IMW study area (i.e., first 12 km of each study stream) are surveyed periodically to assess the boundary between anadromous and resident *O. mykiss*.

Table 13. Fish sample site matrix with completed and proposed sample schedule through to the end of the IMW project. Grey shading represents the length of time each section will be in a "post-restoration" state. All "X's" without shading represent control samples.

Stream	Section	Fish Site	Year 2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Charley	1	CC-F1		X	X	X							
		CC-F2	X	X	X	X	X	X	X	X	X	X	X
	2	CC-F3	X	X	X		X	X	X	X	X	X	X
		CC-F4		X	X								
	3	CC-F5	X	X	X	X	X	X	X	X	X	X	X
		CC-F6		X	X	X	X	X	X	X	X	X	X
North Fork	1	NF-F1	X	X	X	X	X	X	X	X	X	X	X
		NF-F2					X	X	X	X	X	X	X
	2	NF-F3											
		NF-F4	X	X	X	X	X	X	X	X	X	X	X
	3	NF-F5											
		NF-F6	X	X	X	X	X	X	X	X	X	X	X
South Fork	1	SF-F1											
		SF-F2	X	X	X	X	X	X	X	X	X	X	X
	2	SF-F3	X	X	X	X	X	X	X	X	X	X	X
		SF-F4					X	X	X	X	X	X	X
	3	SF-F5	X	X	X	X	X	X	X	X	X	X	X
		SF-F6											
Total Sites/Year			**9**	**12**	**12**	**10**	**12**	**12**	**12**	**12**	**12**	**12**	**12**

* Sites 5-7 km upstream of the IMW study area (i.e., first 12 km of each study stream) are surveyed periodically to assess the boundary between anadromous and resident O. mykiss.

Table 14. Mark-recapture and mobile survey periods from 2008-2011 in the Asotin Creek IMW study streams.

Method	Start Date	End Date	Midpoint Date	Days	Season
Mark-Recapture	7/29/2008	8/6/2008	8/2/2008	9	Summer
Mark-Recapture	6/17/2009	7/30/2009	7/9/2009	44	Summer
Mobile	8/18/2009	9/17/2009	9/2/2009	31	Fall
Mark-Recapture	9/28/2009	10/7/2009	10/3/2009	10	Fall
Mark-Recapture	7/1/2010	8/5/2010	7/19/2010	36	Summer
Mobile	9/7/2010	9/21/2010	9/14/2010	15	Fall
Mark-Recapture	9/26/2010	10/15/2010	10/6/2010	20	Fall
Mobile	12/17/2010	1/13/2011	12/31/2010	28	Winter
Mobile	3/20/2011	3/27/2011	3/24/2011	8	Spring
Mark-Recapture	6/22/2011	7/21/2011	7/7/2011	30	Summer
Mobile	8/25/2011	9/22/2011	8/31/2011	13	Fall
Mark-Recapture	9/28/2011	10/18/2011	10/8/2011	20	Fall
Mobile	1/9/2012	1/13/2012	1/11/2012	5	Winter

Each fish site is approximately 300-600 m long. We capture fish by electro-herding with low voltage electroshocking to scare fish downstream into a seine or dip nets. We normally use a maximum voltage of 100 volts and 45 Hz frequency as per NOAA guidelines (NOAA 2000). Seine nets have a modified fyke net to increase capture efficiency (Appendix C). We use the seine net mostly in the North Fork because it is larger and has higher flows than Charley Creek and South Fork which can be more efficiently fished with dip nets. An entire fish site is typically sampled in 2-3 hours and captured fish are held in live wells for processing and recovery. The live wells are constructed with 20 L plastic buckets with lids and 30-40 5 mm holes drilled throughout to allow water flow. No more than 25 fish are held in a live well and each well is secured to the stream bottom with rocks and logs while capturing continues upstream. All steelhead over 70 mm are anesthetized, tagged with 12 mm PIT tags, measured (fork length to nearest mm), weighed (to the nearest 0.1 g), allowed to recover for 30-40 minutes in a live well, and released into the approximate location where they were captured. Incidental captures of bull trout and Chinook are rare (e.g., < 30 bull trout and < 130 Chinook in 4 years of sampling), but we tag and collect the same metrics from these species to potentially improve our understanding of their life history within Asotin Creek. All other species captured are counted and released immediately. Each site is resampled on the following day in the same manner to estimate population size (see Abundance below).

Our goal is to capture and tag between 150-200 fish per tagging event at a site (i.e., at each 2 day capture and tagging event per site, per season) based on power analysis conducted by ISMEP that suggested that this number of tags per site will provide robust estimates of abundance and survival (Bouwes et al. *in preparation*). Therefore, our annual goal is to tag 3600-4800 juvenile steelhead per year (150-200 per site x 12 sites x 2 seasons).

6.3.2.1 ABUNDANCE AND AGE

To estimate juvenile abundance at each site we used 2-pass mark-recapture surveys (hereafter referred to as ***mark-recapture surveys***) which provide more precise and less biased estimates than traditional depletion estimates (Rosenberger and Dunham 2005). We do not use block nets for the mark-recapture surveys because of the relatively long site lengths we are using (i.e., 300-600 m) and tests that we conducted that indicate we are not violating the assumption of mark-recapture estimates that fish are not leaving the sample site during the capture session. We tested this assumption in the summer of 2009 by conducting 3-pass mark-recapture sessions at all 12 fish sites and plotting relationships between the accumulated number of previously tagged fish and the proportion of tagged fish recaptured during the first and second recapture events (Schnabel 1938; Figure 20). The less linear this relationship is, the more the assumptions of the mark-recapture are violated by either fish leaving the site or unequal catchability (Krebs 1999). We found a strong linear relationship with the 3-pass data at all sites suggesting that few fish are moving out of the sample sites during the mark-recapture surveys; however, the linear relationships were stronger for Charley Creek and decreased with increasing stream width suggesting that the assumptions of mark-recapture are violated in the North Fork more than Charley and the South Fork. Based on these results we now conduct only 2-pass sampling but we may use virtual block nets to further test the assumptions of the mark-recapture method. Virtual block nets are portable PIT tag antennas that are battery powered and can be left at the top and bottom of a reach while we are sampling. Any PIT tagged fish leaving the site will be detected and this information can be used to revise our abundance estimates.

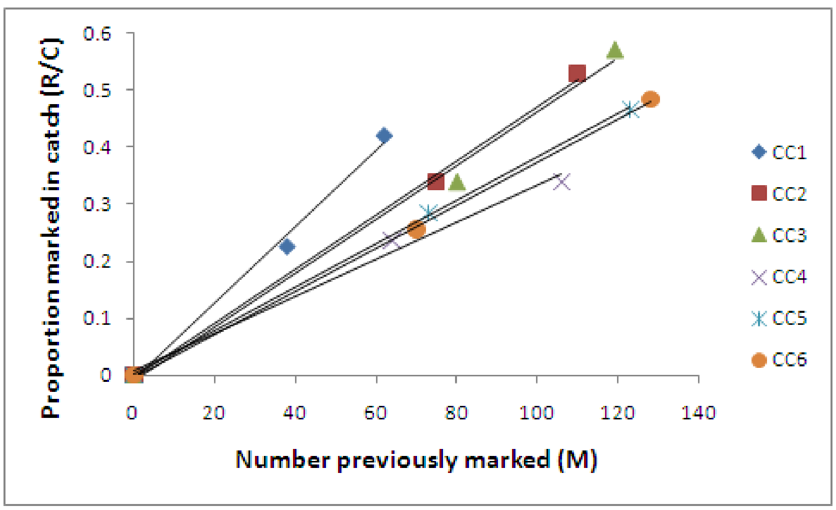


Figure 20. Example of the test of the mark-recapture model assumptions using three pass mark-recapture estimates for Charley Creek (sites 1-6) from the summer of 2009 (r^2 for all correlations >0.98).

We calculated total abundance estimates for 2-pass mark-recapture sampling using the Chapman estimator (Seber 1992). We used a more conservative formula for the abundance estimate whereby we added 1 to the capture, mark, and recapture totals to compensate for a tendency of this formula to over-estimate population size (Equation 1; Krebs 1999).

Equation 1: $N = ((C+1)*(M+1)/(R+1))-1$

Where:
N = Size of Population at time of marking
C = Total number of individuals captured in second sample
M = Number of individuals PIT tagged in first sample (* this includes PIT tagged individuals captured in first sample that were tagged in previous sample sessions)
R = Number of individuals in second sample that were PIT tagged in the first sample

We calculated the sample variance of the population estimate using the procedure of Williams et al. (2001; Equation 2). We used the variance to calculate 90% confidence intervals (CI) on each population estimate and then converted the population estimate to an abundance estimate of juvenile steelhead per m^2. We chose to use 90% CI to lower the risk of failing to detect an effect of restoration when one is present (limiting the potential Type II error; Peterman 1990).

Equation 2: S^2 = ((M+1)*(C+1)*(M-R)*(C-R))/(((R+1)^2)*(R+2))

Scale samples were collected from a subsample of the first 20 fish captured at each fish site during the summer capture sessions to determine a relationship between length and age. All scales were submitted to the WDFW scale reading lab and analyzed by counting annuli according to procedures described in Jearld (1983). In 2011, we collected scales from all fish captured < 120 mm in length to increase our sample size of length and age data.

6.3.2.2 GROWTH

Limited information exists on growth rates of Pacific salmon in natural stream settings despite the potential importance of growth on both freshwater and early ocean survival (Hayes et al. 2008). Freshwater growth rate can strongly affect the age of smolting in salmon and steelhead, which can lead to different life history expressions (Horton et al. 2009, Beakes et al. 2010). Growth rates can be affected directly by environmental factors such as water temperature (Xu et al. 2010), or biotic factors such as food availability (Imre et al. 2004), or density-dependence (Utz and Hartman 2009, Bailey et al. 2010, Foldvik et al. 2010). Changes in stream habitat quality and availability are predicted to improve growth rates due to a more optimal arrangement of habitat types and subsequent stream flows which increase the efficiency of feeding for young salmonids (Hanson et al. 1997, Railsback and Rose 1999, Urabe et al. 2010). We are monitoring individual growth rates to help evaluate changes in freshwater production and better understand the influence of stream restoration on growth during different periods.

Every bull trout, Chinook, and steelhead captured during the summer and fall capture sessions are weighed to nearest 0.1 g and measured to the nearest mm. We then calculate several growth metrics for both length and weight including total growth (unit change over entire period), absolute growth rate (mm and g per day) and relative growth rate (unit change/average unit/day). We calculated relative growth rate to account for differences in growth rate based on the size of the fish and used the average weight during the growth period we were assessing to calculate this metric with minimal bias. Therefore, relative weight was calculated as:

$(W_e - W_s)/[(W_e + W_s)/2]/D_{S09\text{-}F09}$

Where

W_e = end weight

W_s = start weight

$D_{S09\text{-}F09}$ = number of days in the growth period between summer 2009 and fall 2009.

Growth is summarized by specific growth periods that range from 106-366 days in length (Table 15). Only fish that were captured and recaptured at the same site were used to calculate growth so that average growth represents the growth at a fish site assuming limited movement outside a site during the growth period. These measures of growth will be used individually to describe basic growth patterns of juvenile steelhead in Asotin Creek, as well as understand how growth is affected by restoration actions and to estimate overall production in each restoration treatment and control section.

Table 15. Growth periods used to calculate growth rates for PIT tagged fish in Asotin Creek. Growth periods span from summer (S) sample sessions to fall (F) sample sessions within the same year, and from fall to summer sessions in the following year.

Growth Period (Session and Year)	Start Date	End Date	Days/Period
S08-S09	7/29/2008	7/30/2009	366
S09-F09	6/17/2009	10/7/2009	112
F09-S10	9/28/2009	8/5/2010	311
S10-F10	7/1/2010	10/15/2010	106
F10-S11	9/26/2010	7/21/2011	298
S11-F11	6/22/2011	10/18/2011	118

6.3.2.3 SURVIVAL

Mark-recapture data has been used extensively to estimate population abundance, but with the advent of PIT tag technology and computer software, it has allowed estimation of other life history parameters such as survival, emigration, and immigration. There has been a shift towards trying to estimate demographic parameters such as survival rates because these parameters provide information on the processes of population growth or decline compared to abundance estimates that only provide information on the pattern (Lebreton et al. 1992). To estimate changes in juvenile steelhead survival we will be analyzing encounter histories generated for each individual PIT tagged juvenile steelhead from active tagging and mobile surveys, and passive detections at the PIT tag arrays and the smolt trap using Program MARK (Cooch and White 2002). MARK has numerous models for assessing mark-recapture data. Cormack-Jolly-Seber (CJS) models have been well tested and used for survival estimation of PIT tagged fish in small and large freshwater streams (Horton et al. 2009). However, CJS models require captures and recaptures (active sampling period) to occur during discrete and short time periods, relative to the period between active sampling sessions. Detection of PIT tagged individuals at passive instream arrays (PIA), which continuously collect data, provide a valuable source of additional resighting information, but these data cannot be used directly in the CJS sampling framework. However, other mark-recapture models, such as the Barker model, have been developed to accommodate continuously collected resight and recovery data in the interval between sampling occasions (Barker 1997, Barker et al. 2004). The Barker model unlike the CJS model, can estimate true survival compared to apparent survival (survival + emigration) and also can estimate site fidelity and a host of other demographic parameters (Table 16). We are using the Barker model to assess survival rates of juvenile steelhead, however we recognize that we may need to use other modeling approaches, such as multistate mark-recapture models, in the future to further refine our demographic estimates (Lebreton et al. 2009, Horton et al. 2011).

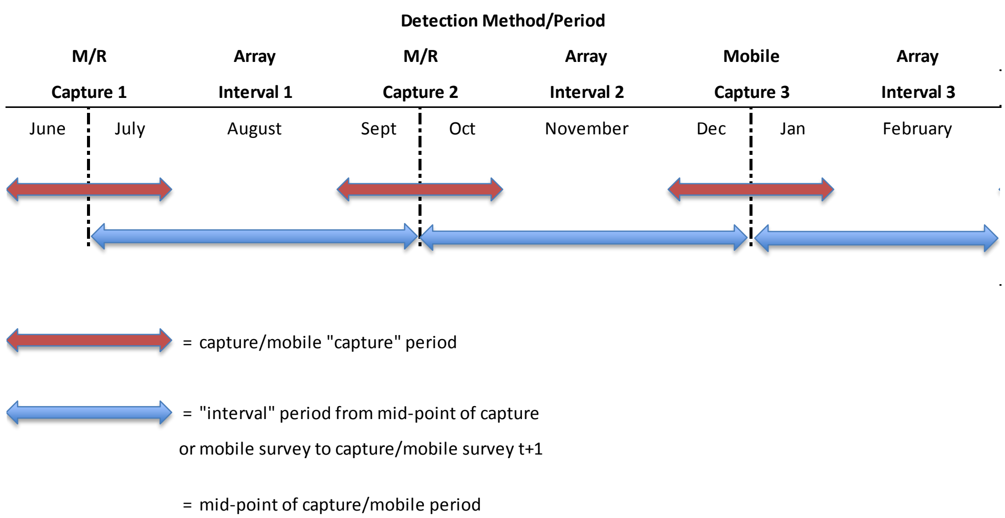
Table 16. Demographic parameters estimated from Cormack-Jolly Seber and Barker population mark-recapture models.

Cormack-Jolly Seber Model	Barker Model	
Φ = apparent survival probability (includes emigration) *p* = capture probability	*S* = survival probability *p* = capture probability *r* = the probability found dead and the tag reported (assume 0) F_i = site fidelity F'_i = immigration rate	*R* = the probability of being resighted (alive) between capture events, and staying alive during the interval *R′* = the probability that the fish dies during the interval, is not found dead but was resighted alive between capture events before it died.

We used the Barker model in MARK to calculate survival over ten periods from 2008–2011 (Table 17). Periods were of unequal length, but we standardized period length in Program MARK so that parameter estimates were monthly (e.g., S = 0.8 is probability animal survived for 1 month). We developed individual encounter histories based on detections of PIT tagged juvenile steelhead from mark-recapture surveys, mobile surveys, and fixed arrays (Figure 21). Detections were grouped into two encounter categories: i) discrete capture periods and ii) passive interval periods. We treated mark-recapture and mobile surveys as discrete “capture” events because they occur over a short time period (i.e., 2-3 hours to 2 days per site) and defined the intervals as the period between the mid-points of each capture period (Table 14).

Table 17. Periods (seasons) over which survival and other Barker model parameters were estimated for steelhead in tributaries of the Asotin Creek.

Period Name	Start Date	End Date	Days	Months
Annual 2008-2009	8/2/2008	7/9/2009	341	11.20
Summer 2009	7/8/2009	9/2/2009	57	1.87
Fall 2009	9/3/2009	10/2/2009	30	0.99
Fall-Summer 2009-2010	10/3/2009	7/18/2010	289	9.51
Summer 2010	7/19/2010	9/14/2010	58	1.91
Fall 2010	9/15/2010	10/5/2010	21	0.69
Fall2 2010	10/6/2010	12/30/2010	86	2.83
Winter 2011	12/31/2010	3/23/2011	83	2.73
Spring-Summer 2011	3/24/2011	7/6/2011	105	3.45
Summer 2011	7/7/2011	8/16/2011	41	1.35



*MARK code examples:

101200 indicates captured during Capture 1 and 2 on site, and detected during Interval 2 with a fixed antenna or captured offsite during capture period 3

100012; -1 indicates captured during Capture 1 on site, not detected during Capture 2, detected with mobile survey during Capture 3 on site, and detected during Interval 3; -1 indicates it crossed the lower Array and is presumed to have emigrated from Asotin Creek.

Figure 21. Example of the capture and interval periods and PIT tag detection methods used to code encounter histories for the estimation of survival with program MARK for juvenile steelhead in the Asotin Creek IMW. Detection methods are mark-recapture surveys (M/R), fixed array detections (Array), and mobile surveys (Mobile). Capture periods include mark-recapture and mobile survey data and interval periods include array data and mark-recapture or mobile data when the fish is detected at a site other than where it was originally tagged (see text for more details).

The Barker model is a joint live/dead mark-recapture model that has a series of physical capture and recapture periods (i.e., where the animal is physically captured) with intervals in between where the animal can be resighted (Barker 1997). For our study, an encounter history for each fish is created by recording the encounters at capture and interval periods using a two digit code. The first position of the code records the detections during the capture period (0 = not detected, 1 = detected) and the second position of the code represents the interval period (0 = not detected, 1 = dead, 2 = detected). In our study, recovering dead juvenile fish is highly unlikely, so this state is not recorded.

We followed the approach of Barker (1997) when creating encounter histories for individual fish from the different sources of PIT tag detections (mark-recapture, mobile, array) and different periods (capture and interval) with the following subtleties. We began creating encounter histories by first assigning each tagged fish a “home” site based on where it was first tagged to allow estimation of survival at the fish site scale. One of the assumptions of the Barker model is that resightings (r, R, and R’) occur over the entire range of the animal, while captures and recaptures (p) occur only on site. However, during mark-recapture and mobile surveys a fish can be detected both on and off its home site. In order to properly estimate S, F, and F’, we categorized mark-recapture and mobile survey data as recaptures if the fish was encountered on its home site (“1” in MARK code), and resights if the fish was encountered off-site (“2” in MARK code). A recapture on the home site was recorded (recorded here refers to how the data were coded for MARK analysis) in the capture period that the detection occurred; however, an off-site recapture was recorded as a resight in the previous interval period. The assignment of off-site recaptures as resightings to the interval before the capture period is because survival is estimated from capture event to capture event; R and R’ estimate the probability surviving or dying over the entire interval to the next capture event for individuals recaptured off the capture site. The Barker model assumes a resight interval occurs after each capture period; data collection always ends at the end of a resighting interval. So, a “12” in the encounter history estimates the probability an off-site fish was resighted and survived or died during the interval from capture 1 to capture 2. If the 2 was put in the interval following capture, as 1002, then MARK would assume the fish survived through the second interval and then survived to the third capture period. All detections of fish at fixed arrays (i.e., resights) during an interval period were recorded in the same interval period. To account for emigration from Asotin Creek we assumed that any juvenile steelhead that crossed the lower array had smolted and had permanently left the population.

We developed a suite of models with fish site (group, or g in model notation) and season (t in model notation) effects for S, F, F’, R, and R’. We fixed r = 0 for all models because we did not have any recovery data. We also constructed more parsimonious models in which parameters were constant (“.” in model notation) in case the data did not support the more parameterized group and season models. We also constructed a model with large woody debris (LWD) as a site covariate for S (wood in model notation). We used Akaike’s Information Criterion corrected for small sample size (AICc) and AICc compared using AICc (Lebreton et al. 1992, Burnham and Anderson 2002) and normalized AICc weights (w_i; Buckland et al. 1997). Models with the lowest AICc values were most supported by the data and generally, models <2 AICc units of the best model were considered competing models.

We estimated an approximate annual survival each year by multiplying the survivals, taken to the appropriate number of months, for a given year. For example, for 2009, annual survival was for July 8, 2009 to July 19, 2010, which is 12.4 months; the calculation was $S^{1.87}S^{0.99}S^{9.51}$. Variance was estimated using the delta method (Seber 1982).

Ideally for a Barker model, resighting of marked animals is done throughout the entire range of the population of interest, while the capture and recapture samples are assumed to be done only on a subset area (e.g., the capture and recapture sampling sites) of the population range (Barker 1997). This assumption allows direct estimation of true survival (S), as opposed to ϕ, and site fidelity (F) or movement off study area/emigration (1 - F). However, steelhead are not resighted throughout their entire range because some proportion migrate to the ocean or downstream to larger streams. Without some type of correction, ocean migration would lead to an estimate of apparent survival (S*F) rather than true survival for the Barker models. To counteract this one can use an ad hoc approach, such as that detailed by Horton and Letcher (2008) to account for emigration. The gist of this approach is the removal of those individuals that emigrated and were detected at a downstream dam by changing their frequency to -1 in the encounter history, which removes their contribution to the likelihood function after the last time they were encountered. Because the capture efficiency of downstream antenna arrays is high (~95%), this is a viable approach that can be adapted to estimate true survival. Another potential approach is a new multi-state model that accounts for permanent emigration (Horton et al. 2011).

6.3.2.4 PRODUCTIVITY, BIOMASS PRODUCTION, AND CARRYING CAPACITY

6.3.2.4.1 Productivity and Biomass Production

We will measure juvenile and smolt productivity of each study stream using either estimates of PIT tagged adults or redd counts from each stream and estimates of juvenile abundance and smolt out-migration from PIT tag and detections at arrays. A calculation of the number of smolts produced per adult (or redd) is a measure of freshwater survival which we assume will be positively affected by the proposed restoration treatments. The calculation of smolts/adult spawner will require estimates of array efficiencies, adults entering study streams (including sex ratios), age estimates of juveniles, and estimates of the number of smolts leaving each tributary. We will work closely with WDFW to make sure these estimates are comparable (i.e., similar assumptions used) with their estimates of adult and juvenile migration.

We will estimate biomass production as a way to interpret the above measures of productivity. The production of ecological systems has been measured as a way to compare the conversion of nutrients and solar energy through biological processes into different forms of biomass per unit area per time. To better understand changes in overall steelhead productivity we will also measure steelhead freshwater biomass production in terms of biomass/unit area/time period/spawning adult or redd. This allows for an objective way of measuring ecosystem output, and in systems that are being actively resorted, measuring biomass production can help assess the effectiveness of the restoration activities (Horton et al. 2009, Wipfli and Baxter 2010).

Some studies have successfully shown a response to stream restoration by measuring increases in fish abundance (fish/m^2; Cederholm et al. 1997, Roni and Quinn 2001) and out migrating smolts (Solazzi et al. 2000). However, these studies did not take into account the influence of the number of spawning adults each year which can vary considerably. By calculating the number of smolts/adult spawner, we can account for changes in adult density to better understand the response to restoration. However, the number of smolts out migrating may be misleading. For example, fewer numbers of larger smolts could be produced, and larger smolts could have a greater survival than smaller smolts. So fewer smolts could be produced but the biomass could be greater.

Biomass production is the combination of the number of individuals in an area (abundance), the growth of those individuals over time (growth), and the survival rate of the group over the time period (see equation below). We calculated each of these variables for each fish site (see above methods). With this information we calculated the production of juveniles (i.e., pre-smolts) and smolts at each site. We defined a smolt as any fish that left the tributary where it was tagged as determined by a detection at the arrays at the mouth of each study stream.

Production = Density (m2) * Growth (g/day) * Survival

Production out of basin, as defined by the smolt to adult return rate (SAR), will be calculated by the WDFW by using the adult weir, redd counts, and smolt trap. We will use this information to provide context to the IMW study and assess the relative influence of out-of-basin effects on production compared to the freshwater production we are measuring.

6.3.2.4.2 Carrying Capacity and Net Energy Intake

We are adapting and expanding a process-based modeling approach of Hayes et al. (2007) to predict how changes in flow affect invertebrate drift density, net rate of energy intact (NREI), and carrying capacity. This approach will improve our ability to synthesize the population and habitat data we are collecting and help us better understand how the habitat currently available to steelhead supports their populations and how changes to habitat might influence carrying capacity of Asotin Creek. The modeling approach involves four main components: a hydraulic model to approximate flow patterns through a section of stream, a model to predict the paths of invertebrates drifting in the water, a foraging model to predict which drifting invertebrates fish might be able to catch, and a bioenergetic model that subtracts the metabolic costs of swimming in the stream from the energy gained by foraging to estimate the net energy flux for fish in the modeled stream section (Figure 22). The modeling approach predicts net rates of energy intake (NREI) for drift-feeding fish throughout the entire modeled stream site. By using a fine prediction resolution (predicting NREI at many locations throughout the stream section), we are able to illustrate which areas of a stream section are energetically profitable (fish would be able to meet their survival and growth requirements) and which areas are energetically deficient (fish would lose weight or not be able to meet their survival requirements). After accounting for depletion of drifting invertebrate food items by foraging fish, we can use the number of locations where fish meet their survival requirements as a rough estimate of carrying capacity.

The inputs needed to support this modeling approach include streambed topography, substrate size information, temperature, information about the size and species composition of drifting invertebrates, and demographic information about the fish populations to be modeled. Fortunately, most of this information is being collected in the Asotin drainages as part of ongoing monitoring efforts. For example, the hydraulic model requires a three-dimensional representation of the streambed's topography and estimates of streambed substrate size. Crews collected this information from 2008-2011 using surveying methods meant to document changes to the streambed shape and structure throughout the restoration process. In addition, information regarding temperature and drifting invertebrates has been collected yearly since 2008 and 2009, respectively, and the necessary details regarding the fish population (mainly size structure and growth rates) have been collected in our annual mark-recapture surveys used to document steelhead populations and their changes throughout the restoration process. In general, the previously mentioned information is sufficient to support this modeling approach, but we do have a graduate student from Utah State University working with a more detailed data set to help calibrate and validate the approach. Once this is done, we hope to apply this approach to a large set of streams including those from the Asotin IMW.

This process-based modeling approach was originally developed for use in large, slow-moving pools and it is assumed settling (sinking) of invertebrates was the dominant process governing the vertical distribution of drifting invertebrates in the water column (Hayes et al. 2007). However, in whole stream sections, more variability in water turbulence and habitat use by invertebrates dictate that drifting is more complex. To try and approximate a more variable drift pattern, we adapted the model to reset drift concentrations (to a reach-averaged value) at locations where water velocities exceeded a threshold (usually in riffles) and let settling be the dominant process elsewhere. This results in a more realistic spatial drift concentration pattern because drift concentrations are high in riffles (and leading into pools or other slow-moving areas), then invertebrates settle out of the water column in the slower-moving areas, then their concentrations increase again in faster-moving sections. This modeling compromise is not perfect and does neglect some important aspects of invertebrate ecology, but we feel it is the best compromise we can make at this stage of the project. To date, we have cooperated with the original authors of the modeling approach to help us make it more applicable in entire stream sections, and with their help, we have written custom computer programs to streamline the process and make it suitable for use in the Asotin streams. We now have custom scripts to take topography surveys and prepare inputs for the hydraulic model in ESRI ArcGIS 10.0. We also have a number of customized computer programs that pass hydraulic model, drifting invertebrate, foraging, and NREI information between them to accomplish the overall modeling process. In total, we have reduced approximately four days of work per stream section (with the original package for this modeling approach) into about half a workday (with the new computer programs) if all input files begin in the correct formats.

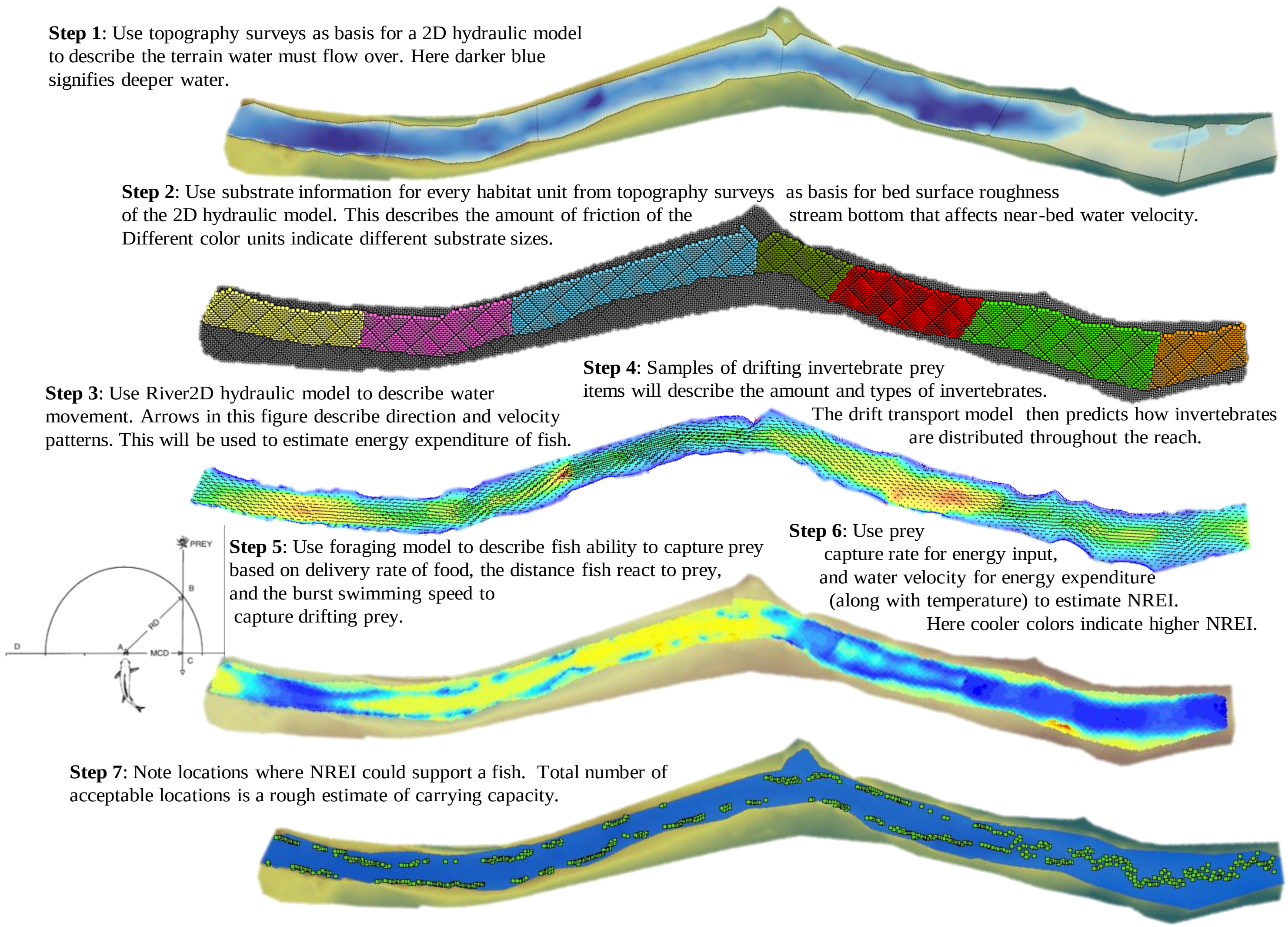


Figure 22. An overview of the modeling process to predict profitable foraging locations and carrying capacity for a stream section.

6.3.2.5 DISTRIBUTION, MOVEMENT, AND RESIGHTING

Characterizing the distribution and movement of steelhead populations is fundamentally important to gaining an understanding of the diversity of life history expressions within a population, the responses to restoration actions, and ultimately for evaluating recovery (Sogard et al. 2009). The distribution and movement of individuals can also provide important insight into territorial behavior, food availability, habitat conditions, growth, and survival (Hilderbrand and Kershner 2004, Lowe 2010). For example, large seasonal movements of individuals in a population could be the result of limited food resources at a currently occupied site, food resources being spatially patchy (Hilderbrand and Kershner 2004), or locally adverse habitat conditions (e.g., winter ice). We are assessing distribution and movement using the capture and tagging sessions and subsequent resighting of PIT tagged individuals using both stationary and mobile PIT tag antennas. Each time a fish is physically captured or detected by a fixed or mobile PIT tag antenna a date/time and location is recorded. An ***encounter history*** can then be created for each individual that can be used to characterize movement and be used to estimate survival (See Section 6.3.2.3).

6.3.2.5.1 Fixed Antenna Detections

We refer to all PIT tag detections at the interrogation sites as ***fixed antenna detections***. Using the interrogation data, the detection history of each PIT tagged fish can be summarized to give an overall picture of fish movement within the watershed. For example, one assumption of our experimental design is that the treatment and control sections are relatively independent. We can test this assumption by assessing movement of PIT tagged fish between sections and between streams. We can also better understand life history expressions by assessing the migration patterns of juvenile steelhead before and after restoration by characterizing the timing and duration of migration by age classes (or size classes). For example, it is unknown how much time juvenile steelhead spend in the mainstem Asotin Creek before migrating out to the Snake River. We can summarize the timing of movement from the tributaries and length of time individuals reside in the mainstem by having fixed antennas at the mouths of the three study streams and along the lower mainstem of Asotin Creek. Each resighting of PIT tagged individuals also increases our ability to estimate survival (See Survival below).

6.3.2.5.2 Mobile Antenna Detections

We started mobile PIT tag antenna surveys (hereafter ***mobile surveys***) in the summer of 2009 using methods similar to those described by O'Donnell et al. (2010). We use a custom made mobile survey antenna which has a PIT tag loop wand on an extendable pole and is attached to a FS2001F-ISO PIT tag Reader (Figure 23). Each time a PIT tag is detected, a data logger attached to the PIT tag reader records the data/time and PIT tag code in a custom mobile survey application on the logger. The mobile logger application also records the latitude and longitude of each PIT tag detection via a GPS attached to the logger. The user manually enters the habitat unit type while conducting the survey so that each PIT tag detection is associated with a habitat unit type. Beginning in the summer of 2011, two people surveyed a site at the same time. In areas where the stream is wide enough to allow it, surveyors walk side by side to maximize the amount of water area scanned by the wands. In Charley Creek and in constricted areas of the other study streams, the surveyors typically walk single file downstream. To increase detection efficiency in pools, one surveyor moves through the pool moving downstream and the other walks around the pool and scans it moving upstream. The addition of a second surveyor has greatly increased the number of detections during each survey.

Figure 23. Mobile PIT tag survey setup including custom antenna, GPS unit, data logger and PIT tag reader used to resight PIT tagged fish in the Asotin IMW study streams. Arrow is pointing to GPS receiver.

We now conduct mobile surveys in later summer, late fall, mid winter and spring (Table 18). The purpose of the mobile surveys is to detect (resight) PIT tagged fish and determine their location, including the type of habitat they are occupying (i.e., pool, riffle, cascade, etc.; see Habitat Monitoring Section for more details). We also use mobile surveys to act as "recapture" events during periods when we do not conduct capture and tagging surveys. We characterize mobile surveys as recaptures when using these data for calculating survival and it allows us to estimate survival of smaller time periods (see Survival below).

Each mobile detection of a PIT tagged fish is imported into GIS and snapped to a stream layer derived from the LiDAR imagery. The location of each fish along an ARC Hydro network was then determined by calculating the distance from the mouth of the tributary where the fish was detected to the location in the tributary. We then calculated the movement of each fish by calculating the distance upstream or downstream a fish had moved if it was resighted during another mobile survey. Positive numbers indicate movement upstream and negative numbers indicate movement downstream.

Table 18. Location of completed (2008-2011) and proposed (2012-2018) mobile PIT tag surveys within Charley Creek, North Fork, and South fork Creek. The rows in between each fish site represent the portion of stream between two fish sites that we surveyed. For the sites that were not back to back (i.e. NF-F4 and NF-F6), we surveyed 1km above and below each site.

			Year										
Stream	**Section**	**Site**	**2008**	**2009**	**2010**	**2011***	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
						X							
		CC-F1		X	X	X	X						
	1					X		X		X		X	
		CC-F2		X	X	X	X	X	X	X	X	X	X
						X		X		X		X	
Charley Creek		CC-F3			X	X	X	X	X	X	X	X	X
	2												
		CC-F4		X	X								
		CC-F5			X	X	X	X	X	X	X	X	X
	3					X		X		X		X	
		CC-F6		X	X	X	X	X	X	X	X	X	X
						X		X		X		X	
						X		X		X		X	
		NF-F1		X	X	X	X	X	X	X	X	X	X
	1					X		X		X		X	
		NF-F2					X	X	X	X	X	X	X
							X		X		X		X
		NF-F3											
North Fork	2					X		X		X		X	
		NF-F4			X	X	X	X	X	X	X	X	X
						X		X		X		X	
		NF-F5											
	3												
		NF-F6		X	X	X	X	X	X	X	X	X	X
						X		X		X		X	
		SF-F1											
	1					X		X		X		X	
		SF-F2			X	X	X	X	X	X	X	X	X
						X		X		X		X	
South Fork		SF-F3		X	X	X	X	X	X	X	X	X	X
	2					X		X		X		X	
		SF-F4					X	X	X	X	X	X	X
						X		X		X		X	
		SF-F5		X	X	X	X	X	X	X	X	X	X
	3					X		X		X		X	
		SF-F6											
Total Sites/Year			**0**	**8**	**12**	**25**	**14**	**26**	**13**	**26**	**13**	**26**	**13**

The majority of the mobile surveys are conducted within the fish sites in each of the study streams. We did this because very few PIT tags were detected outside of the fish sites during trials in 2009. We have since expanded some mobile surveys to include areas between the fish sites to reconfirm this assumption. Future surveys may include areas of the mainstem to better understand the location and habitat use of the mainstem by migrating fish PIT tagged in the study streams.

6.3.2.6 TAG RETENTION

The retention rate of PIT tags in a study can strongly influence the results and it is important to be able to estimate this parameter. Several studies have reported alarming rates of PIT tag loss in salmonids either in controlled conditions (i.e., hatcheries), or wild settings (Bateman et al. 2009). Rates of PIT tag loss have been reported as high as 45% in some cases, although other studies have reported much lower rates (Sigourney et al. 2005). Tag loss can occur by the tag either exiting the original insertion point before the tissue has healed, or through forced expulsion through the skin or during spawning. Shed tags are can be a problem because when they are detected in the stream it is often difficult to determine if they are indeed a shed tag, dead fish, or a live fish that is not moving (i.e., buried in the gravel or under some other obstruction). As part of this IMW we will be working with other researchers to develop methods and analyses to determine tag loss rates and the status of tags detected during monitoring efforts.

In 2011, we began a tag retention pilot study to determine the tag retention of PIT tags over 24 hour periods as well as over the summer, and winter/spring periods. We also clipped a small portion of the lower caudal fin of all PIT tagged steelhead in 2011 to act as a double mark and aid in the assessment of tag retention. To assess the 24 hour retention of tags with retained 25 fish per site in live wells overnight after the second day of tagging activities. The site was then revisited within 24 hours and all fish were rescanned to determine if the PIT tag was retained overnight. When we revisited the fish sample sites in the fall of 2011 we recorded all previously PIT tagged and fin clipped steelhead. Each fish was marked as either a recapture with a PIT tag and fin clip, recapture with a only a PIT tag, a recapture with only a fin clip, or a capture with no tag or clip. These counts were used to calculate the tag retention rate over the summer period from approximately the beginning of July to end of September (i.e., number of fish with PIT tags and fin clips recaptured in the fall / number of fish with fin clips recaptured in the fall). We also use the presence or absence of tags scars (incision point where tag was inserted) to aid in this analysis as some fin clips were hard to distinguish due to regrowth or natural wear or damage.

6.3.3 ADULTS

6.3.3.1 WEIR/ISEMP TAGGING

To understand the response of juvenile steelhead to restoration actions we need to be able to standardize annual juvenile abundance by the number of returning adults. The primary source of this data will be the WDFW adult weir operated on the lower Asotin mainstem (see WDFW Steelhead Monitoring above). Since 2010, WDFW has PIT tagged all untagged wild adult steelhead that are captured at the weir (Crawford et al. 2012). Adult escapement is calculated by mark-recapture methods using anchor tags and documenting the number of post spawning marked and unmarked fish returning to the weir (Crawford et al. 2012). The age and sex structure of each adult escapement is determined each year by collecting scale samples of almost all adults captured at the weir and determining the sex of each fish by visual inspection.

An adult estimation program was initiated at Lower Granite Dam in 2009 (J. White Pers. Comm.). The program was initiated by ISEMP and other state and management agencies to operate a "year-around" PIT tagging operation at the Lower Granite Dam Ladder Trap, while the ladder is operational (March 1 - November 30). The project's objective is to estimate escapement of adult spring/summer Chinook salmon (March 1 - August 17) and steelhead (July 1 - June 30) in Snake River tributaries upstream of PIT interrogation sites or collection locations (weirs). A percentage of the upstream migrating adults (9-10% between 2009-2011) were systematically PIT tagged at the Lower Granite Dam Ladder Trap (LGD). The escapement of adult steelhead and Chinook can then be estimated when these fish enter tributary locations upstream of LGD and cross existing PIT tag arrays by using the estimated number tags and the tagging rate at Lower Granite Dam (assuming the detection efficiency of the arrays is known). We will use the ISEMP adult tagging program and the WDFW adult weir escapement estimates to assess adult numbers in Asotin Creek.

We are also using the PIT tagged adults entering Asotin Creek (ISMEP or WDFW tags) to further refine the adult escapement estimates into subbasin escapements. The PIT tag detections of adults at the lower arrays on the mainstem and the tributary arrays will be used to assess the proportion of the adult escapement within subbasins. These estimates will be compared to redd counts to further validate escapement estimates (see below).

6.3.3.2 REDD COUNTS

A large portion of the available habitat upstream of the adult weir is surveyed on foot several times during the spawning season (March-May) to enumerate redds, estimate the number of spawners per redd, and resight anchor tagged (and untagged) adults (Bumgarner and Dedloff 2009, Crawford et al. 2012). These surveys have been conducted relatively consistently since the mid 1980's; however, surveys are regularly hampered by poor stream visibility which makes accurate and consistent enumeration difficult. Also until recently redds were counted but only spatially referenced at the scale of a reference reach (i.e., usually 2-3 km long). As of 2010, redd surveyors now use a hand held GPS to record the location of each redd. The objective of recording the redd location with a GPS is to better understand the spatial arrangement of redds, and use these data to determine if restoration actions affect the abundance and spatial arrangement of redds within treatment sections (i.e., are redds associated with the location of LWD structures). IMW staff will attempt to aid in the surveying of redds to collect this valuable information.

6.4 MACROINVERTEBRATES

Juvenile salmonids depend on aquatic and terrestrial macroinvertebrates as their primary food resource (Elliott 1973), and numerous studies suggest that macroinvertebrate abundance might explain variation in salmonid growth and survival in freshwater rearing environments (Cada et al. 1987, Filbert and Hawkins 1995, Nislow et al. 1998). Stream monitoring programs commonly collect benthic macroinvertebrate samples usually in the form of kick-net or surber samples (Peck et al. 2006, Heitke et al. 2010). Most often the information taken from this sampling is used to assess water quality based on benthic invertebrate community composition, and rarely are invertebrates evaluated as they directly influence salmonid populations as a food resource. Further, it is generally known that salmonids in lotic environments primarily forage on macroinvertebrates that are actively drifting in the water column (Chapman 1966), however drift samples are rarely collected by salmonid habitat assessment programs. To address this disparity, we are working with ISEMP to develop relationships that describe how macroinvertebrate food abundance influences salmonid productivity and biomass production, and also refining invertebrate sampling approaches that can be incorporated into rapid assessment habitat monitoring programs.

We are collecting both benthic and drifting macroinvertebrates in the Asotin Creek IMW study streams to quantify the abundance and diversity of the invertebrate community in Asotin Creek pre and post restoration and to directly assess the available food for juvenile steelhead and how changes in habitat may affect feeding, growth, and ultimately fish productivity/production. During summer base flow periods we collect macroinvertebrate samples at each habitat site. We collect drifting macroinvertebrates using two drift nets set up just upstream of the end of each site. We place the drift nets in fast moving water and record the water velocity at the opening of each net. The nets are left in place for at least three hours during the habitat surveys and care is taken to not disturb the area upstream of the nets. In 2008 we collected macroinvertebrate samples at 11 sites, in 2009 we sampled 24 sites, in 2010 we sampled 12 sites, and in 2011 we sampled 10 habitat sites, where only drift samples were collected. From 2008 to 2010 we collected benthic invertebrates using a surber sampler in the first four fast-water habitat units of each. Two subsamples are taken within each unit. We preserved all macroinvertebrate samples with 95% EtOH and after the field collections identify and count species to different taxonomic levels depending on the species. General procedures for processing invertebrate samples were similar to those recommended by the United States Geological Survey and are described in greater detail and rationalized in Vinson and Hawkins (1996). Samples were sub-sampled if the sample appeared to contain more than 600 organisms. From 2009 to present we collected macroinvertebrate drift samples using the CHaMP protocol. Two nets were set upstream of a habitat monitoring site and drift was collected for several hours. Velocity and depth of water at the mouth of the nets was measured and the length of time each net was in the water.

A number of metrics or ecological summaries can be calculated from a macroinvertebrate sample. A summary and description of commonly used metrics is available in Barbour et al. (1999). To determine the relative health of the Asotin Creek aquatic invertebrate assemblages we will use total taxa richness, EPT taxa richness, % EPT abundance, and the Hilsenhoff Biotic Index. We are in the process of reviewing our macroinvertebrate sampling program and may reduce the number of samples or frequency of our sampling in the future.

6.5 HABITAT MONITORING

Numerous habitat and riparian monitoring protocols have been developed by land management agencies in response to degradation of stream and riparian habitat (Johnson et al. 2001, Reeves et al. 2003, Heitke et al. 2010). One of the main goals of these protocols is to assess the effectiveness of changes to management policies that are intended to improve stream and riparian conditions and ultimately restore fish populations. However, numerous studies have shown that detecting changes in stream and riparian habitat attributes can be compromised by i) the inherent variability of these attributes in time and space, ii) observer variability, iii) measurement error, iv) crew training, and v) an inability to relocate repeat sights accurately (Roper and Bouwes 2002, Whitacre et al. 2007, Roper et al. 2008, Bunte et al. 2009, Roper et al. 2010). Recently many protocols have focused on reducing these sources of variability which is an important goal, but in doing so have sometimes moved away from measuring attributes that have a proven direct relationship to fish abundance. Our monitoring plans for stream and riparian habitat strive to strike a balance between high precision and accuracy and a focus on attributes that directly relate to fish abundance and production. This approach should improve our ability to determine the cause-and-effect relationships between habitat conditions and fish abundance and the effectiveness of the IMW restoration actions at increasing steelhead production.

6.5.1 STREAM HABITAT, CHANNEL, FLOODPLAIN, AND RIPARIAN HABITAT MONITORING

The key variables to measure are indicators of stream habitat structure, in-stream habitat complexity, sediment supply and quality, riparian forest connectivity and health, and riparian floodplain-hillslope connectivity and morphology. We are monitoring habitat variables at two general scales: the site level and the treatment/control section or stream level. We will monitor both using a combination of remote sensing and field based monitoring protocols. While instream variables describe habitat structure directly related to fish, they also represent manifestations of site specific biophysical processes functioning at various scales (Brierley and Fryirs 2005, Steiger et al. 2005). Understanding streams at each of these process scales is relevant to mechanisms and controls that determine the availability of habitat along river channels over time. This information is necessary in appraisals of fish dynamics as they utilize differing functional habitats at different life stages. Riparian vegetation and morphological variables are critical components in tying site specific instream habitat structure into reach and catchment scale biophysical context (Van Holt et al. 2006, Wall and Berry Jr 2006).

The original IMW design called for stream habitat to be assessed at permanent and rotating habitat sites once each year and riparian vegetation and flood plain conditions to be assessed every three to five years (Bennett and Bouwes 2009; Figure 13 and Table 6). There was one annual habitat site and two rotating habitat sites within each fish site. The annual site is surveyed every year and one of the rotating sites is surveyed each year in a rotating panel design (Thornton 1994). Habitat sites were approximately 150-170 m long depending on site characteristics. This allowed us to monitor all the habitat sites in each fish reach every two years. We have reviewed this survey scheme in light of the new experimental design and have refined it to reflect a shift in the restoration treatments and our adoption of a new habitat monitoring protocol (see below). We will review the new habitat monitoring plan periodically to determine if the habitat sampling can be done less frequently (i.e. if habitat changes are slow).

The new habitat monitoring plan calls for all habitat sites to be permanent (i.e., sampled annually) but the method within sites will vary. We have also reallocated some habitat sites from control sections to treatment sections to increase our coverage in treatment sections. We are doing this to ensure that a minimum of 18% (700 m) of each 4 km long treatment section is surveyed using a detailed topographic mapping procedure outlined in the Columbia Basin Habitat Monitoring Protocol (see details in Section 6.5.1.1; Table 19). This level of effort will result in approximately 30-40 dynamic woody structures being “captured” by the topographic surveys (based on 18% of 200 DWS/4km). The remainder of the permanent habitat sites in each control section will also be surveyed each year using CHaMP whereas the rotating sites not selected to be transformed into permanent sites (in the treatment sections) will be surveyed using a rapid survey approach that focuses on large wood, pools, and sediment sources (see

Section 6.5.1.3). These changes in the arrangement and surveying of habitat sites mean that we will attempt to complete 18 CHaMP surveys and 18 rapid habitat surveys each year if time and budget are available. These changes are outlined further in Appendix A.

Table 19. Location of completed (2008-2011) and proposed (2012-2018) habitat surveys within Charley Creek, North Fork, and South fork Creek. Grey shading represents the length of time each treatment section will be in a "post-restoration" state. We are using two methods to survey habitat: CHaMP to collect topographic data ("C") and rapid surveys to measure attributes that are a focus of the IMW (i.e., LWD, pools, sediment sources; "R").

					Year/Protocol										
					PIBO		DRAFT CHaMP	FULL CHaMP							
Stream	Section	Type	Fish Site	Habitat Site	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Charley	1	Control	CC-F1	Permanent		X	X								
				Permanent		X	X	C	Dropping from sample design						
				Rapid			X								
			CC-F2	Permanent	X	X	X	C	C	C	C	C	C	C	C
				Permanent		X	X		R	R	R	R	R	R	R
				Rapid			X		R	R	R	R	R	R	R
	2	Control	CC-F3	Rapid		X	X		R	R	R	R	R	R	R
				Permanent	X	X	X		C	C	C	C	C	C	C
				Rapid			X		R	R	R	R	R	R	R
			CC-F4				X								
						X	X		Dropping from sample design						
						X	X								
	3	Treatment	CC-F5	Permanent	X	X	X	C	C	C	C	C	C	C	C
				Rapid		X	X		C	C	C	C	C	C	C
				Rapid			X		R	R	R	R	R	R	R
			CC-F6			X	X	C	C	C	C	C	C	C	C
						X	X		C	C	C	C	C	C	C
							X		R	R	R	R	R	R	R
North Fork	1	Treatment	NF-F1	Rapid		X	X		C	C	C	C	C	C	C
				Permanent	X	X	X	C	C	C	C	C	C	C	C
				Rapid			X		R	R	R	R	R	R	R
			NF-F2	Permanent					C	C	C	C	C	C	C
				Rapid					C	C	C	C	C	C	C
				Rapid					R	R	R	R	R	R	R
	2	Control	NF-F3	Not sampled											
			NF-F4	Permanent	X	X	X	C	C	C	C	C	C	C	C
				Rapid		X	X		R	R	R	R	R	R	R
				Rapid			X		R	R	R	R	R	R	R
	3	Control	NF-F5	Permanent											
				Permanent											
				Rapid											
			NF-F6	Rapid		X	X		R	R	R	R	R	R	R
				Permanent	X	X	X	C	C	C	C	C	C	C	C
				Permanent			X		R	R	R	R	R	R	R
South Fork	1	Control	SF-F1	Not sampled											
			SF-F2	Rapid		X	X		R	R	R	R	R	R	R
				Permanent	X	X	X	C	C	C	C	C	C	C	C
				Rapid			X		R	R	R	R	R	R	R
	2	Treatment	SF-F3	Rapid		X	X		R	R	R	R	R	R	R
				Permanent	X	X	X	C	C	C	C	C	C	C	C
				Permanent			X		C	C	C	C	C	C	C
			SF-F4	Permanent					C	C	C	C	C	C	C
				Permanent					C	C	C	C	C	C	C
				Rapid					R	R	R	R	R	R	R
	3	Control	SF-F5	Rapid			X		R	R	R	R	R	R	R
				Rapid		X	X		R	R	R	R	R	R	R
				Permanent	X	X	X	C	C	C	C	C	C	C	C
			SF-F6	Not sampled											
Total FULL CHaMP Sites/Year					**9**	**24**	**36**	**10**	**18**	**18**	**18**	**18**	**18**	**18**	**18**
Total Rapid Survey Sites/Year					-	-	-	-	**18**	**18**	**18**	**18**	**18**	**18**	**18**

X - pre CHaMP surveys (i.e., PIBO and ChaMP stick and tape)
C - full CHaMP survey (topo and auxillary data)
R - rapid survey (i.e., fluvial audit georeferencing all LWD, pools, and sediment sources/sinks)

6.5.1.1 STREAM AND RIPARIAN HABITAT AT THE SITE LEVEL (CHAMP)

Riparian and stream habitat characteristics were measured using the PACFISH/INFISH Biological Opinion (PIBO) Effectiveness Monitoring Program riparian and stream habitat protocols from 2008 to 2009 (Heitke et al. 2010, Leary and Ebertowski 2010). However, since 2010 we have transitioned to using the Columbia Habitat Monitoring Program (CHaMP; Bouwes et al. 2011). The PIBO and CHaMP protocols use many similar methods to assess riparian and stream habitat conditions and CHaMP but we feel that the CHaMP protocol in combination with remote sensing (see below) will provide data that will be more directly related to fish habitat requirements. The CHaMP protocol provides standard measures of key stream characteristics such as pool frequency, large wood abundance, width to depth ratio, and substrate size, as well as site level attributes such as food abundance (drift samples), topographic mapping of the channel and banks (i.e., digital elevation models), air and water temperature, discharge, and solar radiation input (degree days of solar energy). The CHaMP approach also identifies and maps habitat units that will allow a more detailed assessment of habitat available for fish and allow us to better understand the influence of stream restoration on specific habitat attributes.

A key advantage of CHaMP is that crews use a total station to collect topographically stratified surveys of the sample site (Brasington et al. 2000). The total station survey will also be used to generate a high resolution digital elevation model (DEM) of the site (Figure 24). The spatial information collected during the total station survey is referenced to known control points that we had a surveyor establish throughout the study streams in 2011 (Appendix D). This allows sites to be mapped for further watershed spatial analyses within the Columbia River Basin Biophysical Framework (see Section 6.1). Approximately 500-1000 points are collected with the total station in a day of surveying and crews use these points to capture the major gradient breaks in the streambed and bank topography (Bouwes et al. 2011). Gradient lines are used to capture distinct features such as top-of-bank, toe of bank, edge-of-water, and bankfull indicators. CHaMP crews are given responsibility for editing their raw topographic data to ensure derived maps represent the site characteristics accurately. In addition to surveying topography crews: delineate habitat units and many of the stream site characteristics (pools, LWD, undercut banks, etc.) are georeferenced along with the topographic data.

The CHaMP program is also working in conjunction with ESSA Technologies to refine the River Bathymetry Tool Kit (RBT) to allow automated data analysis of the CHaMP topographic surveys (McKean et al. 2009). The River Bathymetry Toolkit is a GIS program that can rapidly evaluate digital elevation models (DEM). Tools within the RBT will be used to extract hydrologic parameters such as wetted area, bankfull width, water depths, hydraulic radius, gradient, sinuosity, pool volume, fast water volume (McKean et al. 2009), erosion and depositional patterns and budgets and uncertainty in the DEM (Wheaton et al. 2010). We will also use the RBT to recreate metrics collected by other survey protocols that use cross-sectional and longitudinal profile approaches (e.g., PIBO). The digital elevation models created by our CHaMP surveys can also be linked to 1D, 2D, and 3D hydraulic models that will allow us to model feeding behavior and carrying capacity of sites for juvenile steelhead (see Section 6.3.2.5.2). This will further expand the ability to analyze and interpret the influence of the proposed restoration on stream habitat, channel form, and sediment transport. We propose to continue using the CHaMP protocol. See Appendix E for a list of habitat metrics that are common to both the PIBO and CHaMP protocols as well as a list of metrics that CHaMP collects in addition to the PIBO metrics.

In 2009 we sampled the riparian zone at 24 habitat sites using methods similar to the PIBO riparian protocol. We ran 20 m transects following a compass bearing perpendicular to the stream on each side approximately every 40 m of the site. Every 2 m we used a 1x1 m plot frame placed on the ground following the transect to designate a sample area. We identified the five most abundant plant species in the herb and shrub layers at each plot. We also estimated the percent of ground cover each species in the herb layer was providing. For the shrub layer we estimated the percent of cover each species provided up to 1 m in height. As we moved away from the stream, we recorded the habitat type each plot was in using riparian, dry forest and sage brush as the dominant habitats. Along the same transects we identified the species and measured the diameter breast height of each tree that was within 1 m of the transect line. Using a tree corer we aged a subsample of tree species found at each fish site. We measured the diameter breast height and counted the rings from a core sample on up to four size classes (<10cm, 10-20cm, 20-30cm and >30cm) of the five most abundant tree species. We collected data on up to five trees from each size class and recorded whether the tree was growing in the riparian zone, the floodplain or upland.

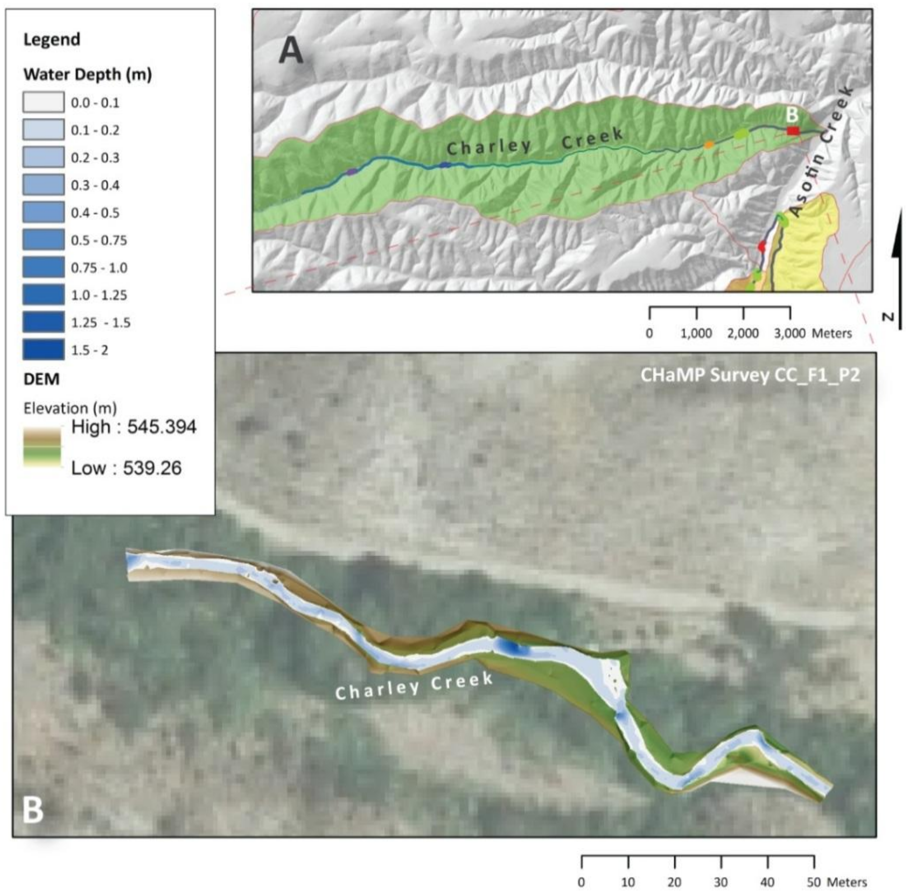


Figure 24. An example of a CHaMP topographic survey collected at a habitat site within fish site CC-F1 along Charley Creek. A) Shows the location of the habitat sites along Charley Creek, B) is the topographic survey data plotted on top of 1 m resolution aerial photography. The topographic survey shows a water depth map (in blue) and the bank elevations (green to brown).

6.5.1.2 STREAM, CHANNEL, FLOODPLAIN, AND RIPARIAN SURVEYS AT THE STREAM SCALE

We will assess the current condition and changes in stream habitat, channel and floodplain form, and riparian habitat at the stream scale using Light Detection and Ranging (LiDAR) combined with Geographic Positioning System (GPS) and 3-band digital aerial photography. Airborne LiDAR uses optical laser light pulses to measure ground elevations at high point density (~1 m) in order to create a continuous surface digital elevation model (DEM) of the terrain with high accuracy (i.e. ~15 cm vertical, ~30 cm horizontal). Collecting high resolution topographic data using LiDAR across large continuous areas will allow us to combine localized site data collected at fish monitoring sites with stream corridor data, in order to appraise fish dynamics across the study streams (Jones et al. 2007, Marcus and Fonstad 2008).

Most of the Charley Creek study sites were surveyed using ground based LiDAR and aerial photography (using a blimp) in 2009. The ground based LiDAR surveys from 2009 has been augmented with aerial LIDAR and photography surveys in 2011 that cover the entire Asotin Creek mainstem from the mouth to the confluence of the North Fork and South Fork as well as the lower approximately 15 km of each of the study streams. The aerial photography will be used to assess LWD, pool habitat, and water depth when used in conjunction with georeferenced water depth measurements. Both the LiDAR and aerial imagery will be used to determine the extent of riparian habitat and the condition (e.g., average height, density, and species composition) and these data will be combined with field surveys to determine the overall condition and response of riparian habitat to restoration actions. The LiDAR and aerial photographic surveys will also provide context for the IMW study and allow us to determine changes in the stream channel form and riparian extent. We propose to synthesize the LiDAR and photographic data and make it all publically available. We also propose to repeat these surveys after restoration has been completed based on funding availability.

Using Geographic Information Systems, we will be able to extract a variety of quantitative and qualitative channel and riparian descriptors from these data, such as cross-section geometry, planform, sinuosity, and longitudinal gradient profile, channel-floodplain connectivity, and drainage network geometry and connectivity. These descriptors will provide evidence to support multi-scalar classification of reach geomorphic typology, condition assessment and predictions of recovery potential, which are all assessed within a landscape framed biophysical context to inform site level analyses of fish dynamics. Our goal is to repeat LiDAR surveys over the study area every 3-5 years and summarize the changes in the habitat variables above.

6.5.1.3 SPATIALLY EXPLICIT RAPID HABITAT SURVEYS AT THE STREAM LEVEL

We began conducting spatially explicit rapid habitat surveys of the entire lower 12 km of each study stream in 2010 to assist in the development of the restoration plan and assess how representative our permanent sample sites are of the study streams. During these rapid surveys we determined the geomorphic reach type based on the Montgomery and Buffington (1997) categories. We used the dominant substrate, gradient, and channel confinement to classify reaches as we walked upstream. We will further refine these reach types with LiDAR, aerial imagery, and data collected as part of our CRB Biophysical Framework (see Section 6.1). Determining the reach type will be important in determining the potential response of the channel to restoration and understanding the arrangement of critical fish habitat (e.g., springs, spawning areas, winter refugia, etc.). During the rapid habitat surveys we also georeferenced attributes that we expect to use as response variables to detect changes due to restoration which include: abundance of LWD, pools, inset bars, and sediment sources. For each pool we determined the main forcing mechanisms (i.e., how was the pool created) to better understand how to design restoration structures that could mimic these mechanisms. We propose to repeat these surveys after restoration actions have been completed to help understand the spatial influence of restoration actions: for example, are LWD moving downstream from restoration sections to non-restoration sections?

6.6 DATA COLLECTION AND MANAGEMENT

A vast amount of fish and habitat data is being produced from this IMW project. To manage these data we are working closely with ISEMP to utilize and assist in the development of data management tools to store, analyze, and distribute the data. Where possible we are using data loggers and custom applications to collect the data in the field and upload the data to custom built databases. Appendix F explains the data collection tools, transfer process to data storage, and where appropriate, path of the data to larger regional databases. Our PIT tag array data is all loaded to PTAGIS either daily (automatically) or monthly (manually) depending on how well the internet connection of the sites is working. Mark-recapture tagging is loaded at the end of each capture session (once in the summer and once in the fall). Data with a spatial component is being loaded into a GIS to allow analysis of spatial arrangement of attributes and estimate movement patterns and habitat use (e.g., mobile fish surveys and fluvial audits). All CHaMP data is loaded to champmonitoring.org where it is put through rigorous quality assurance and will be publically available.

7 PRETREATMENT MONITORING RESULTS

One partial and three full years of pre-treatment monitoring of the fish populations and stream habitat have been completed in Asotin Creek (2008-2011). The following section summarizes the pretreatment data for the major attributes of interest in the IMW study. All data are available in stand alone Access databases, in GIS files (e.g., LiDAR), stored online (e.g., PTAGIS, CHaMP), or in excel spreadsheets.

7.1 FISH MONITORING

This section mainly provides summary statistics from summer and fall fish capture surveys and detection histories from the arrays and mobile surveys. We also provide some context for the IMW sampling by briefly reviewing the findings of the WDFW Asotin Assessment. Further modeling of fish/habitat relationships will be in future reports.

7.1.1 WDFW STEELHEAD MONITORING

WDFW have completed seven years of their assessment of the Asotin Creek steelhead populations. Data are now available for the timing of adult and juvenile migration timing, age and size structure, sex ratios, efficiency of the smolt trap and arrays, and population productivity (SAR, R/S). Please see WDFW annual reports for a complete review of these findings (e.g., Mayer et al. 2008, Crawford et al. 2012). Below we present a brief review of the smolt and weir data and major findings of the WDFW Asotin Assessment.

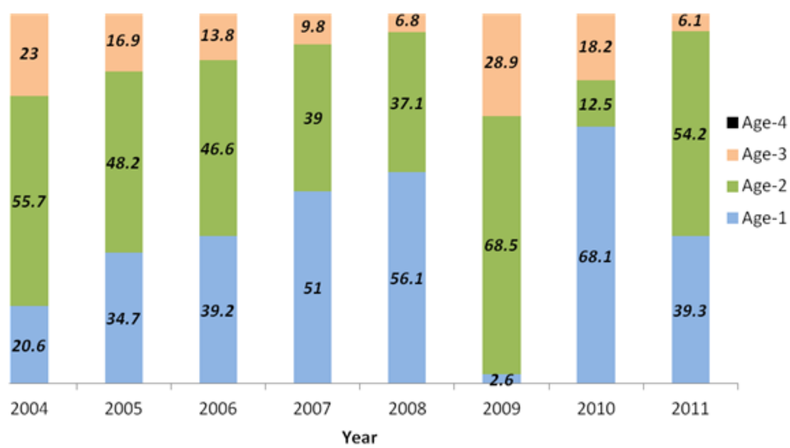
Adult steelhead return to Asotin Creek starting in late December or early January and usually peak around mid to late March (Mayer et al. 2009, Crawford et al. 2012). Significant numbers of wild adult steelhead have returned to Asotin Creek since 2005 with an average estimated escapement of 658 wild fish (Table 20). There are two juvenile out migration periods: one in the spring which starts in February or March and peaks in May and one in the fall that begins in September and peaks in October or November. The spring juvenile outmigration is on average more than three times larger than the fall migration except for 2007 when the fall migration was larger than the spring migration. There is no apparent trend in either the adult escapement or smolt production but a large adult escapement was observed in 2010 and 2011.

Table 20. Summary of the adult escapement estimates and juvenile out-migrants as determined by the WDFW Asotin Assessment Project from 2004-2011. Data summarized from annual reports where available (e.g., Mayer et al. 2008, Crawford et al. 2012).

	Adults		Juveniles	
Year	**Hatchery**	**Wild**	**Spring**	**Fall**
2004	NA	NA	43,457	2,287
2005	41	611	24,422	2,865
2006	46	509	25,741	10,827
2007	60	284	22,848	27,527
2008	20	300	30,148	6,618
2009	12	363	16,870	8,596
2010	7	1,411	20,829	2,432
2011	4	1,128	34,997	5,869
Average	**27**	**658**	**27,414**	**8,378**

The majority of smolts outmigrating in both the spring and fall are age 1 and 2 but the age one fall migrants make up a much larger proportion of the out-migrants. No age 0 out-migrants are caught during the spring but age 0 steelhead make up on average 18.6% of the fall out-migrants (Figure 25). There is significant overlap between the length-at-age of all age classes in both the spring and fall migrant populations (Figure 26). However, during the spring out-migration there is less overlap between age 1 out-migrants and all other ages in most years (Figure 26). For example in six of the eight years there is data, the median size of age 1 spring out-migrants was ~ 100 mm compared to ~ 150 mm for age 2+ steelhead. Two notable exceptions were 2009 and 2010 when the median length-at-age of age 1 fish overlapped significantly with age 2+ fish (~140 mm). The median length-at-age of age 0 and 1 fall out-migrants overlaps significantly but is typically < 100 mm compared to age 2+ fish that have a median length of ~ 150 mm (Crawford et al. 2012).

a)



b)

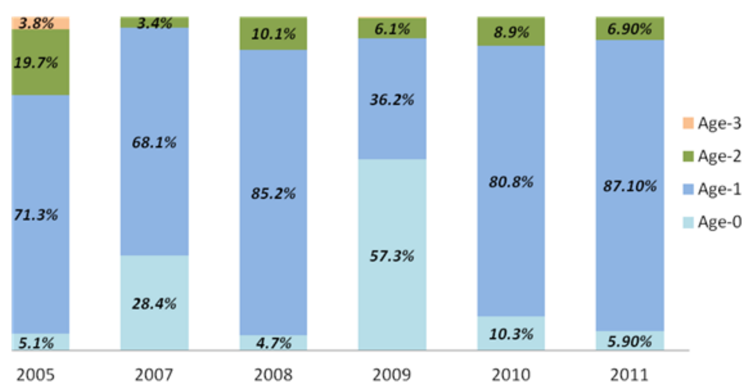


Figure 25. Percent of juvenile steelhead out-migrants by age captured at the smolt trap during a) spring and b) fall surveys by the WDFW (reproduced from Crawford et al. 2012).

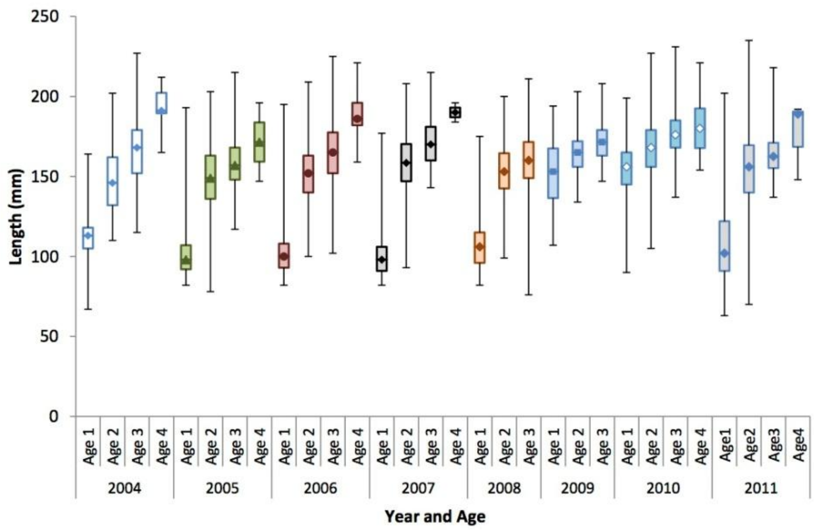


Figure 26. Length-at-age distribution of juvenile steelhead in Asotin Creek during spring out-migrations: 2004-2011 (n = 9,607). Boxes represent 25th and 75 percentiles, whiskers are min and max values, and shapes in boxes are medians (reproduced from Crawford et al. 2012).

Despite the large number of age 1 smolts that are captured at the smolt trap, very few adults that spent 1 year rearing in Asotin Creek return to spawn (Figure 27). The majority of returning adults spend two years rearing in Asotin Creek and 1-2 years maturing in the ocean. Females spend on average 2 years in the ocean compared to males that spend on average 1 year in the ocean. Repeat spawning is rare (~3% on average) for females and has not been recorded for males.

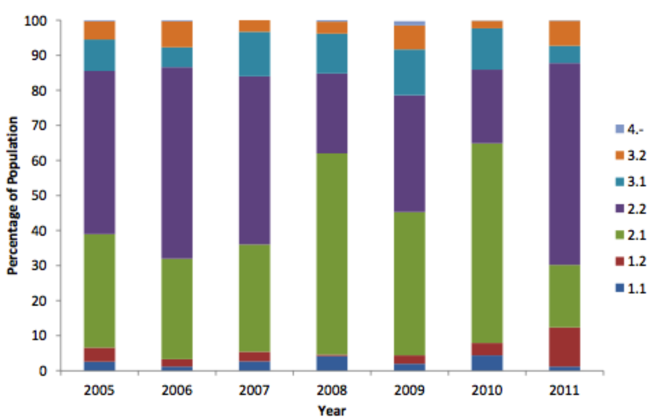


Figure 27. Age structure of returning wild adult steelhead to Asotin Creek. First number is the time spent in Asotin Creek, the second number is the time spent in the ocean (reproduced from Crawford et al. 2012).

Preliminary productivity measures of the Asotin steelhead population are being produced from the adult and juvenile data collected by WDFW (e.g., smolt to adult survival, recruits/spawner; Crawford et al. 2012). When estimates of these metrics are finalized we will compare estimates from pre and post restoration periods as one test of the restoration effectiveness. Crawford et al. (2012) noted that some steelhead tagged as wild smolts in the Tucannon River were captured as adults at the adult weir in Asotin Creek. These types of findings will confound calculations of productivity and need to be addressed in future.

7.1.2 JUVENILE CAPTURE AND TAGGING IN THE STUDY STREAMS

During the IMW mark-recapture tagging surveys from 2008-2011 we captured/recaptured almost 23,000 juvenile steelhead (Table 21). Bull trout and juvenile Chinook made up < 0.6% of the total number of salmonids we have captured. We PIT tagged 12,512 juvenile steelhead $\geq$ 70 mm, 18 bull trout, and 3 Chinook over four years in the IMW study streams (Table 22). At the WDFW smolt trap approximately 20 km downstream WDFW captured and tagged 15,324 juvenile steelhead from 2005 to 2011.

Table 21. Summary of all listed species captured/recaptured and released by year and creek during the first four years of pre-treatment monitoring for the Asotin IMW.

Year	Stream	Bull Trout	Chinook	Steelhead
2008	Charley	-	-	454
	North Fork	-	-	410
	South Fork	1	-	613
subtotal		**1**	**0**	**1,477**
2009	Charley			2,062
	North Fork	7	69	631
	South Fork	-	-	1,253
subtotal		**7**	**69**	**3,946**
2010	Charley	1	3	3,514
	North Fork	7	21	2,019
	South Fork	-	21	3,141
subtotal		**8**	**45**	**8,674**
2011	Charley	-	-	2,574
	North Fork	8	7	2,093
	South Fork	2	5	4,004
subtotal		**10**	**12**	**8,671**
Total		**26**	**126**	**22,768**

Table 22. Summary of the number of juvenile steelhead (> 70 mm) PIT tagged in Asotin Creek from 2005 to 2011.

Stream	2005	2006	2007	2008	2009	2010	2011	Total
Asotin	2,462	1,552	1,895	1,862	946	2,605	4,002	15,324
Charley	-	-	-	423	1,294	1,953	1,282	4,952
North Fork	-	-	-	372	470	1,396	906	3,144
South Fork	-	-	-	549	735	1857	1275	4,416
IMW subtotal	-	-	-	1,344	2,499	5,206	3,463	12,512
Total	2,462	1,552	1,895	3,206	3,445	7,811	7,465	**27,836**

* Fish PIT tagged in Asotin Creek were captured at the WDFW smolt trap on the mainstem. All other fish were captured in tributaries during IMW mark-recapture surveys.

7.1.2.1 LENGTH, WEIGHT, AND AGE

We estimated the length, weight, and condition factor of 22,795 juvenile steelhead over four years (see Appendix G for summary by Year, Stream, and Season). Unless otherwise stated, juvenile steelhead include all fish $\geq$ 70 mm which are presumed to be $\geq$ age 1 at the time of sampling. The mean length of juvenile steelhead was 113.9 mm (SD = 29.5, min = 42, max = 255, median = 110). There was significant differences among the mean length of juvenile steelhead across years, seasons, streams, and sites (Figure 28; $p < 0.001$). The mean length of juvenile steelhead was larger in 2008 and 2009, larger in Charley Creek and the North Fork, larger in the summer, and larger in all sites in Charley Creek and North Fork except CC-F1 and CC-F5. The largest juvenile steelhead captured was 255 mm. Steelhead < 65 mm were usually released immediately upon capture or only incidentally sampled. The mean weight of juvenile steelhead showed a similar pattern to length (see Appendix H). Condition factor was also significantly different across years, seasons, streams, and sites but there was far more variability among sites within streams and between years (Appendix H). Although juvenile steelhead in Charley Creek and North Fork tended to be larger (length and weight) compared to the South Fork, fish in the South Fork had a better condition factor.

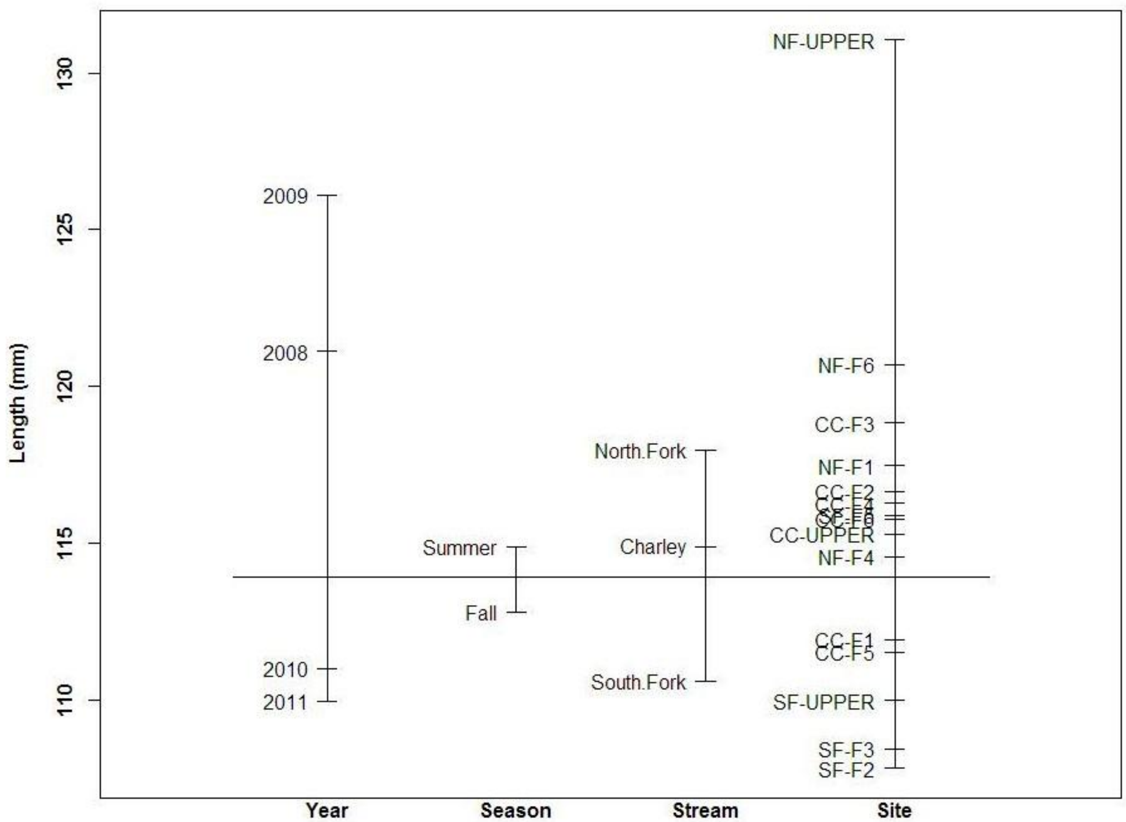


Figure 28. Main effects of four significant factors (Year, Season, Stream, and Site) on the mean length of juvenile steelhead > 70 mm based on two pass mark-recapture estimates in Asotin Creek. Horizontal line represents the mean length and location of measures within a factor indicates its mean (e.g., "2009" on Year factor represents the mean length of all juvenile steelhead > 70 mm from all seasons, streams, and sites combined for 2009).

Age

Based on 1,464 scales that were successfully read from 2008-2011 (605 summer and 860 fall scale samples), we found similar patterns of age and length-at-age as the much larger sample sizes collected at the smolt trap by WDFW. The majority of steelhead we captured and aged in all years were age 1 and 2 (Table 23; note, we were not targeting age 0 fish). The median length of age 1 steelhead was 102.2 mm for all years which was considerably less than WDFW noted at the smolt trap (Figure 26 and 29). This may indicate that many of the larger age 1 fish leave in the spring. We found overlap of length distributions among all ages but there was a strong pattern of the median length-at-age increasing with each age class.

Table 23.Summary statistics for length-at age of juvenile steelhead captured during the summer in Charley Creek, North Fork, and South Fork: 2008-2011. Length percentages represent quartiles (i.e., 0% = minimum length, 50% = median length, 90% = length at which 90% of fish are <u><</u>, and 100% = maximum length for each age).

YEAR: 2008

	Length (mm)								
	mean	**sd**	**0%**	**25%**	**50%**	**75%**	**90%**	**100%**	**N**
0	-	-	-	-	-	-	-	-	-
1	103.7	15.7	79.0	90.8	101.5	115.5	125.0	139.0	36
2	140.9	21.7	103.0	131.0	139.5	150.8	168.0	180.0	12
3	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-
								total	48

YEAR: 2009

	Length (mm)								
AGE	**mean**	**sd**	**0%**	**25%**	**50%**	**75%**	**90%**	**100%**	**N**
0	79.5	0.7	79.0	79.3	79.5	79.8	79.9	80.0	2
1	101.2	11.2	79.0	93.0	104.0	108.0	115.0	125.0	61
2	135.3	16.0	105.0	121.8	136.0	145.3	156.0	173.0	76
3	168.4	21.0	115.0	157.5	172.5	182.3	194.0	197.0	20
5	225.0	NA	225.0	225.0	225.0	225.0	225.0	225.0	1
								total	160

YEAR: 2010

	Length (mm)								
AGE	**mean**	**sd**	**0%**	**25%**	**50%**	**75%**	**90%**	**100%**	**N**
0	-	-	-	-	-	-	-	-	-
1	107.1	17.6	67.0	94.0	106.0	120.3	130.0	159.0	176
2	138.5	18.7	103.0	127.8	138.5	151.5	157.7	169.0	22
3	167.0	19.3	140.0	154.5	171.5	175.8	185.0	193.0	6
4	200.7	27.1	179.0	185.5	192.0	211.5	223.2	231.0	3
5	-	-	-	-	-	-	-	-	-
								total	207

YEAR: 2011 Summer

	Length (mm)								
AGE	**mean**	**sd**	**0%**	**25%**	**50%**	**75%**	**90%**	**100%**	**N**
0	-	-	-	-	-	-	-	-	-
1	94.2	15.7	63.0	83.0	92.0	102.8	114.0	150.0	162
2	132.2	22.7	94.0	122.5	129.5	143.8	162.2	177.0	22
3	162.0	26.3	130.0	145.0	158.0	184.0	189.4	193.0	5
4	145.0	NA	145.0	145.0	145.0	145.0	145.0	145.0	1
5	-	-	-	-	-	-	-	-	-
								total	190

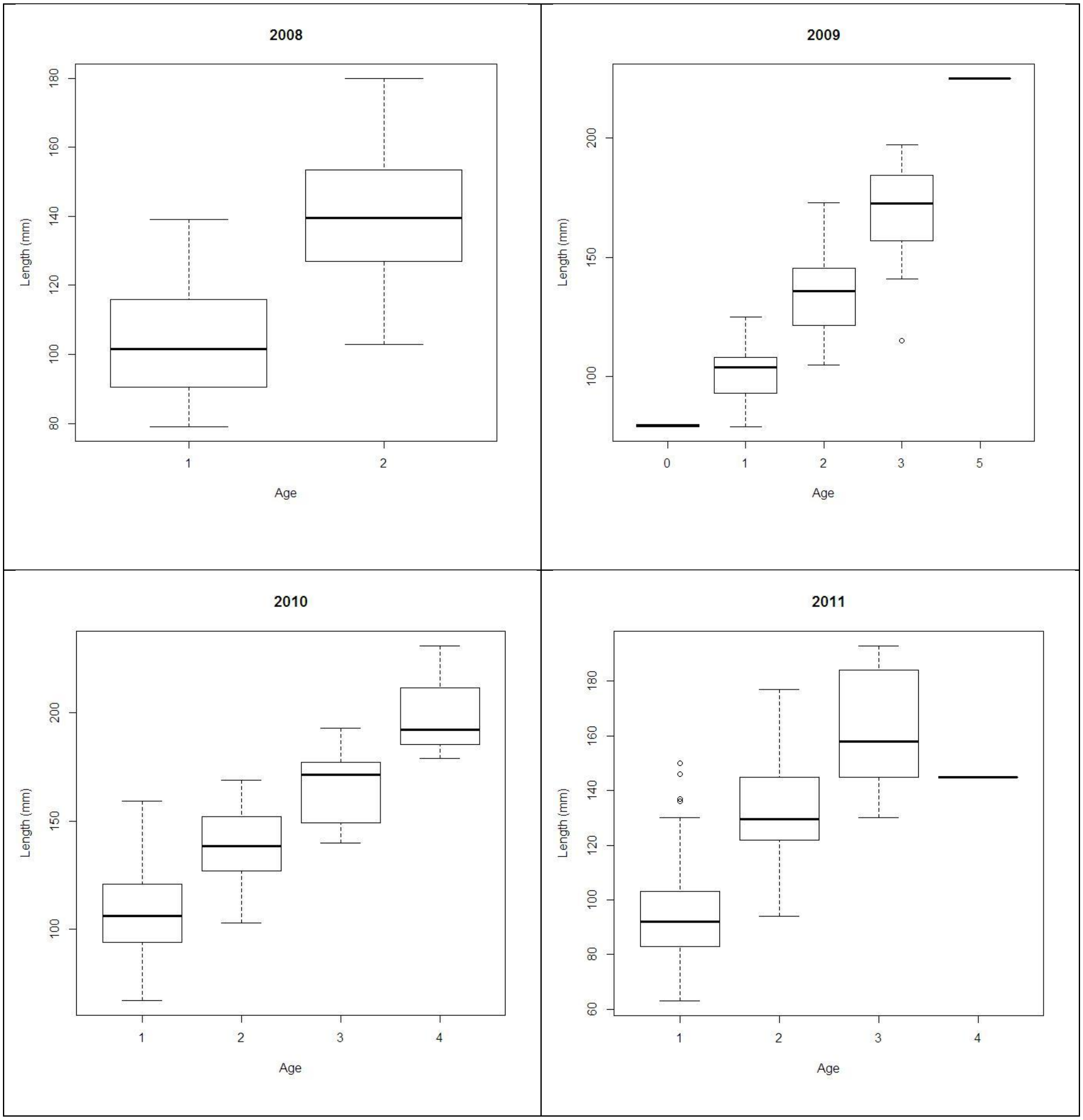


Figure 29. Distributions of length-at age of juvenile steelhead captured during the summer in Charley Creek, North Fork, and South Fork from 2008-2011. Box ends represent the 25th and 75th percentiles, the line in the box is the median, the whiskers are 1.5 x the interquartile range (IQR), and the open circles are outliers. See table 23 for sample sizes.

7.1.2.2 ABUNDANCE

Our overall recapture rate of PIT tagged juvenile steelhead $\geq$ 70 mm was relatively high (average = 0.29, min = 0.08, max = 0.50, n = 76) which suggests that we have marked a significant portion of the population (Figure 30). The mean number of recaptures on the second pass of each mark-recapture survey was 35.3 (SD = 26.9, min = 3, max = 140, n = 76). Charley Creek had the highest average recapture rate (0.33) followed by South Fork (0.29) and North Fork (0.23). There were only three second passes where we recaptured < 7 fish tagged on the previous day (i.e., the minimum recommended number for estimating abundance using the Chapman estimator). These recapture rates will increase our ability to detect changes in abundance and strengthen our ability to more precisely estimate growth and survival.

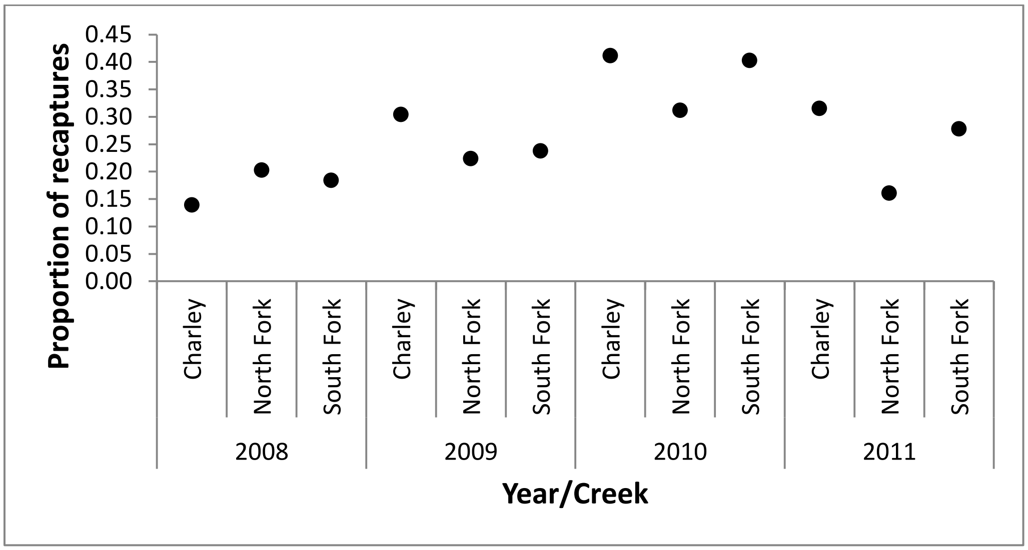


Figure 30. Mean recapture rate of PIT tagged steelhead $\geq$ 70 mm during mark-recapture surveys by year and stream in Asotin Creek. The recapture rate is for all PIT tagged fish observed on pass 1 (i.e., previously tagged and recaptured or newly tagged) that were recaptured on pass 2.

We calculated the number of juvenile steelhead per distance (km) and density (m^2) but will only present densities of steelhead for the remainder of this report because density estimates can be used to calculate overall production (see Appendix I for a summary of abundance by year, stream, season, and site in fish/km and density). Overall the average density of steelhead was 0.246/m^2 (SD = 0.09, min = 0.09, max = 0.50, n = 76). The mean density of steelhead was significantly different across years, streams, and sites, but not seasons (Figure 31; ANOVA $p < 0.01$). We performed a Tukey multiple comparison test and found that the mean density of steelhead was lower in 2009 ($p < 0.008$), lower in the North Fork than both Charley and the South Fork ($p < 0.05$), and higher at sites CC-F4 and SF-F5 ($p < 0.04$). There are no apparent trends in the mean density of steelhead in either the summer or fall (Figure 32 and Figure 33).

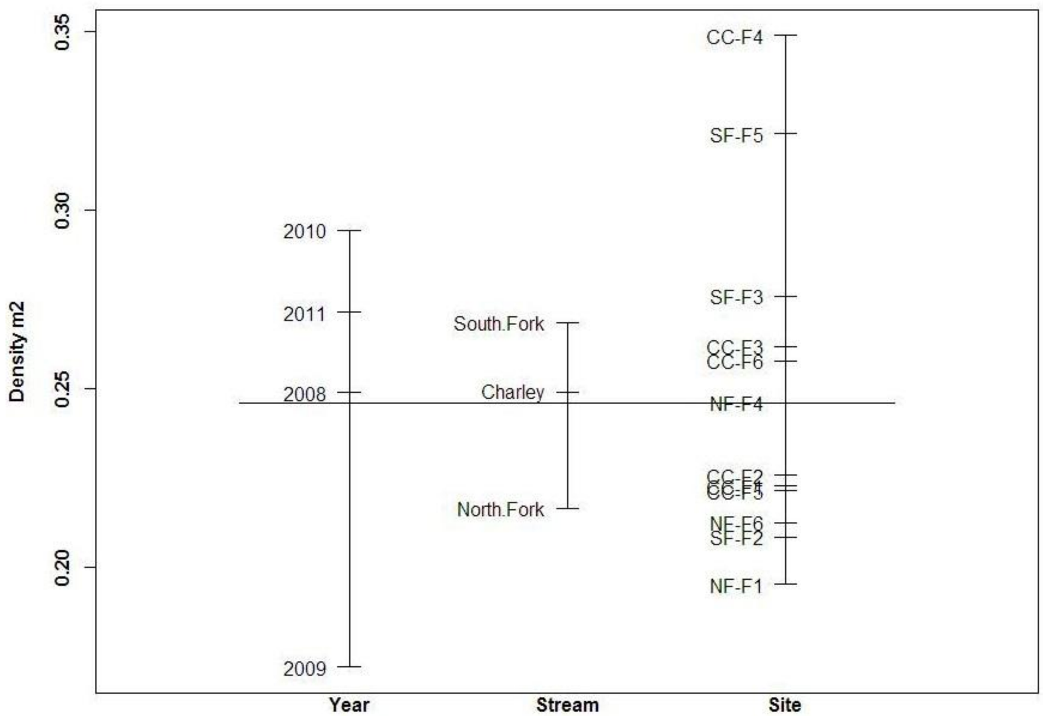


Figure 31. Main effects of three significant factors (Year, Stream, and Site) on the mean abundance of juvenile steelhead > 70 mm based on two pass mark-recapture estimates in Asotin Creek. See Figure 28 for interpretation of main effects graph.

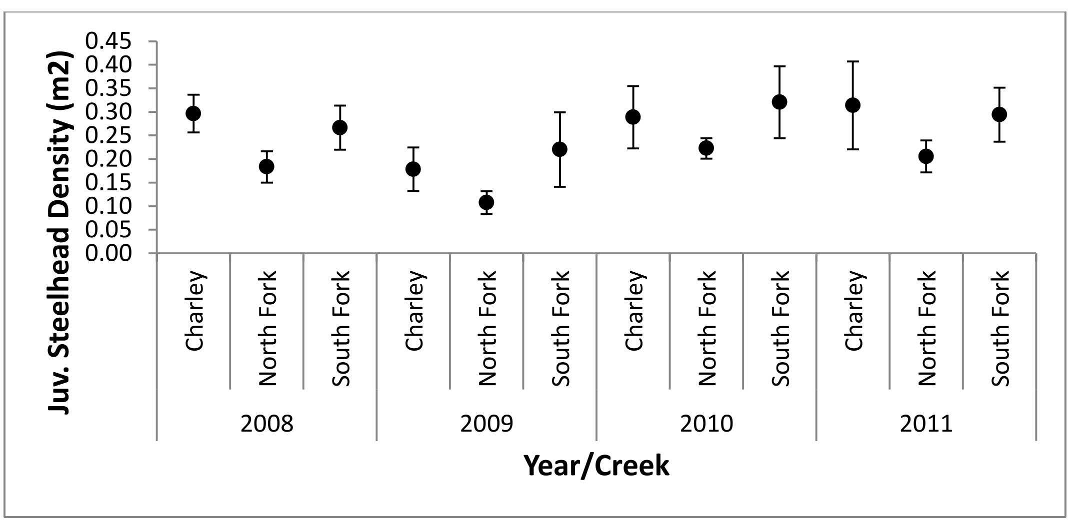


Figure 32. Summer (June-July) mean juvenile steelhead density (m^2) by stream and year in Charley Creek, North Fork, and South Fork. Error bars = + 1 SD.

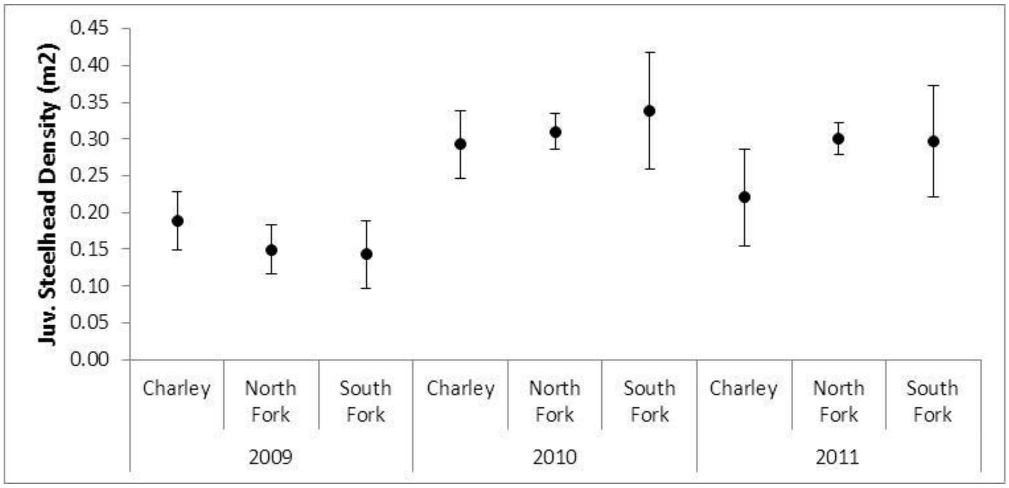


Figure 33. Fall (September - October) mean juvenile steelhead density (m^2) by stream and year in Charley Creek, North Fork, and South Forks. Error bars = ± 1 SD.

We calculated the abundance of steelhead in seven distinct capture periods (four summer and three fall seasons). There was a significant relationship between the mean density of steelhead in the three study streams across capture periods (Figure 34; p = 0.03, r^2 = 0.22). The relationship between steelhead density within streams and capture periods suggests that control and treatment sites are responding to changing environmental conditions (e.g., water temperature and flow) in a similar fashion during the pre-treatment period.

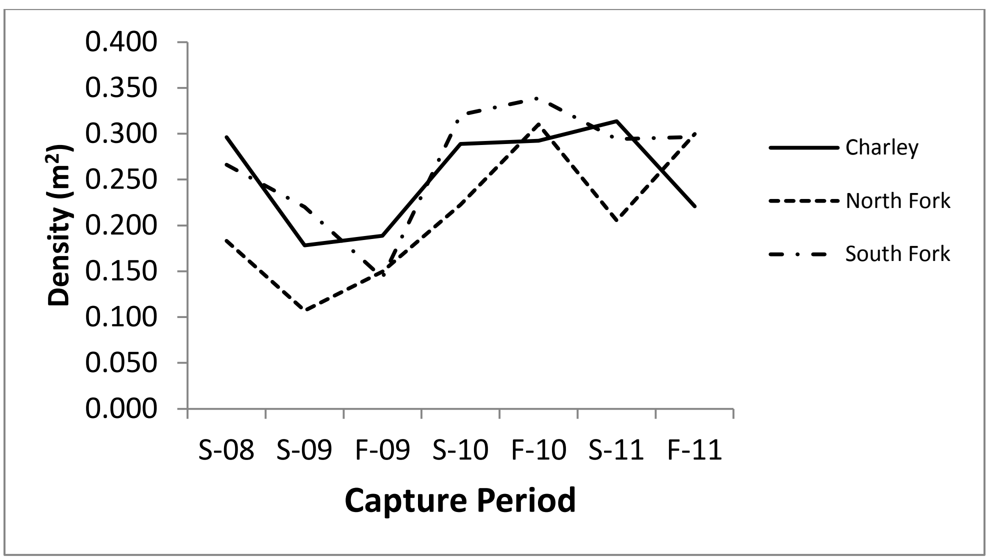


Figure 34. Correlation between the average density of juvenile steelhead ≥ 70 mm (m^2) within Charley Creek, North Fork, and South Fork and capture period. Capture periods S = Summer, F = Fall and numbers = years (e.g., 08 = 2008).

7.1.2.3 GROWTH

We calculated the absolute and relative growth of steelhead in mm and g for six growth periods. We are only presenting relative growth per period in g/g/d because it is a more direct measure of biomass produced per growth period (see Appendix J for a summary of absolute and relative growth by growth period, stream, and site). To calculate growth rates per growth period we needed to recapture fish that we captured and tagged at the beginning and end of each growth period. On average we recaptured 64.8 steelhead per growth period to estimate growth rates (Median = 55.5, SD = 62.3, min = 3, max = 322, n = 64). Only five sites had recaptures < 10 (Table 24).

Table 24. Sample size for each estimate of growth rate (g/g/d) for growth periods and 12 sites from 2008-2011 in Asotin Creek.

	Stream/Site												
	Charley						North Fork			South Fork			
Growth Period	**CC-F1**	**CC-F2**	**CC-F3**	**CC-F4**	**CC-F5**	**CC-F6**	**NF-F1**	**NF-F4**	**NF-F6**	**SF-F2**	**SF-F3**	**SF-F5**	**Total**
S08-S09		13	14		18		3	4	6	13	56		127
S09-F09	24	77	63	73	80	96	22	15	24	57	55	86	672
F09-S10	3	10	36	55	46	42	14	14	17	9	35	41	322
S10-F10	104	178	118	145	101	205	80	117	104	195	322	266	1935
F10-S11	15	58			75	69	11	29	11	50	73	67	458
S11-F11	62	101			90	75	13	27	22	60	66	114	630
Total	208	437	231	273	410	487	143	206	184	384	607	574	4144

Overall the average growth of steelhead was 0.0016 g/g/d (SD = 0.0022, min = -0.014, max = 0.011, n = 4144). The mean growth of steelhead was significantly different across growth periods, streams, and sites (Figure 35; ANOVA p < 0.001). The mean growth rate of steelhead was significantly lower in all summer to fall periods (i.e., July-October; p < 0.01), lower in Charley Creek (p <0 0.0001), and all sites in Charley Creek except CC-F4 and CC-F5 (Tukey multiple comparison test p < 0.001). All sites had relatively low growth that was highly variable, and negative growth was recorded for all sites (Figure 36). However, the mean growth rate across streams appears to be correlated over time periods (Figure 37).

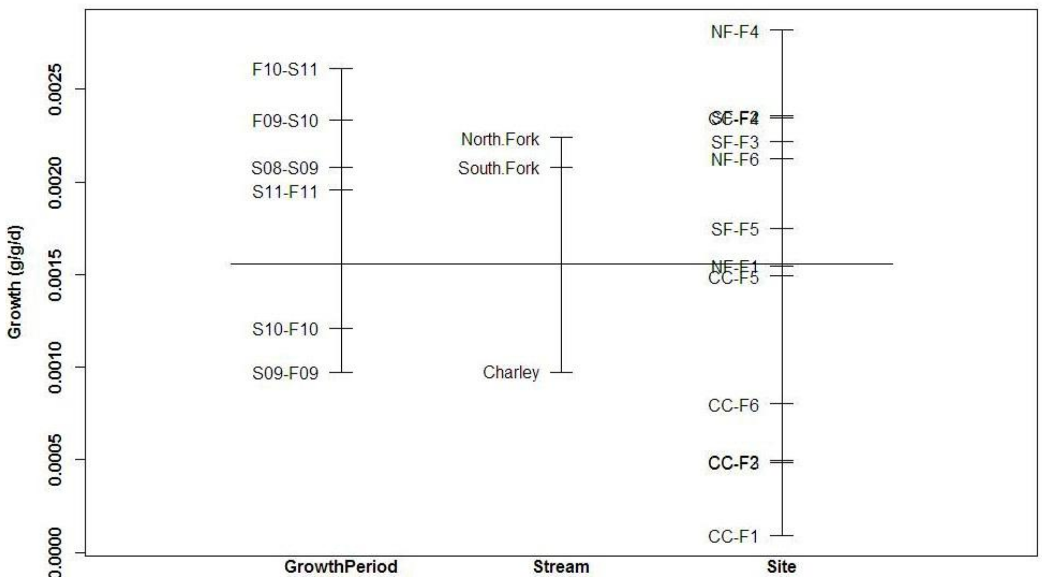


Figure 35. Main effects of three significant factors (Growth Period, Stream, and Site) on the mean growth rate of juvenile steelhead ≥ 70 mm in Asotin Creek. See Figure 28 for interpretation of main effects graphs.

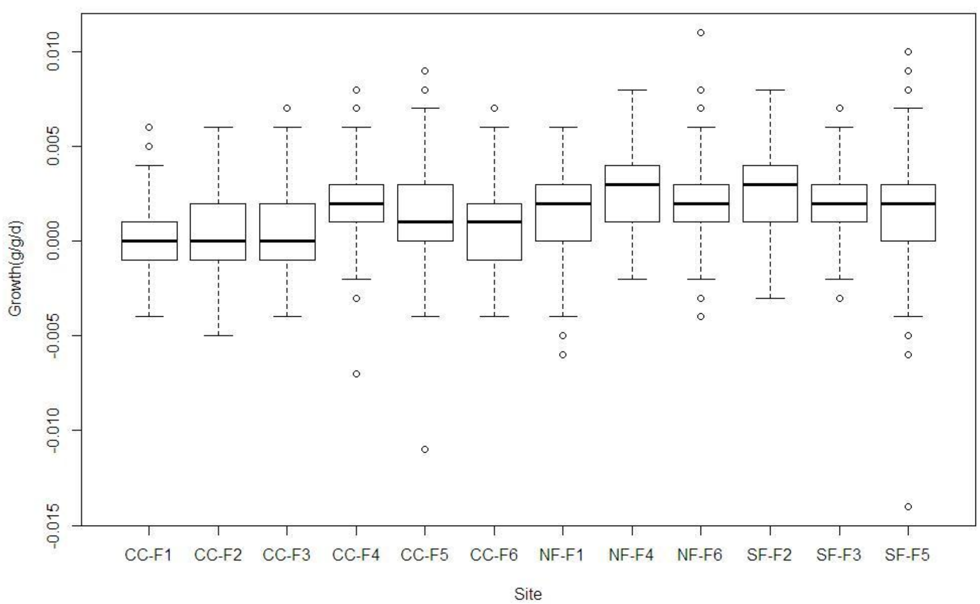


Figure 36. Distribution of growth rates combined by site over all growth periods from 2008-2011 in Charley Creek, North Fork, and South Fork (n = 4,144). Box ends represent the 25th and 75th percentiles, the line in the box is the median, the whiskers are 1.5 x the interquartile range (IQR), and the open circles are outliers.

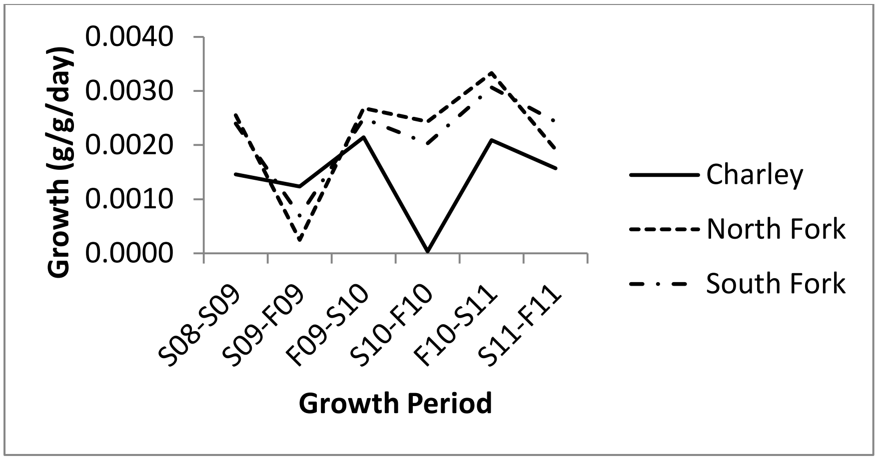


Figure 37. Mean growth (g/g/day) averaged by stream over six growth periods (S= summer, F = fall; number refers to year) in Charley Creek, North Fork, and South Fork.

We grouped fish into two age classes based on the average 90th percentile length-at-age data from our tagging work (2009 and 2010 age data). All fish ≤ 128 mm were classed as age 1 and all fish > 128 mm were classified as age 2+ steelhead. The mean growth rate of age 1 steelhead (0.0021 g/g/day, SD =0.0022, min = - 0.011, max = 0.010, median = 0.002, n = 2,898) was significantly higher than the mean growth rate of age 2+ steelhead (0.0003, SD = 0.0018, min = -0.014, max = 0.011, median = 0.000, n = 1,246; $p < 0.0001$; Figure 38). Both age classes have the same general pattern with low growth rates in the summer to fall periods (e.g., S09-F09 and S10-F10) but the mean growth rate is negative for age 2+ steelhead in all streams during these periods except for S10-F10 in North Fork (Figure 39).

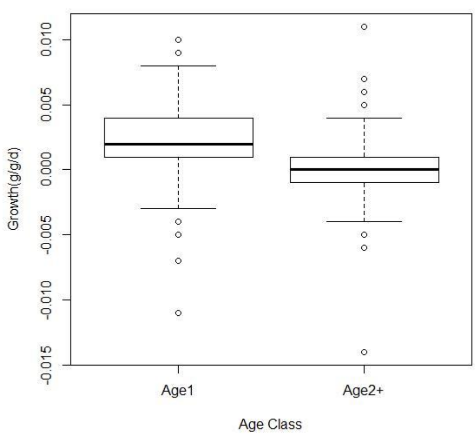


Figure 38. Distribution of juvenile steelhead growth rates (g/g/d) across all years, growth periods, and streams by age classes: 2008-2011. Age class 1 = all steelhead ≤ 128 mm fork length, Age class 2+ = all steelhead > 128 mm fork length. Box ends represent the 25th and 75th percentiles, the line in the box is the median, the whiskers are 1.5 x the interquartile range (IQR), and the open circles are outliers.

a) b)

Figure 39. Mean growth rates (g/g/d) for Charley Creek, North Fork, and South Fork by a) age 1 and b) age 2 by growth periods: 2008-2011.

We tested for a density dependent relationship between growth rate and survival by plotting the growth per day against our summer population estimates from mark-recapture surveys by age class and for all age classes combined. We found no density-dependence between growth rate and juvenile steelhead abundance for individual age classes or for all ages combined (r^2 = 0.02, P > 0.2; Figure 40).

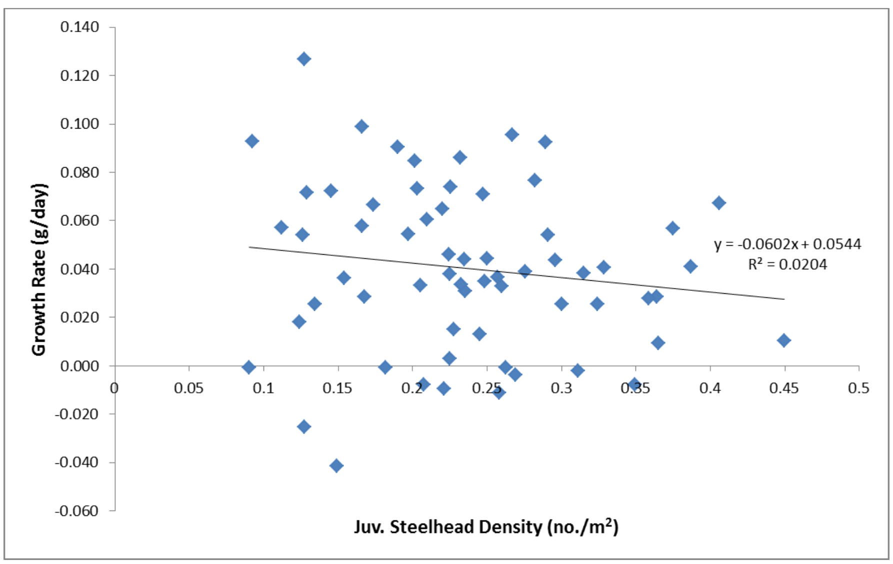


Figure 40. Relationship between juvenile steelhead density (fish ≥ age 1/m^2) and growth rate (g/day) for all sites and years combined in Asotin Creek IMW study streams: 2008-2011.

7.1.2.4 SURVIVAL

The top model, where survival varied by site and time (i.e., interactive*)*, was >75ΔAICc units from the next best model (Table 25); consequently all estimates we present are from the top model (rather than model averaged). The only difference between the top model and the next model is that site and season were interactive for survival (S), which means survival estimates are unique for each of the 12 sites and

10 seasons. The top model essentially suggests that the survival rate varies by site and time. However, these model results are preliminary and further analyses are planned to refine our approach. For example, we used array detections at Cloverland Bridge (ACB) to identify out-migrants for this analysis. This means that the calculation of true survival applies to the Asotin Creek as a whole and not the individual tributaries. Also, the second model where site and time are additive may be a better model than these results suggest because some sites were not surveyed during all capture periods (e.g., CC-F1 and CC-F4 were not sampled in 2008 or 2011) which makes the interactive model appear more robust.

Monthly survival estimates were high for most periods, streams, and sites averaging 0.91 across all sites and periods (range 0.41-1.00; Appendix K, Figure 41). The pattern of survival appeared to be relatively consistent from period to period but each stream had at least one site that had low survival when other sites in that stream had high survival or vice-versa. Survival in the fall and spring was lower on average than summer and winter periods but this only occurred in 2009 and 2011, whereas in 2010 survival was high during all periods. Annual survival of juvenile steelhead was high across streams and sites ranging from 0.16 - 0.32 (

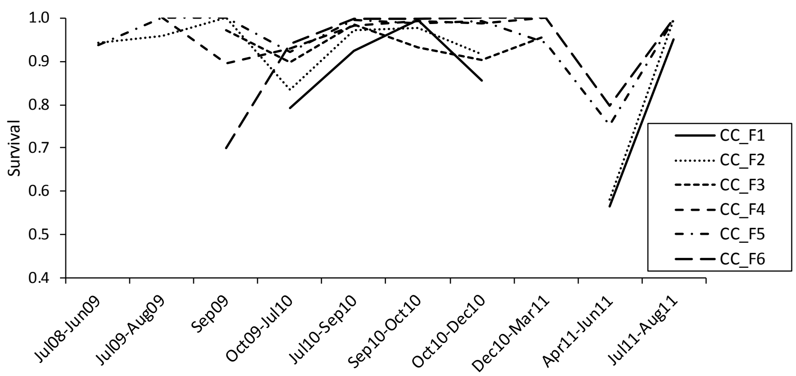
Table 26). Charley Creek and South Fork appear to have double the annual survival rate compared to the North Fork. We did not test for density dependent survival, but will test for it once we re-run the survival models with 2012 data.

Table 25. Model selection results from mark–recapture analysis for steelhead in Asotin Creek based on data from captures and resightings for August 2008–August 2011. Analysis was done using the Barker model in Program MARK. Notation as follows: g = group or site, t = time, S = survival, p = capture probability, r = probability found dead, R = probability of resight, R' = probability that fish that dies was seen alive in previous period, F_i = site fidelity, F'_i = immigration rate.

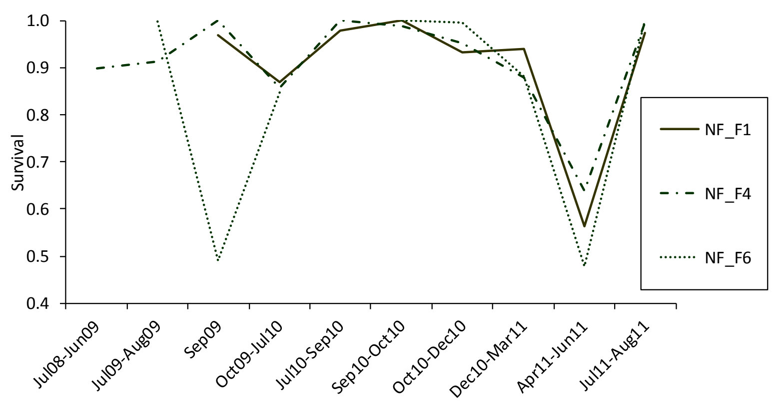
Model	AICc	ΔAICc	w_i	N	Deviance
[S(g*t) p(g*t) r(0) R(g+t) R'(t) F(g+t) F'(t)]	39003.90	0.00	1.00	264	7497.79
[S(g+t) p(g*t) r(0) R(g+t) R'(t) F(g+t) F'(t)]	39079.38	75.49	0.00	144	7819.67
[S(g+t) p(g*t) r(0) R(g+t) R'(t) F(g+t) F'(g+t)]	39092.42	88.52	0.00	146	7828.63
[S(g+t) p(g*t) r(0) R(g+t) R'(t) F(g+t) F'(g)]	39123.63	119.73	0.00	143	7865.95
[S(wood*t) p(g*t) r(0) R(g+t) R'(t) F(wood+t) F'(t)]	39128.46	124.56	0.00	165	7825.90
[S(g*t) p(g*t) r(0) R(t) R'(t) F(.) F'(.)]	39182.16	178.27	0.00	242	7721.52
[S(g+t) p(g*t) r(0) R(g+t) R'(t) F(g+t) F'(.)]	39230.30	226.40	0.00	128	8003.15
[S(reach*t) p(g*t) r(0) R(g+t) R'(t) F(reach+t) F'(t)]	39273.22	269.32	0.00	136	8029.79

AIC_c = Akaike's information criteria corrected for small sample size; ΔAIC = the difference between the model with the lowest AICc and every other model; w_i = normalized relative likelihood of the AIC weights; N = number of parameters in the model.

a)



b)



c)

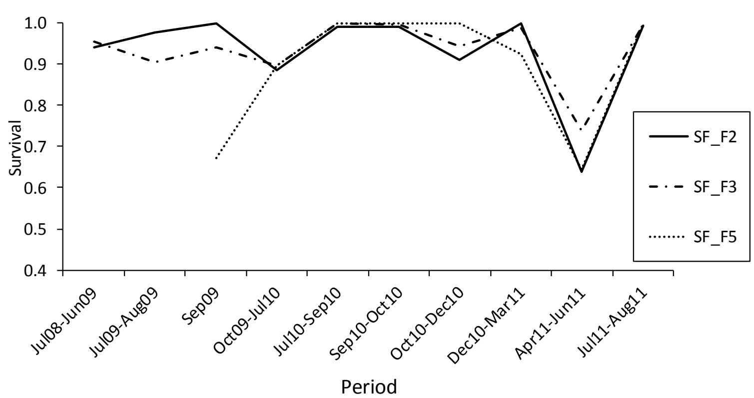


Figure 41. Monthly survival by sites in a) Charley Creek, b) North Fork, and c) South Fork over ten periods from 2008-2011. Missing values represent periods that were not sampled or estimates that were not calculated due to limited captures.

Table 26. Annual survival estimates for juvenile steelhead > 70 mm in Charley Creek, North Fork, and South Fork by fish survey site. Confidence in the estimates are based on the coefficient of variation (CV) with < 20 = GOOD, 20-35 = MODERATE, and > 35 = POOR (NA = estimate not available; Roper et al. 2010).

Stream	Site	Year	Survival	SE	LCI	UCI	CV	Confidence
Charley	**CC-F1**	2008-09	NA	NA	NA	NA	NA	NA
		2009-10	0.11	0.08	0.00	0.27	74.8	POOR
		2010-11	0.08	0.06	0.00	0.19	74.4	POOR
	CC-F2	2008-09	0.52	0.03	0.46	0.59	6.4	GOOD
		2009-10	0.16	0.06	0.05	0.28	34.5	MOD
		2010-11	0.11	0.09	0.00	0.29	79.1	POOR
	CC-F3	2008-09	0.28	0.03	0.22	0.33	10.0	GOOD
		2009-10	0.35	0.06	0.24	0.46	16.0	GOOD
		2010-11	NA	NA	NA	NA	NA	NA
	CC-F4	2008-09	NA	NA	NA	NA	NA	NA
		2009-10	0.45	0.06	0.33	0.58	14.0	GOOD
		2010-11	NA	NA	NA	NA	NA	NA
	CC-F5	2008-09	0.46	0.03	0.40	0.51	6.6	GOOD
		2009-10	0.46	0.06	0.34	0.58	13.0	GOOD
		2010-11	0.31	0.00	0.30	0.31	0.8	GOOD
	CC-F6	2008-09	NA	NA	NA	NA	NA	NA
		2009-10	0.40	0.08	0.24	0.55	19.8	GOOD
		2010-11	0.45	0.00	0.45	0.46	0.6	GOOD
Charley Average			0.32	0.05	0.23	0.42	26.92	
North Fork	**NF-F1**	2008-09	0.10	0.03	0.04	0.16	29.2	MOD
		2009-10	0.25	0.17	0.00	0.59	67.1	POOR
		2010-11	0.09	0.07	0.00	0.24	81.9	POOR
	NF-F4	2008-09	0.27	0.04	0.19	0.35	14.7	GOOD
		2009-10	0.20	0.07	0.06	0.33	34.9	POOR
		2010-11	0.13	0.03	0.06	0.19	26.1	MOD
	NF-F6	2008-09	0.21	0.05	0.12	0.31	23.1	MOD
		2009-10	0.10	0.06	0.00	0.22	56.5	POOR
		2010-11	0.05	0.11	0.00	0.26	196.3	POOR
North Fork Average			0.16	0.07	0.05	0.29	58.85	
South Fork	**SF-F2**	2008-09	0.48	0.03	0.42	0.54	6.6	GOOD
		2009-10	0.30	0.05	0.20	0.40	17.2	GOOD
		2010-11	0.16	0.07	0.03	0.29	41.3	POOR
	SF-F3	2008-09	0.58	0.02	0.53	0.62	4.1	GOOD
		2009-10	0.27	0.05	0.17	0.38	19.9	GOOD
		2010-11	0.29	0.06	0.17	0.40	20.6	MOD
	SF-F5	2008-09	0.19	0.04	0.12	0.27	20.5	MOD
		2009-10	0.24	0.05	0.14	0.35	22.2	MOD
		2010-11	0.18	0.03	0.13	0.23	14.3	GOOD
South Fork Average			0.30	0.04	0.21	0.39	18.51	

The capture probability estimated by MARK for each site was similar to the recapture rates from our mark-recapture surveys and suggests that the number of tagged fish at each site is high. On average our capture probability across all sites was 0.26 (range = 0.14 – 0.38) with North Fork having the lowest mean capture probability (0.19) compared to Charley Creek (0.29), and South Fork (0.31; Appendix K). Site Fidelity was also extremely high for all sites and periods and suggests that fish that are captured and tagged at a site do not move out of the site until they are ready to out-migrate (mean = 0.99, min = 0.97, max – 1.00; Appendix K).

7.1.2.5 PRODUCTION AND CARRYING CAPACITY

7.1.2.5.1 Productivity

This report has focused on summarizing population metrics at the site scale (abundance, growth, survival, and movement). These population metrics will be important in determining and interpreting fish responses to restoration. We recognize that productivity measures (i.e., population growth rate) for the entire life cycle, or portions of the life cycle, are also an important measure of the restoration effectiveness. We will be calculating measures of productivity in the next report which will include data from the 2012 field season.

7.1.2.5.2 Biomass Production

We calculated the biomass production of juvenile steelhead $\geq$ 70 mm by taking the product of our abundance (fish/100 m^2), growth (g/g/d), and survival estimates for six periods and converted the units into g/ha/day. The six periods we calculated production for spanned from the summer 2008 to the summer 2011. The mean production across all sites, streams, and periods was variable (12.1 g/ha/day; SD = 24.7, min = -11.1, max = 145.5, median = 3.8). Production was significantly different between periods, streams, and sites ($p < 0.08$; Figure 42Figure 42). Production was higher in South Fork and over the summer to fall 2010 periods (i.e., July to September). Mean production in the summer to fall period was higher but more variable (mean = 27.3 g/ha/d, SD = 36.6) compared to the fall to summer period (mean = 4.2 g/ha/d, SD = 5.4; Figure 43Figure 43). Charley Creek was the only tributary where the overall production was negative in two of the three summer to fall periods.

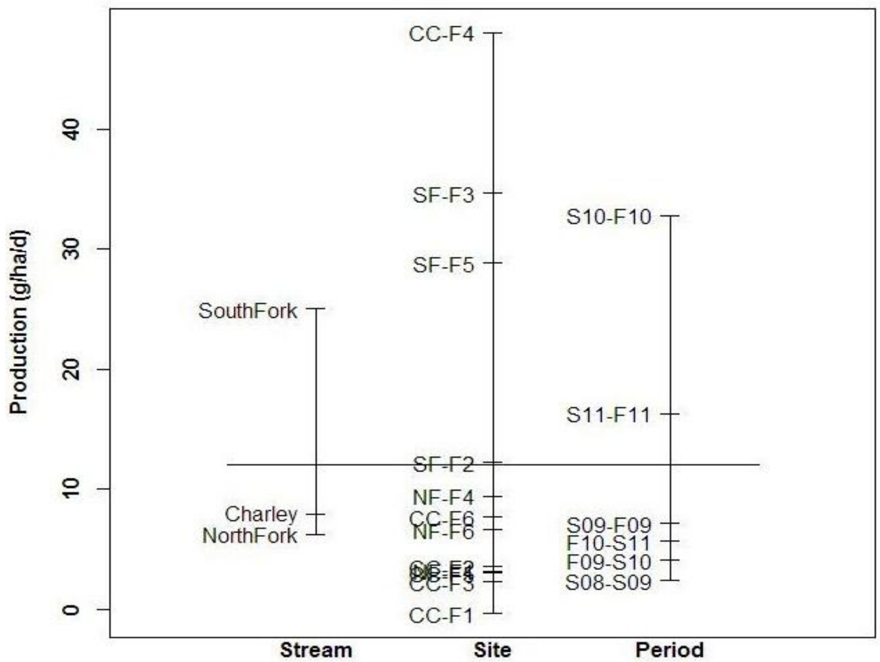
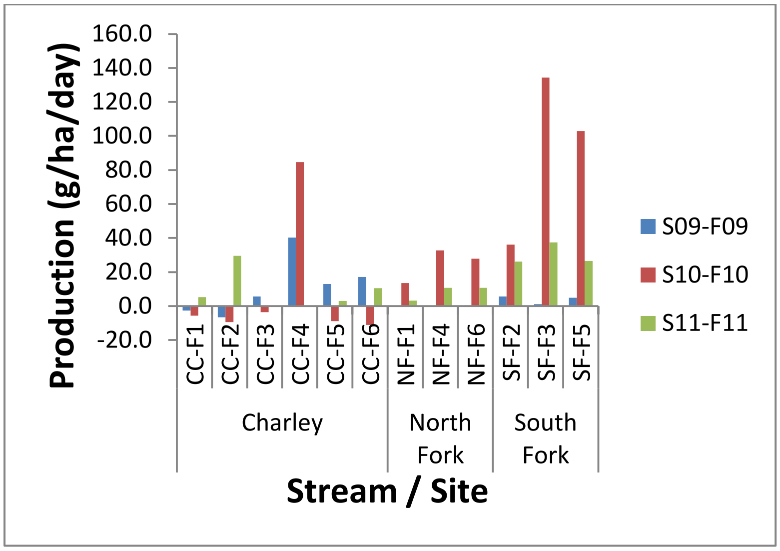


Figure 42. Main effects of three significant factors (Stream, Site, and Period) on the total production (g/ha/day) of juvenile steelhead ≥ 70 mm in Charley Creek, North Fork, and South Fork: Summer 2008 (S08) to summer 2011 (S11).

We are only in the very preliminary stages of trying to understand what factors control population abundance, growth, survival, production, and ultimately productivity at different spatial and temporal stages within Asotin Creek. We have looked at simple correlations between some common abiotic factors (e.g., pool and wood frequency, solar input, temperature) and biotic factors (e.g., fish density and drift biomass) and so far we have not found any strong relationships. However solar input does correlate positively with overall production which suggests that the orientation of sites and shading (i.e., riparian cover) varies across sites enough to influence overall production (Figure 44Figure 44). We will be using a multivariate approach in future analyses of the relationship between production/productivity and explanatory variables (e.g., random forest models; Knudby et al. 2010).

a)



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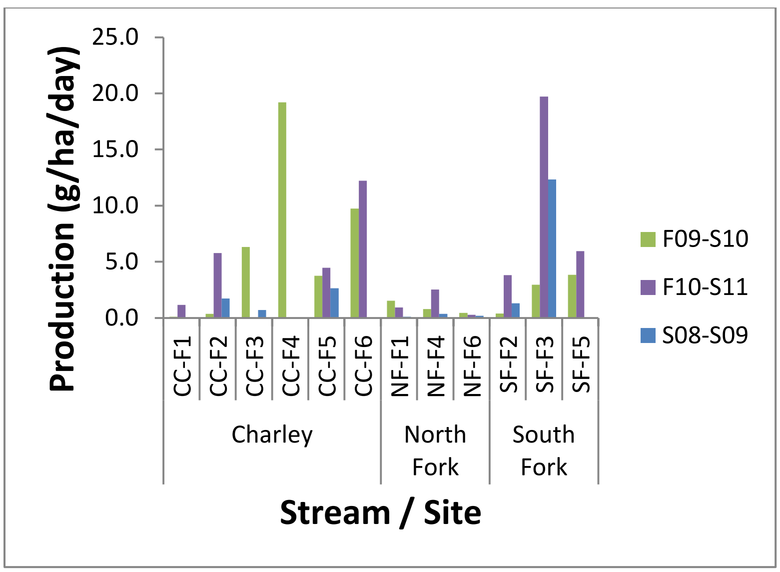


Figure 43. Total production of juvenile steelhead (g/ha/day) during a) three summer production periods and b) two fall to summer production periods by stream and site in Charley Creek, North Fork, and South Forks. S09-F09, S10-F10, and S11-F11 are three month periods from July-September in 2009, 2010, and 2011 respectively. F09-S10 and F10-S10 are eight month periods from October–July in 2009/2010 and 2010/2011 respectively. We included S08-S09 with the fall to summer periods because it also spans a large period (i.e., August 2008 to July 2009). Note the difference in the y-axis between the two graphs.

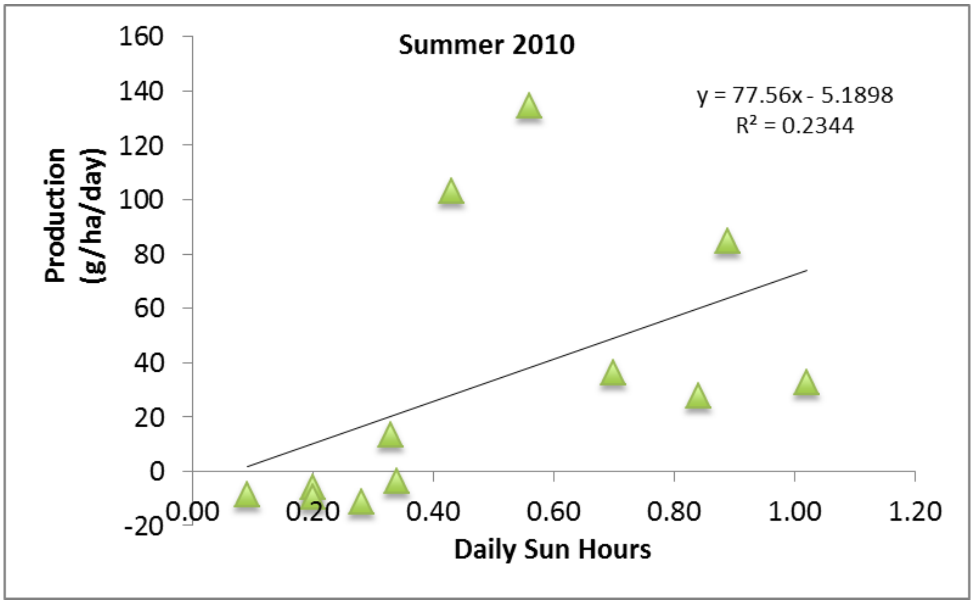


Figure 44. Correlation between total sun hours for all fish sites in summer 2010 (n = 12) and estimated juvenile steelhead production (g/ha/day) of each site.

7.1.2.5.3 Carrying Capacity and Net Rate of Energy Intake

We are continuing to develop and refine a modeling approach to estimating carrying capacity using methods similar to Hayes et al. (2007) but expanded to the site scale. We have successfully created a net rate of energy intake surface(NREI) to for an entire site using a CHaMP topographic survey, substrate measurements, 2 D flow model, drift samples, bioenergetics models, temperature, and fish abundance estimates (“NREI (Before)” Figure 45). We then simulated proposed restoration actions (i.e., LWD additions) to create a hypothetical streambed topography and corresponding NREI surface that has more pools (“NREI (After)”Figure 45). By differencing the predicted NREI surfaces from the before and after scenarios we can generate a visual depiction of how the proposed restoration actions could influence the ability of drift-feeding fish to acquire the energy they need (“NREI of Difference” Figure 45). To further help us understand how the changes might influence fish, we could then create a histogram of the magnitudes of all changes in a site (“Histogram of NREI of Difference” Figure 45) to illustrate the overall pattern of changes to the energetic landscape for fish following restoration.

We are continuing to develop this approach to further streamline the process, reduce processing time, and improve realism in the modeling approach. We hope to reduce the number of computer programs needed to use this approach (currently about 5 separate software packages) to one or two programs as this would make the process faster and simpler. Currently, the model used to predict the paths of drifting invertebrates and the fish foraging model are command-line programs written by our collaborators. In the future, we hope to code our own versions of these programs using scripting languages like R and Python to give us even more control over the modeling environment. Though still in development, we hope this modeling approach will provide insight into how physical habitat, flow, food, and temperature combine to influence the lives of fish in the Asotin drainage and to help us understand the range of possible results following restoration.

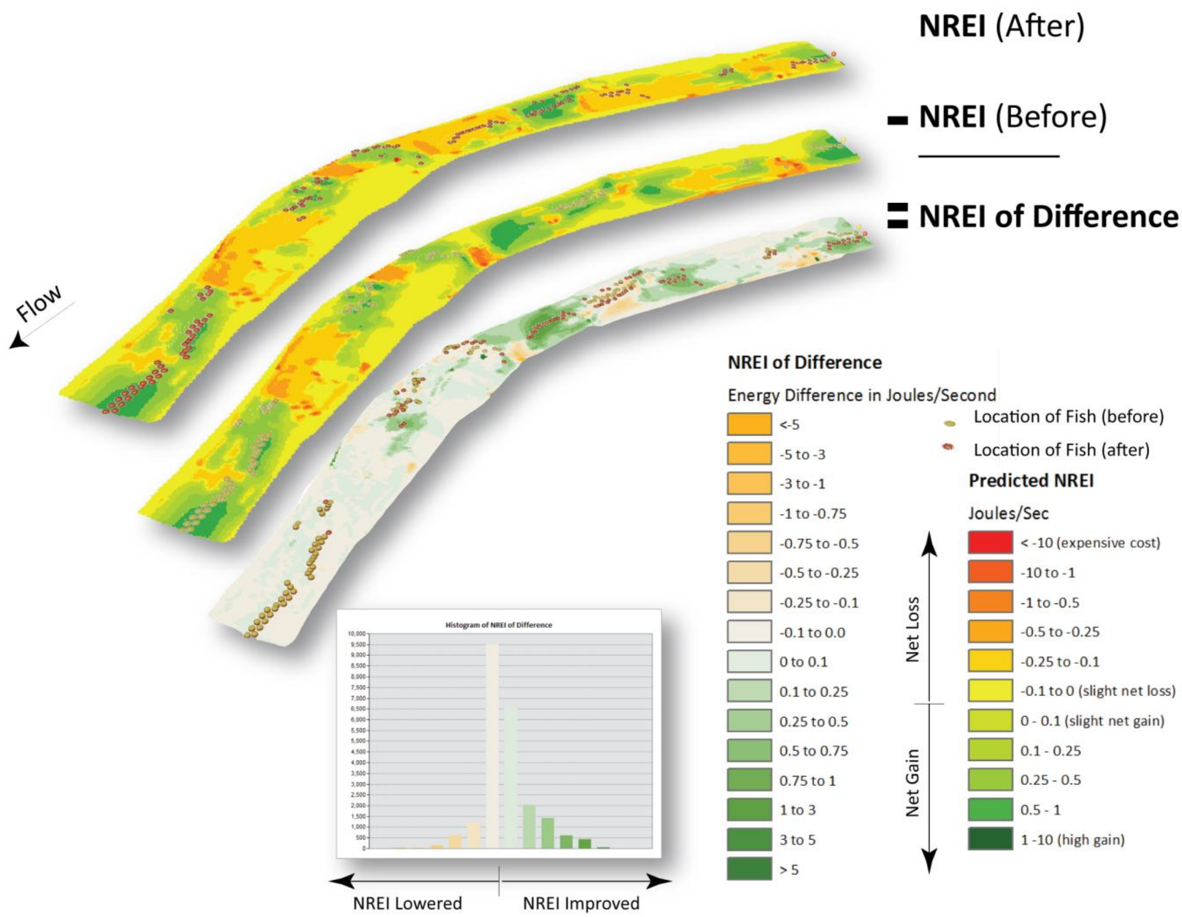


Figure 45. Net rate of energy intact (NREI) and fish location predictions for pre-treatment (Before), hypothetical post-treatment (After; following creation of pools and flow refugia via wood additions), and the difference (subtraction of Before from After) in a reach of the South Fork of Asotin Creek. The difference surface describes the change in energy available and carrying capacity of the reach due to restoration.

7.1.2.6 DISTRIBUTION, MOVEMENT, AND RESIGHTING

In the following sections we report on the movement and distribution of juvenile steelhead based on resighting of PIT tagged individuals from three primary sources: recaptures at our permanent fish sites, detections during mobile surveys, and array detections at the mouths of tributaries and lower Asotin Creek mainstem. We present this data based on the scale movement we observed: between streams, between sites, within sites, out-migration, and residency. We use the term "***on-site***" to refer to fish that are captured, recaptured, or resighted within the site where they were first tagged and the term "***off-site***" to refer to fish that are encountered outside of the site where they were originally tagged. We use the term "***home stream***" to refer to the stream where the fish was originally tagged.

7.1.2.6.1 Movement Between Streams

Very few PIT tagged juvenile steelhead moved from the stream where they were tagged to another tributary (Table 27). For example, 1002 PIT tagged juvenile steelhead were detected leaving Charley Creek since August 2009 (when the array was installed) and 339 have been detected at the lower arrays on Asotin Creek (and presumed to have out-migrated). However, 25 (2.3%) of the tagged fish that left Charley Creek were detected crossing the AFC array 6 on Asotin Creek just downstream of the confluence of North Fork and South Fork (Table 27; see Appendix B for a complete description of the interrogation sites and arrays). The fish that were tagged in Charley Creek and crossed the AFC array 6 then entered both the North Fork (19 detections at AFC array 7) and the South Fork (13 detections at AFC array 8). The most movement between creeks was between South Fork and North Fork where 167 (21.1%) of the fish that left the South Fork were detected at the array at the mouth of the North fork (Table 27). However, it does not appear that many of these fish moved very far up the North Fork because only one fish tagged in the South Fork was captured at a fish site in the North Fork (Table 28) and only one fish tagged in the South Fork was resighted during mobile surveys in the North Fork (Appendix L). No fish that were tagged in Charley Creek and left were recaptured in either the North fork or South Fork (Table 28) and only one was resighted in the South Fork (Appendix L).

Table 27. Number of unique detections of PIT tagged juvenile steelhead at interrogation sites/arrays. *Tag location* refers to the site (stream) where the fish was originally captured and tagged and *Detection Location* refers to the array/ interrogation site where the fish was detected. See Table 10 and Appendix B for a description of the interrogation sites and arrays at each site.

Detection Location		Tag Location			
Stream	**Interrogation Site/Array**	**Smolt Trap**	**Charley**	**North Fork**	**South Fork**
Asotin Creek	**ACM & ACB/1-2, & 3**	1976	339	309	398
Charley Creek	**CCA/ 4-5**	0	1002	3	26
Asotin Creek	**AFC/ 6**	0	25	554	792
North Fork	**AFC/ 7**	0	19	503	167
South Fork	**AFC/ 8**	0	13	47	771

Table 28. Captures and recaptures of PIT tagged juvenile steelhead at each fish site in the Asotin Creek IMW study streams: 2008-2011. CC = Charley Creek, NF = North Fork, SF = South Fork. *Tag Site* refers to the fish site where the fish was originally captured and tagged and *Recapture Site* refers to the fish site where the fish was recaptured.

	Tag Site														
Recapture Site	**CC-F1**	**CC-F2**	**CC-F3**	**CC-F4**	**CC-F5**	**CC-F6**	**CC-UPPER**	**NF-F1**	**NF-F4**	**NF-F6**	**NF-UPPER**	**SF-F2**	**SF-F3**	**SF-F5**	**SF-UPPER**
CC-F1	815	3	4	1	4	3						1			
CC-F2	1	967	4	1	5	1									
CC-F3		2	621	1											
CC-F4			2	670	3	1									
CC-F5			2	1	1054	2									
CC-F6				2	6	709									
CC-UPPER							117								
NF-F1								837						1	
NF-F4									1149	1					
NF-F6									1	1078					
NF-UPPER											93				
SF-F2												1543	3	2	
SF-F3												7	1440	1	
SF-F5												2	1	1309	
SF-UPPER															127
% Captured Off-Site	0.1	0.5	1.9	0.9	1.7	1.0	0.0	0.0	0.1	0.1	0.0	0.6	0.3	0.3	0.0

7.1.2.6.2 Movement Between Sites

We would expect to recapture a significant number of PIT tagged juvenile steelhead that were tagged at different fish sites (within the same stream they were tagged) if there was significant movement within streams. However, on average only 0.5% (SD = 0.6, Min = 0.0, Max = 2.9, Median = 0.3) of the fish we recaptured were found at a site other than the site they were originally tagged (Table 28; n = 6,491 recaptures). The mobile surveys detected more fish off-site, however, the proportion of fish detected off-site was low averaging 5.4% and most of these fish were caught downstream of where they were tagged (Appendix L).

We conducted test mobile surveys 100-200 m downstream of fish sites in 2009 and 2010 and resighted no tagged fish. In 2011, we conducted longer mobile surveys upstream and/or downstream of 8 of the 12 fish sites to confirm that there is very limited movement off-site (Appendix L). We surveyed 14 km with the mobile antenna and detected 119 unique tags or 8.5 fish/km.

For all fish that were resighted in more than one mobile survey period we calculated the distance upstream or downstream the fish had moved since its first detection. We included the mobile data outside the fish sites in 2011. The mean distance fish moved was 165.9 m (SD = 362, min = 1.9, max = 1256, median = -39.1, n = 690; Appendix L).

7.1.2.6.3 Movement Within Sites

The vast majority of our mobile resighting of PIT tagged juvenile steelhead were on-site (94% were resighted within the site they were originally tagged). We therefore excluded the 6% of resightings off-site to evaluate how much fish were moving within a fish site if they did not leave. We used negative values for downstream movements and positive values for upstream movement. The mean movement of fish resighted on-site was very low averaging -7.5 m across sites (SD = 10.1, Min = 0.0, Max = 25.8, Median = -4.6, n = 647; Figure 46). This movement data within sites confirms previous mobile surveys that suggests many fish are occupying a relative small area within a site and do not move much within a site. These mobile surveys occurred in all seasons (see Table 14) suggesting that there is little movement within a site regardless of the time of year.

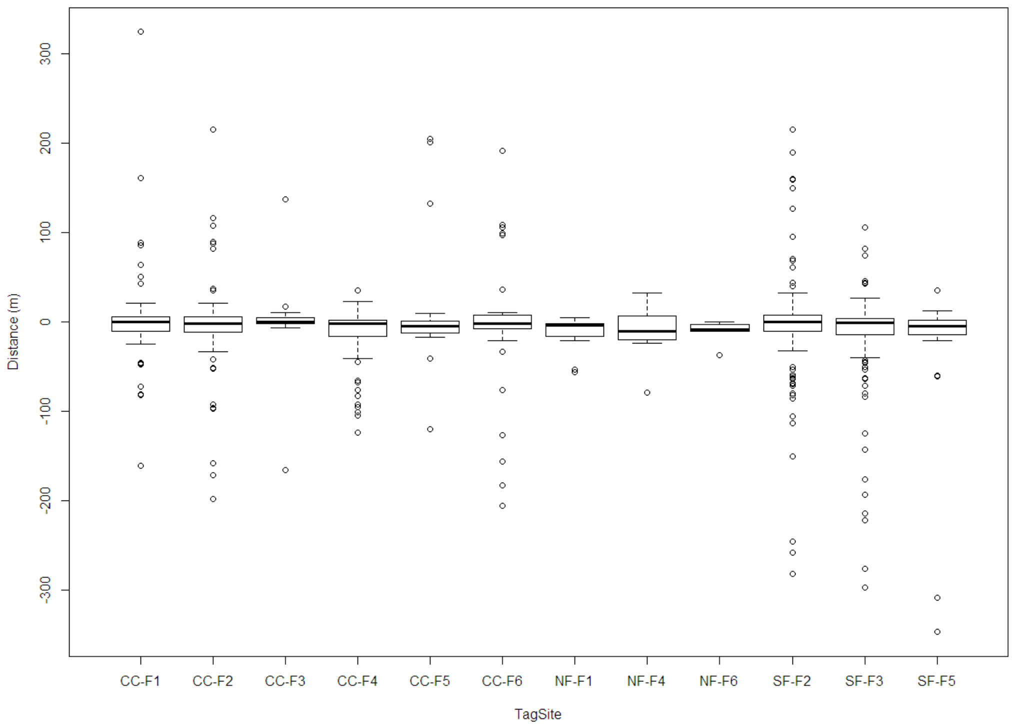


Figure 46. Distribution of distance moved from the first mobile detection of a PIT tagged juvenile steelhead to any other mobile resighting within the same fish site. Negative values indicate movement downstream and positive values indicate movement upstream. Boxes ends represent the 25th and 75th percentiles, the line in the box is the median, the whiskers are 1.5 x the interquartile range (IQR), and the open circles are outliers.

7.1.2.6.4 Out-migration and Residency

We estimate that a minimum of approximately 2,611 juvenile steelhead out-migrated from the tributaries where they were tagged based on a combination of expansions based on smolt trap captures of IMW tagged fish and array detections at the mouths of the tributaries (Table 29). Our goal is to determine the number of out-migrating juvenile steelhead from each tributary and site each year and season. PIT tag arrays were not installed until the fall of 2009 so we estimated the number of out-migrants by using capture rates of IMW tagged fish at the WDFW smolt trap. WDFW has captured 147 juvenile steelhead PIT tagged in the IMW study streams since 2008 (Table 30). Based on the lower array (ACB and ACM) we estimate that 1,031 juvenile steelhead have pasted the array and presumably left

Asotin Creek. Therefore, the maximum capture rate of IMW tagged fish at the smolt trap is 14.3 % across all years. We will review this further before using the smolt trap data to expand out-migrant estimates when the arrays were not installed and to break these estimates down by age classes once the length at age data has been further analyzed.

Table 29. Count of the out-migrants detected at PIT tag arrays leaving the tributary where they were tagged: 2008-2011. Counts represent minimum estimates of out-migrants from tributaries and have not been expanded yet based on array detection efficiencies and population estimates within the tributaries.

	Year				
Stream	**2008***	**2009***	**2010**	**2011**	**Total**
Charley	52	136	377	530	1095
North Fork	34	61	236	256	587
South Fork	60	92	344	434	930
Total	**145**	**289**	**957**	**1220**	**2611**

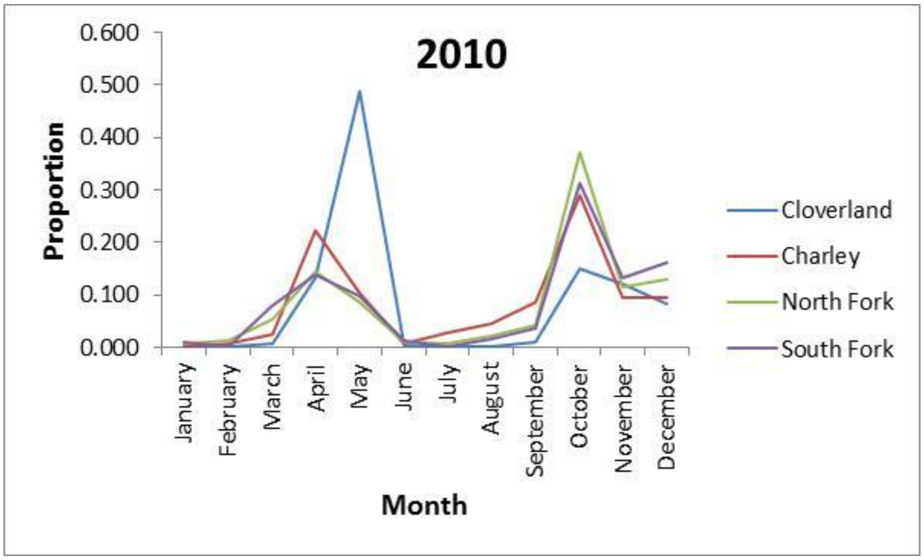
* 2008 and 2009 counts are based on expansion of smolt trap captures and efficiency rates, and detection of PIT tagged fish once the arrays were installed.

Table 30. Number of juvenile steelhead captured at the WDFW smolt trap (spring and fall) that were tagged in the Asotin Creek IMW study streams: 2008-2011. *In 2008 tagging started in July so the captures represent fall out-migrants only.

Year	**Charley**	**North Fork**	**South Fork**	**Total**
2008	14	9	16	39
2009	28	18	13	59
2010	18	9	18	45
2011		2	2	4
Total	**60**	**38**	**49**	**147**

We assessed the timing of out-migration from the tributaries with the two years of complete array detection data: 2010 and 2011. The majority of juvenile steelhead left the study streams during two peaks in April-May and October-November each year (Figure 47). In 2010 the proportion of fish leaving the study streams in the fall was larger than the spring out-migration but this trend reversed in 2011. However, in both years the proportion that left the Asotin (i.e., detected at the lower array) was larger in the spring suggesting that fish that leave in the fall may spend more time in the mainstem before leaving. Very few fish leave during the summer (n = 24; Figure 48Figure 48). Charley Creek had higher proportion of fish leaving in the summer in both years and in both years fish out-migrating from Charley Creek peaked in April versus May for the other tributaries. In the winter of 2010/2011 (i.e., December 2010 to February 2011) there was also a significant proportion of fish that out-migrated from the tributaries but to a lesser extent Asotin Creek. There does not appear to be the same winter movement in 2011/2012 but we are still collecting these data.

a)



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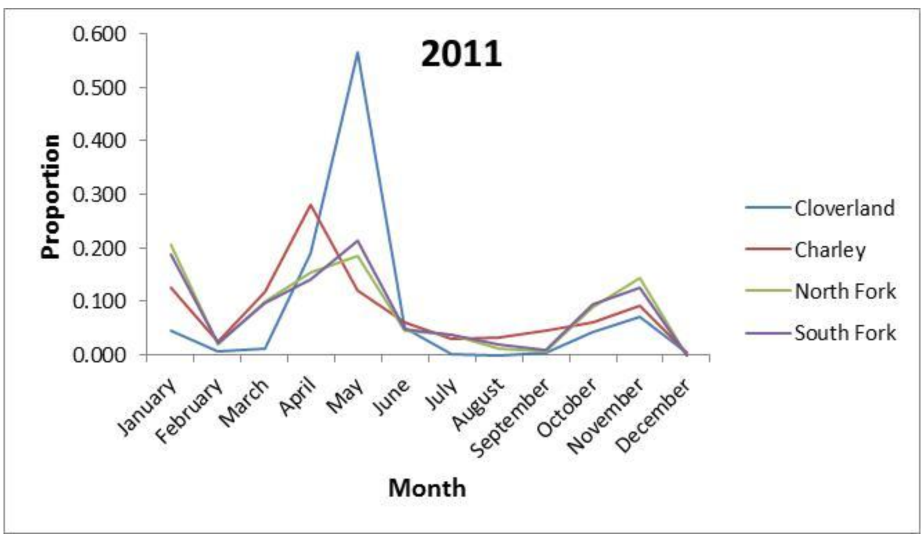

Figure 47. Proportion of out-migrating juvenile steelhead in a) 2010 and b) 2011 as determined by unique PIT tag detections at the arrays at the mouth of Charley Creek, North Fork, and South Fork. Cloverland refers to the array at Cloverland Bridge and detections there are presumed to be of juveniles leaving the Asotin watershed.

More fish have left the tributaries than have been detected at the lower arrays (2,402 left tributaries, 1,031 left Asotin). To investigate this further we calculated the number of days that every fish took from first being detected leaving the tributary they were tagged in to being detected at the lower array. The mean number of days juvenile steelhead took to travel from the mouth of their tributary to the lower array was 39.2 days (SD = 57.9, min = 1.0, max = 363, median = 16.0, n = 986; Figure 48). Steelhead that left the tributaries in the spring tended to spend the least amount of time in the mainstem of Asotin

Creek before crossing the lower array averaging 21.3 days between arrays (SD = 29.7). Fish that left the tributaries in the summer and winter spent the most time in the mainstem.

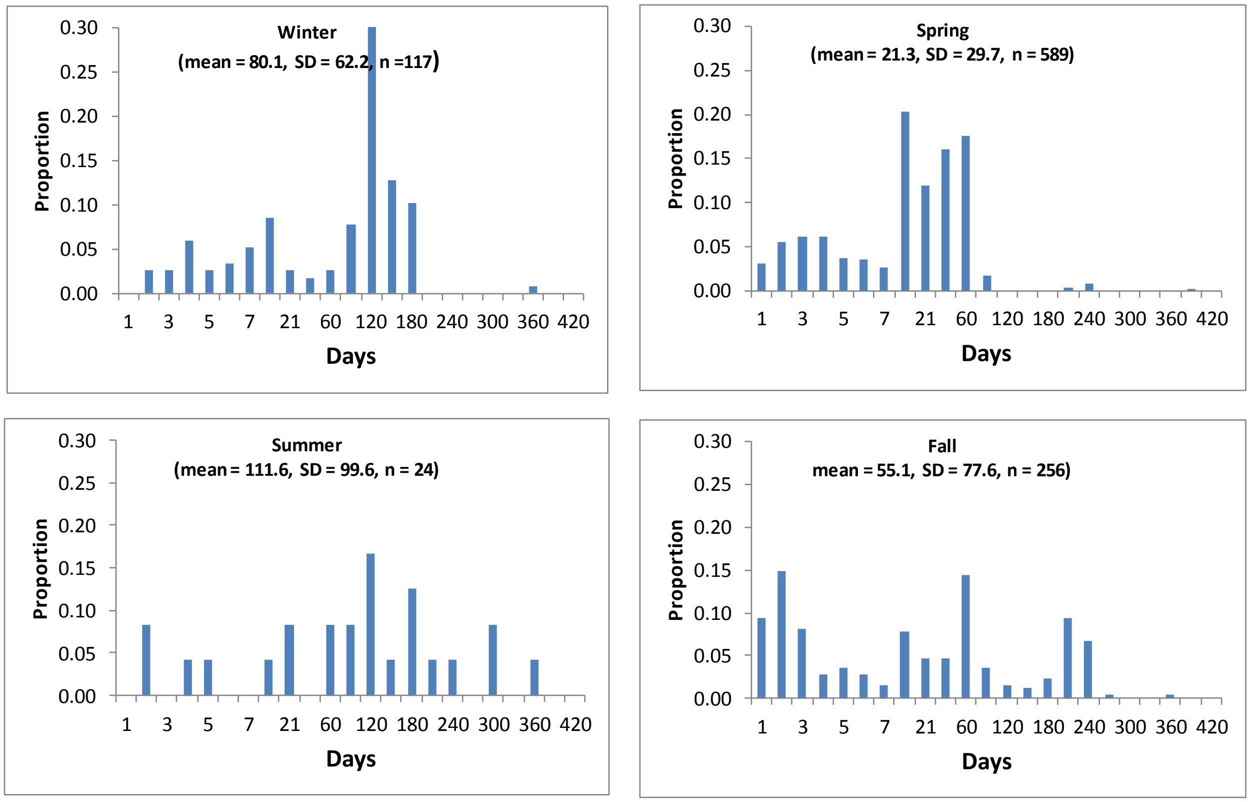

Figure 48. Proportion of juvenile steelhead and the number of days spent between the mouth of the tributary where they were tagged and the lower array approximately 5 km upstream from the mouth of Asotin Creek plotted by the season that they left the tributary. Data based on PIT tag detections at arrays from August 2009 to January 2012. Total number of juvenile steelhead that left the tributaries and were detected at the lower array = 986.

We determined the proportion of PIT tagged juvenile steelhead from each fish site that left their home stream to assess if there is was a greater propensity for juvenile steelhead to be resident in the upper sites compared to the lower sites of the IMW study streams (Figure 49). The upper sites (i.e., sites 5, 6, “upper”) in all three tributaries had a smaller proportion of juvenile steelhead leave the tributary (i.e., mean = 8%, range 0 -12) compared to the lower sites (i.e., sites $\leq$ 4; mean 24%, range 18-33). There were also a smaller proportion of fish from upper sites that were detected at the lower arrays on Asotin Creek (i.e., that presumably out-migrated). However, a higher proportion of the fish from upper sites that left their home stream have left Asotin Creek (Figure 50). This relationship was stronger for North Fork and South Fork compared to Charley Creek and could indicate difference in the proportion of steelhead and resident rainbow trout. We will evaluate this pattern further as more data is collected.

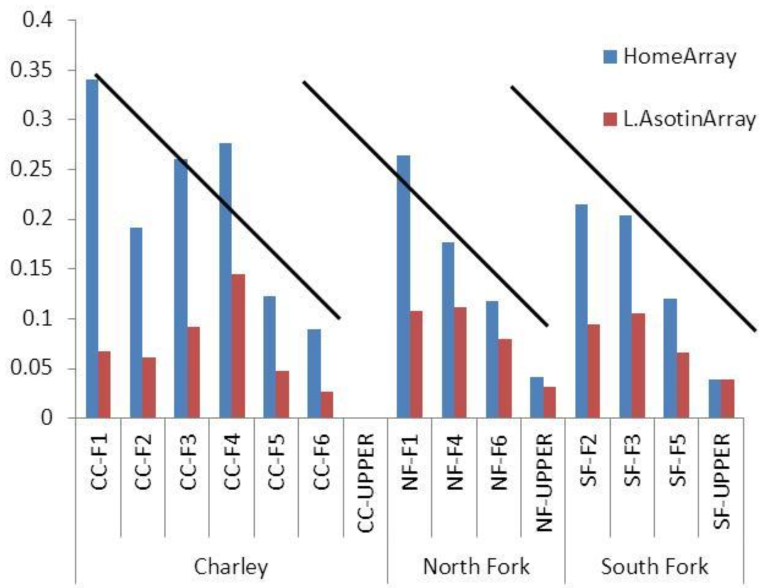

Figure 49. Proportion of juvenile steelhead PIT tagged at each site that left their home stream (blue bars) and the proportion of tagged fish at each site that were detected at the lower array on Asotin Creek (red bars; total tagged = 12,533, total detected leaving home stream = 2,343). Data based on detections at arrays from August 2009 – Jan 2012. Black bars indicate decreasing propensity to leave sites the further upstream the sites are.

Figure 50. Proportion of juvenile steelhead PIT tagged at each site that left their home stream and that were detected at the lower array on Asotin Creek (total tagged = 12,533, total detected leaving home stream = 2,343). Data based on detections at arrays from August 2009 – Jan 2012. Black bars indicate increasing propensity to leave Asotin Creek if the fish leave their home stream.

7.1.2.6.5 Movement down the hydro system

Thirty six juvenile steelhead have been detected at both ACB and Bonneville dam. It took these fish an average of 20 days to move between ACB and Bonneville dam (SD = 24.39). As of 3/26/2011, there has been 367 IMW juvenile steelhead detected moving downstream through Lower Granite Dam (Figure 51). The number of detections decreases at each dam moving downstream through the hydrosystem. Only 58 juvenile steelhead have been detected at Bonneville dam. Twelve adult steelhead have been tagged at IMW sites as juveniles, left Asotin Creek, and been detected at Bonneville as they returned as adults. Of these adults, five have been detected at Lower Granite dam, the final dam before Asotin Creek (Figure 52Figure 52). Three have returned to Asotin Creek, and were last detected by our PIT tag interrogation sites, returning to the same study stream they were originally tagged in.

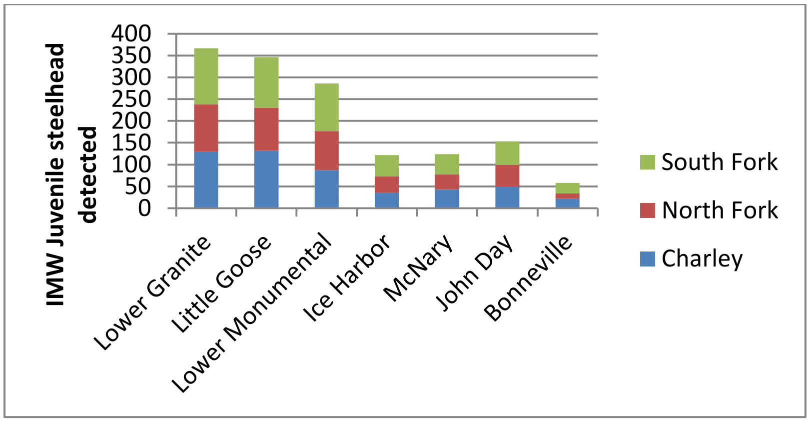

Figure 51. Count of PIT tagged juvenile steelhead that were detected migrating down the Snake and Columbia River hydro system. Fish were originally tagged in Charley Creek, North Fork, and South Fork: 2008-2011.

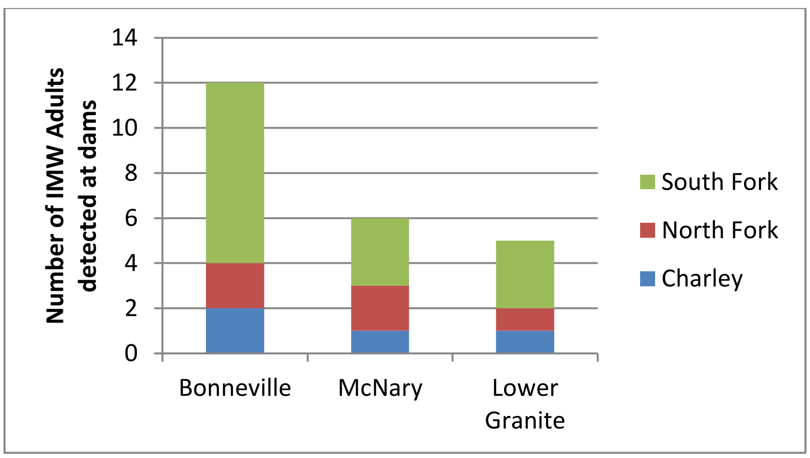

Figure 52. Count of PIT tagged adult steelhead moving upstream through the Columbia and Snake River hydrosystems. Fish were originally tagged at tagged in Charley Creek, North Fork, and South Fork: 2008-2011.

7.1.3 ADULT STEELHEAD

The adult data have not been fully analyzed to date. We only began PIT tagging adults in 2010 and red counts have been difficult to complete due to water conditions. These data as well as historic redd count data will be further examined in future reports.

7.1.3.1 ABUNDANCE, DISTRIBUTION, AND MOVEMENT

Abundance

There was a threefold increase in the number of adults entering Asotin Creek between 2008 and 2011 (Crawford et al. 2012; Table 20). In 2008 and 2009 adults were not PIT tagged at the weir so we will review the WDFW redd count data to estimate the number of adults entering the IMW study streams. In 2010 WDFW began PIT tagging all adult steelhead captured at the weir. We used the number of PIT tag detections at arrays throughout Asotin Creek to estimate the abundance, distribution, and movement of adults within Asotin Creek in 2010 and 2011. We present estimates of the known number of tagged adults entering the study streams each year. Future analysis will expand these estimates based on detection efficiencies of the arrays.

We estimated that 41% and 46% of the adult steelhead that were captured and PIT tagged at the weir entered the study streams in 2010 and 2011 respectively (Figure 53). The majority of the PIT tagged adults that entered the study streams went into North Fork in both 2010 and 2011. In both years we observed adult steelhead entering multiple tributaries and spending a varying amount of time in each tributary (Figure 54). We will review these data further to determine how this movement between tributaries may influence recruits per spawner estimates. In 2010, we noted that adults entered all streams prior to an increase in the discharge and very few fish entered once flows were consistently high (Figure 55).

Adult steelhead took an average of 7.1 days to travel from the adult weir to the study streams and spent on average 11 days in the tributaries based on combined data from 2010 and 2011 (Figure 56 and Figure 57. Mean number of days adult steelhead remained above the tributary arrays in 2010 and 2011.). Adult steelhead spent slightly longer above the tributary arrays in 2011 than they did in 2010. In 2010, 54% of adult steelhead detected at a tributary array were male, versus 36% in 2011 (Figure 58).

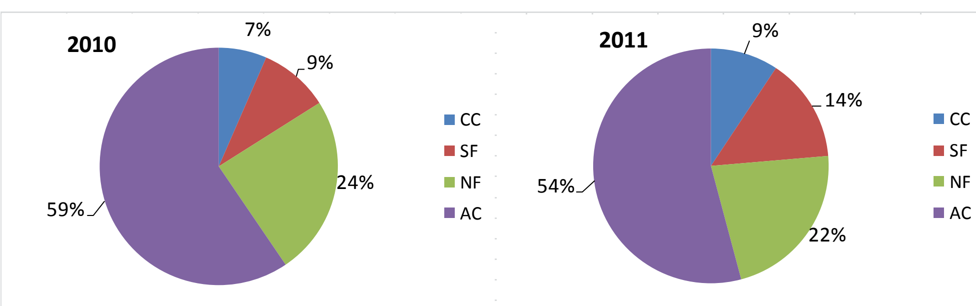

Figure 53. Proportion of PIT tagged adult steelhead that were captured at the WDFW weir on Asotin Creek that entered the IMW study streams or stayed in the mainstem Asotin Creek in 2010 and 2011. CC = Charley Creek, SF = South Fork, NF = North Fork, and AC = Asotin Creek mainstem.

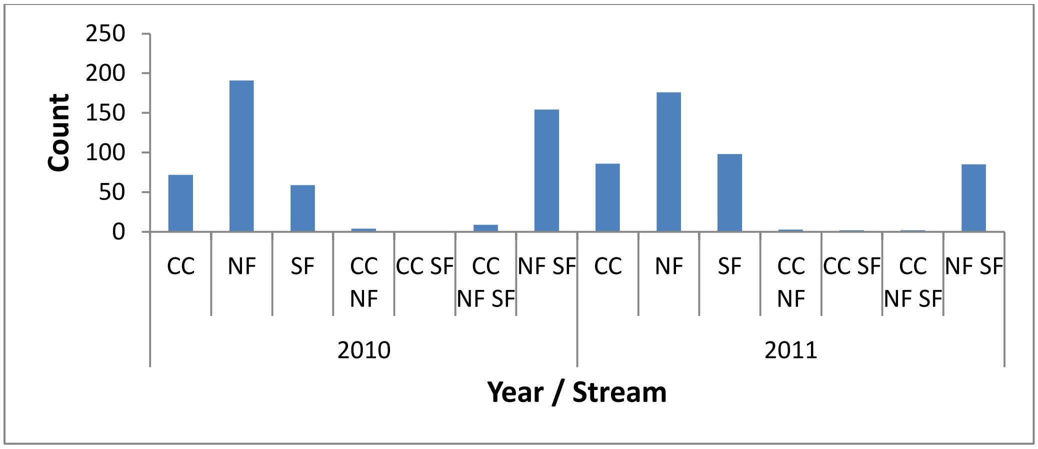

Figure 54. Count of PIT tagged adult steelhead detected entering the study streams (CC = Charley Creek, NF = North Fork, SF = South Fork) in 2010 and 2011. Multiple listing of streams per bar indicate the number of fish that went up more than one tributary (e.g., CC NF = count of adult steelhead entering both Charley Creek and North Fork).

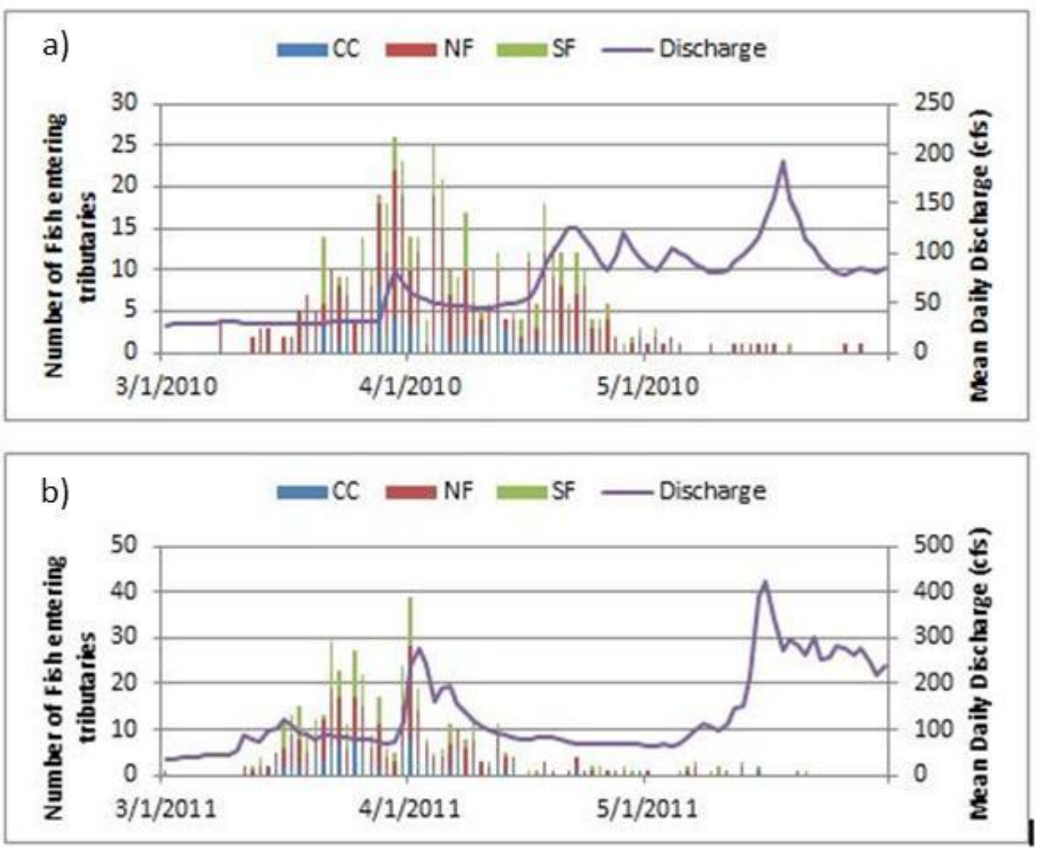

Figure 55. Timing of adult steelhead entry into the Asotin IMW study streams in a) 2010 and b) 2011 compared to the average daily discharge measured at the confluence of North Fork and South Fork Asotin Creeks.

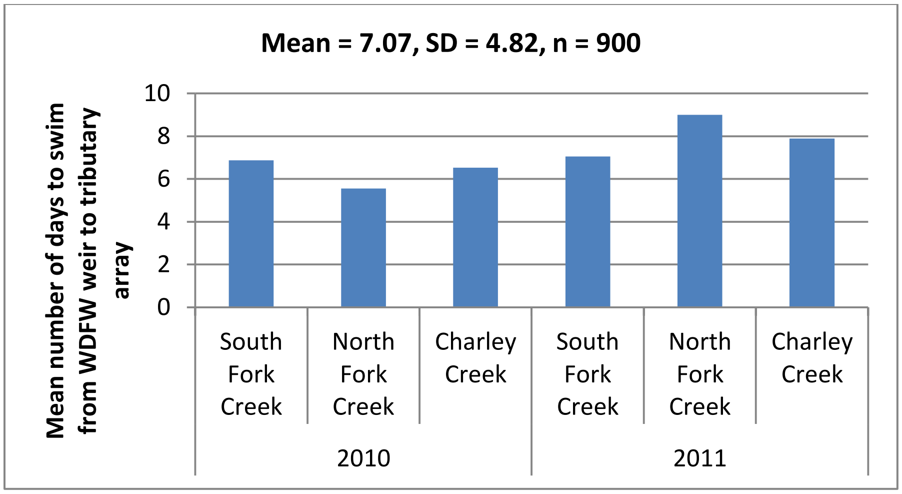

Figure 56. The average number of days between an adult steelhead passing the WDFW weir and being first detected at an array in one of the study streams in 2010 and 2011.

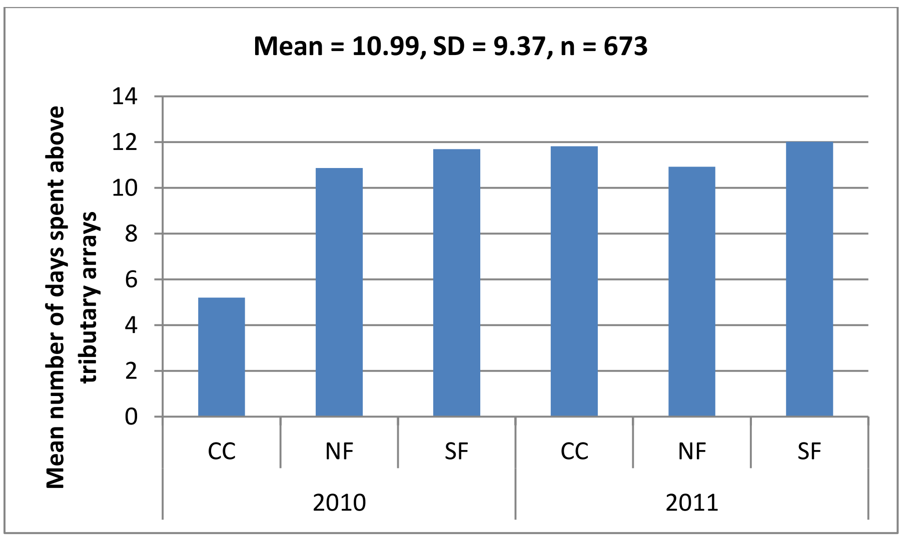

Figure 57. Mean number of days adult steelhead remained above the tributary arrays in 2010 and 2011.

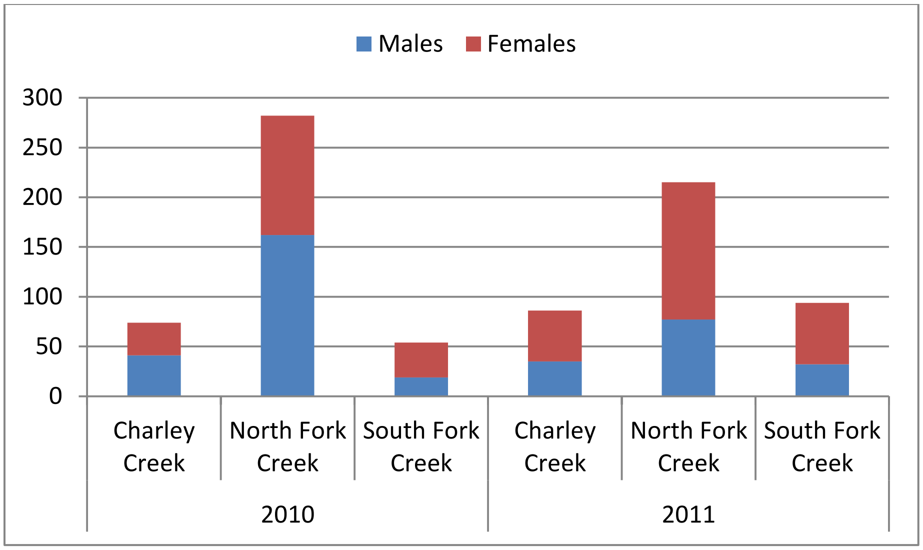

Figure 58. Number of adult steelhead that went up each study stream by sex in 2010 and 2011. Sex was determined at the WDFW weir (n=805).

7.1.3.2 REDD COUNTS IN TRIBUTARIES

These data are still being compiled and analyzed.

7.1.4 MACROINVERTEBRATES

From 2008 to 2010 we collected benthic invertebrates. We provided a summary of benthic genera and diversity indices in Bennett and Bouwes (2009). Since 2009 we have been collecting invertebrate drift samples. Estimates of the species composition, size classes, source (aquatic or terrestrial), and biomass per volume of water will be used to model carrying capacity and model net energy intake (see section 7.1.2.5.3). We will also assess the health of each study stream by using state aquatic invertebrate models time and budget permitting.

A preliminary assessment of benthic samples found that the percent of species from Ephemeroptera, Plecotera, and Tricoptera (EPT) compared to all other species groups averaged 45% across all streams from 2008-2010 which suggests that the study streams have moderate to good water quality (Figure 59Figure 59). Drift samples suggest that a large proportion of the food available to juvenile steelhead may be from terrestrial sources which indicates that the riparian areas are an important source of food (Figure 60Figure 60). These types of data will be used in future analyses to explain fish response and model fish and habitat relationships.

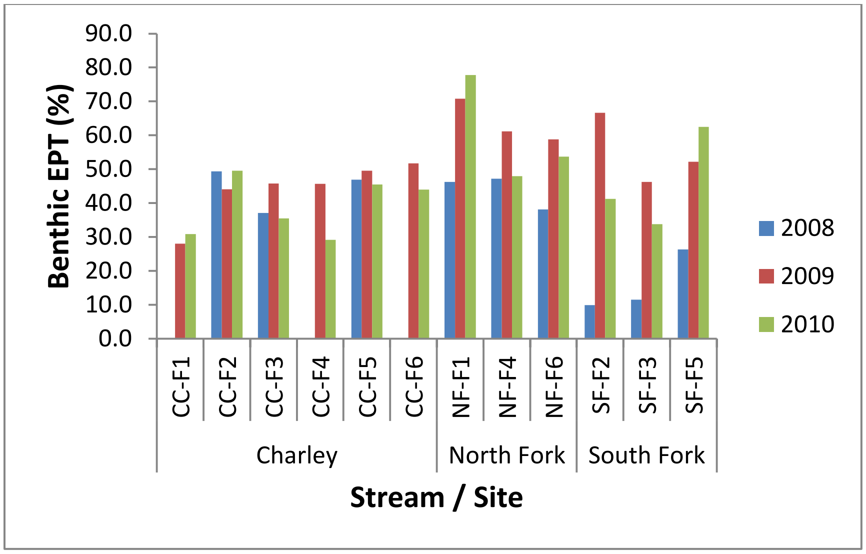

Figure 59. Percent of Ephemeroptera, Plecotera, and Tricoptera genera (EPT) within benthic samples from 2008-2010 by each study stream and site.

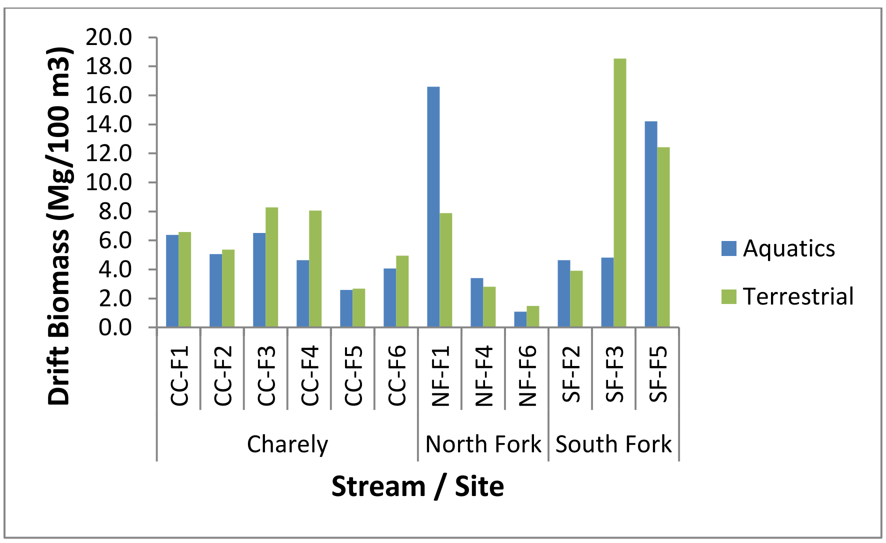

Figure 60. Drift biomass separated by origin (aquatic or terrestrial) for 2010 by site and stream.

7.2 STREAM HABITAT AND CHANEL RESULTS

A total of nine stream habitat surveys were conducted in 2008 and 24 surveys were conducted in 2009 using PIBO protocols (Table 19). All the sites surveyed in 2008 were resurveyed in 2009 as per the monitoring design (i.e., permanent and alternate sites). The stream habitat sites overlap the fish survey sites so that direct comparisons can be made between fish abundance and habitat conditions (Figure 13). Twelve surveys were conducted in 2010 using a draft version of the Columbia Habitat Monitoring Protocol (CHaMP). In 2010 we surveyed the entire length of each fish site with the draft CHaMP protocol which used a “stick and tape” method instead of a total station survey (i.e., all three habitat sites per fish site). In 2011 we implemented the newly developed CHaMP protocol using a total station survey at 10 habitat sites. Below we summarize key habitat attributes that the IMW will focus on, and compare treatment and control sites to each other and to estimates of reference conditions.

7.2.1 STREAM HABITAT

7.2.1.1 LARGE WOODY DEBRIS

During the first year of pretreatment monitoring in 2008, the abundance of large woody debris was found to be significantly lower in all study streams compared to mean abundance of LWD in reference conditions from published and unpublished reports from similar sites in eastern Washington (Carlson et al. 1997, Fox and Bolton 2007, PIBO 2008). The combined results from four years of pretreatment monitoring show the same significant difference between the abundance of LWD in each treatment stream and reference conditions (Figure 61Figure 61). On average the Asotin study streams had < 20 pieces of LWD/100 m compared to 40 pieces/100 m at the reference sites.

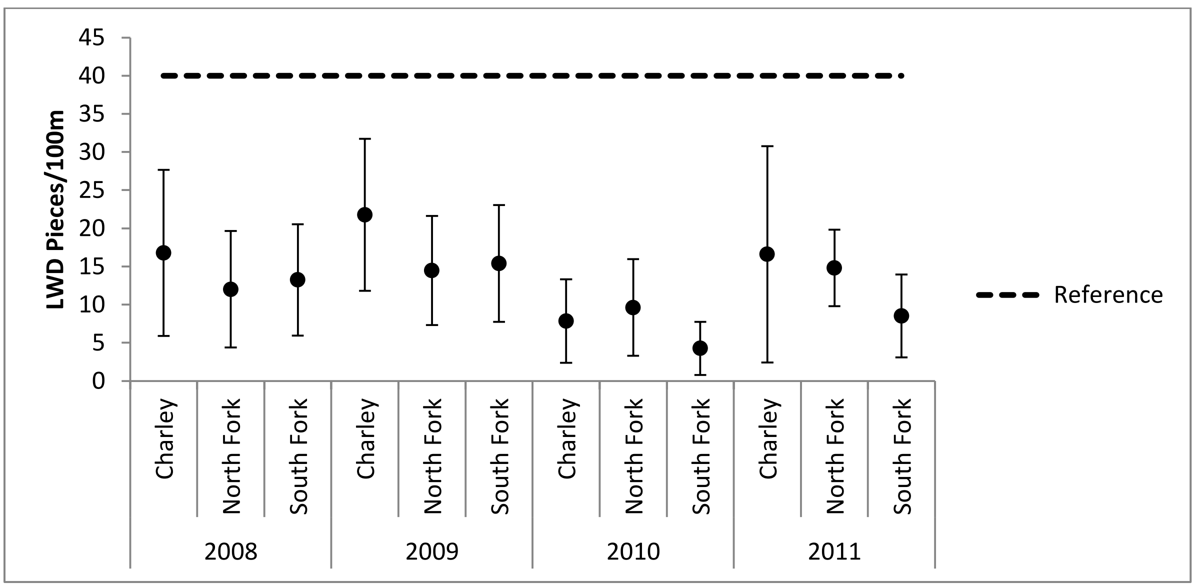

Figure 61. Mean abundance of large woody debris (> 10 cm diameter and 1 m long within the bankfull width) in Charley Creek, North Fork, South Fork. See text for source of reference conditions. Error bars = ± 1 SD.

7.2.2 HABITAT UNITS

The CHaMP monitoring protocol uses a habitat unit approach to collect data. We found that the proportion of habitat units were mostly fast water habitats which is consistent with results from previous sampling (see Bennett and Bouwes 2009). In Charley Creek for example, almost 73% of the habitat was classified as fast water habitat (i.e., riffles, rapids and cascades; Figure 62Figure 62). It is expected that the proportion of pools and other habitat types (e.g., undercuts, bars, side channels) will increase dramatically after restoration.

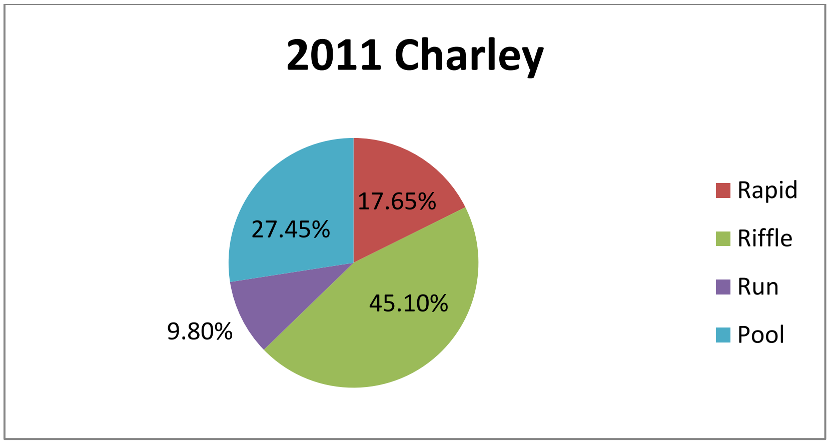

Figure 62. An example of the proportion of habitat units in Charley Creek based on 4 CHaMP habitat surveys in Charley Creek in 2011.

7.2.2.1 POOLS

The number of pools remained low over all years of sampling compared to reference conditions (Figure 63Figure 63). Only 7 pools out of 204 measured between 2008 and 2009 had maximum depths $\geq$ 0.9 m and residual pool depths of all pools averaged <0.3 m.

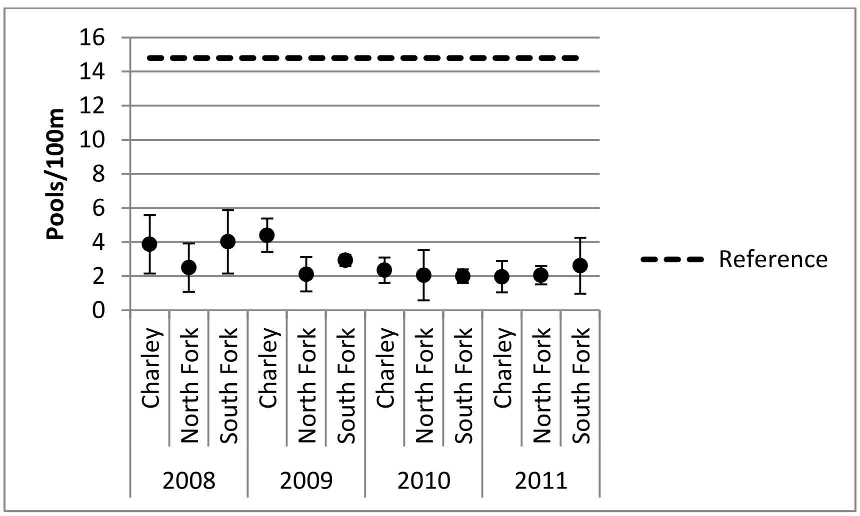

Figure 63. Mean abundance of pools in Charley Creek, North Fork and South Fork compared to reference pool frequency conditions. Error bars = $\pm$ 1 SD.

We measured pool tail fines in the study streams during low flow from 2008 to 2011. Charley Creek consistently had more fines present in pool tails the other streams (Figure 64Figure 64). The North Fork had the least amount of fines. In 2011, the average percent of pool tail fines in the study streams was much higher than in the previous three years (Figure 65).

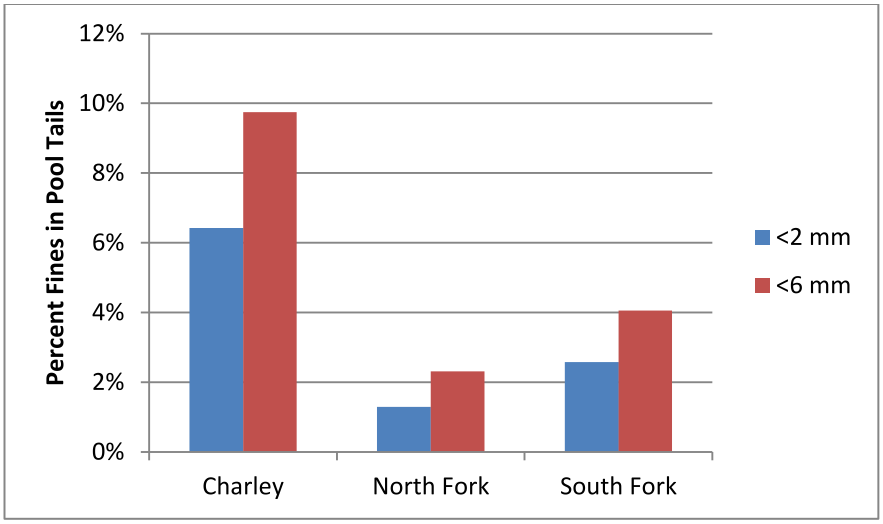

Figure 64. Percent of pool tail fines from habitat sites averaged by stream from 2008-2011.

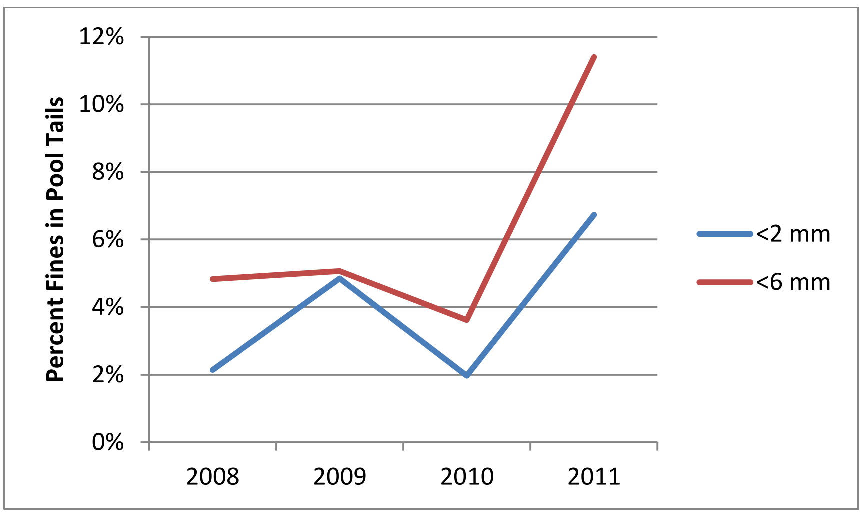

Figure 65. Percent of pool tail fines averaged across all study streams by year.

7.2.3 TEMPERATURE AND WATER QUALITY

Temperature loggers are located in each fish reach and strategically throughout the watershed to assess water temperature fluctuations and spot water quality sampling was conducted at each fish reach during low flow conditions annually. Stream temperatures continue to exceed the 7-day maximum temperature limits set by the WDOE for salmonid spawning, rearing, and migration (17.5 ˚C) and the adult migration criteria of 20.1 ˚C recommended by Hicks (2002) and USEPA (2003). The mainstem of Asotin Creek was the warmest and the North Fork and Charley Creek were the coolest. However, all streams exceeded the criteria for less time during the period of the IMW (2008-2011) compared to an earlier period recorded by Bumgarner et al. (2004; Figure 66 and Figure 67Figure 67). High average stream flows from 2008-2011 were likely responsible for the lower average summer temperatures compared to the period 2000-2004.

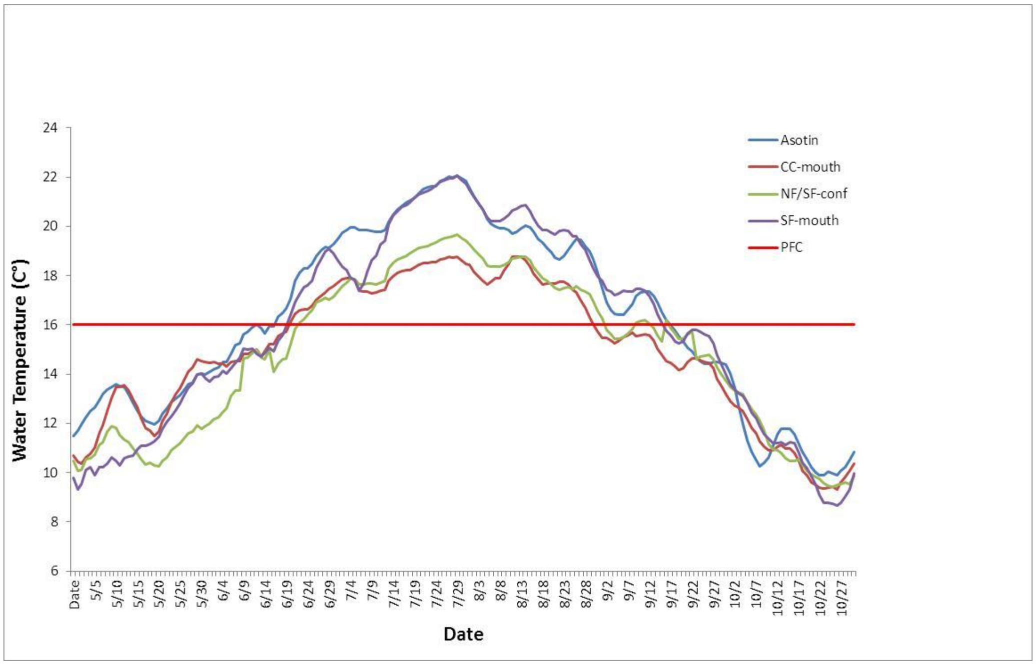

Figure 66. Seven day moving average maximum daily water temperature in Asotin Creek and the three IMW study streams compared to the proper functioning condition (PFC) temperature standard for the period of 2008-2011.

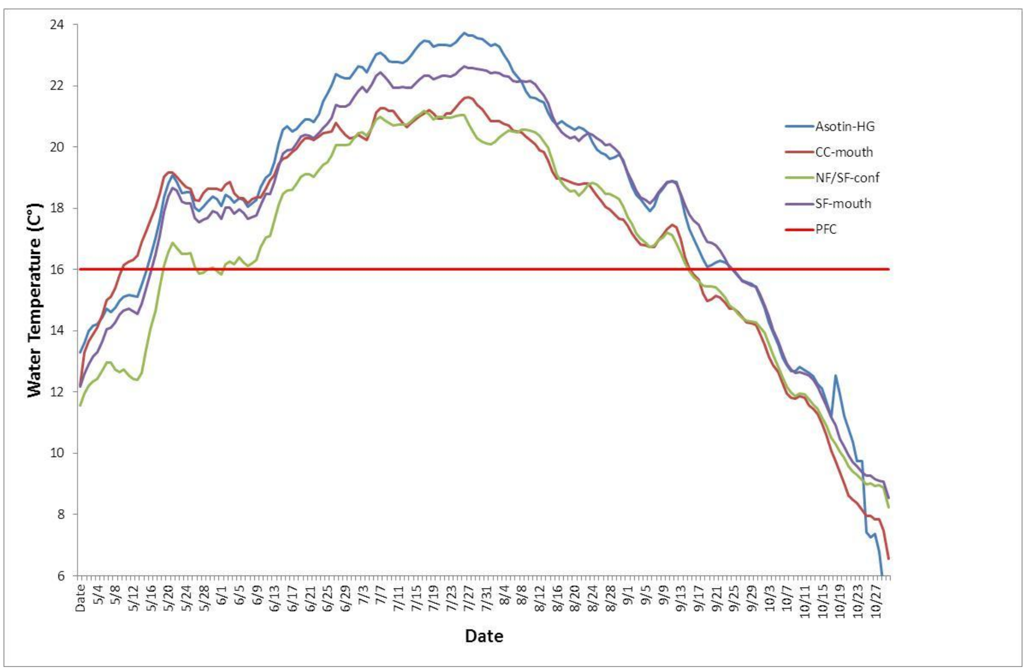

Figure 67. Seven day moving average maximum daily water temperature in Asotin Creek and the three IMW study streams compared to the proper functioning condition (PFC) temperature for the period of 2000 to 2004 (data collected by Bumgarner et al. 2004).

We calculated the change in temperature per river kilometer for each study stream and over sections of the mainstem of Asotin Creek (Figure 68). We used temperature data from July 15 to August 15, 2010-2011, when summer temperatures are typically at their peak. We analyzed data from temperature loggers placed throughout the study area. All the sections of each stream showed an increase in temperature moving downstream. The South Fork of Asotin Creek increases the most at >1° F/RKM. The mainstem of Asotin increases <.4° F/RKM in each section we calculated in this analysis. These results are consistent with the increases shown by Bumgarner et al. (2004) in a similar analysis.

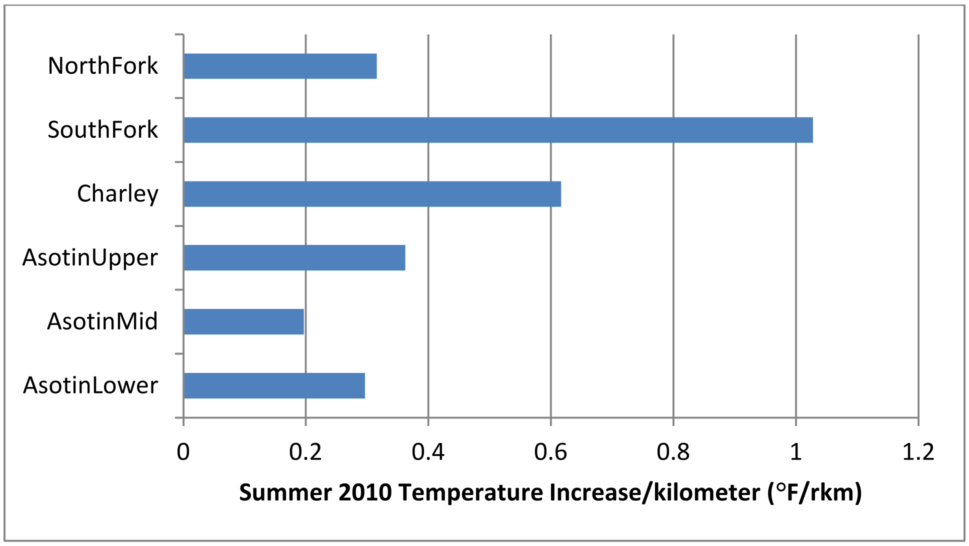

Figure 68. Average temperature increase per river kilometer in Asotin Creek and its tributaries between July 15 and August 15, 2010. Data from the North Fork is from July 15 to August 15, 2011.

Water quality parameters were similar to those reported in the late 1990's (Table 31; WSU 2000). Turbidity and nutrient levels do not seem to be a problem but dissolved oxygen levels are low, likely due to the relatively high water temperatures during the summer. We did not monitor fecal coliform levels but suspect that they could be high during spring and early summer in Charley Creek when cattle and horses were observed having open access to the creek.

Table 31 and Table 32 show the results of water quality parameters measured using a field test kit in 2009 and 2010, respectively. All of the measurements are similar with the exception of a rise in dissolved oxygen in the South Fork and North Fork.

Table 31. Water quality results from single visits during the summer of 2009 to fish sample reaches in Charley Creek (CC), North Fork (NF), and South Fork (SF).

Site	Turbidity (JTU)	Phosphate (ppm)	D.O. (ppm)	Alkalinity (ppm)	Nitrogen (ppm)	pH	Temp (^oC)
CC-01	0	0	8.8	72	0	7	14
CC-02	0	0	8.4	71	0	7	14.5
CC-03	5	0.2	8.2	72	0	7	15
CC-04	0	0	9.6	62	0	7	12
CC-05	0	0	9.2	59	0	7	11.5
CC-06	-	-	-	-	-	-	-
SF-F2	5	0	8.2	48	0	7	15.5
SF-F3	5	0	7.8	60	0	7	14.5
SF-F5	0	0	8.6	52	0	7	13
NF-F1	0	0	8.2	55	0	7	19
NF-F4	0	0	7.8	42	0	7	17.5
NF-F6	0	0	8.2	42	0	7	15.5

Table 32. Water quality results from single visits during the summer of 2010 to fish sample reaches in Charley Creek (CC), North Fork (NF), and South Fork (SF).

Site	Turbidity (JTU)	Phosphate (ppm)	D.O. (ppm)	Alkalinity (ppm)	Nitrogen (ppm)	pH	Temp (^oC)
CC-01	0	0	8.9	55	0	7	14.5
CC-02	0	0	8.8	68	0	7	14
CC-03	0	0	8.8	64	0	7	13
CC-04	0	0	9.4	64	0	7	13
CC-05	0	0	9.2	68	0	7	10
CC-06	0	0	9.2	69	0	7	10
SF-F2	0	0	9.2	76	0	7	16.2
SF-F3	0	0	8.2	60	0	7	16
SF-F5	0	0	9.4	50	0	7	9
NF-F1	0	0	8.1	70	0	7.5	17
NF-F4	0	0	8.9	52	0	7.5	11.5
NF-F6	0	0	9.0	44	0	7	12

7.2.4 RIPARIAN HABITAT

Riparian surveys were conducted using the PIBO protocol at each stream habitat site in 2009 (24 sites total). We estimated the percent cover of the top five most abundant plant species inside a 1 m x 1 m plot at the herb layer (<.5m) and the shrub layer <.5 m – 1.5 m). Grasses were the most abundant plants identified in the herb layer and mock orange was the most abundant species in the shrub layer (Figure 69; Appendix M). The average cover of the top five species in each layer was 5-25%. Tree ages were also calculated from tree core analysis of a representative sample of each major tree species identified. The width of the riparian area was narrow at all sites (e.g., 4-5 m) and cover was highly variable. Alder trees were the most common tree species at all sites and averaged 70% of all the tree species counted within a riparian plot (Figure 70). Black cottonwood, Grand fir, Douglas fir, and ponderosa pine were the next most common tree species. Although alder is by far the most abundant tree species found in the study streams, the average diameter is small at <15 cm. The average diameter of all tree species across all sites was 20.6 cm and only one site (CC-F3) had an average tree diameter >30 cm dbh (Figure 71). Trees within the riparian and floodplain were younger and smaller on average than upland trees (Figure 72).

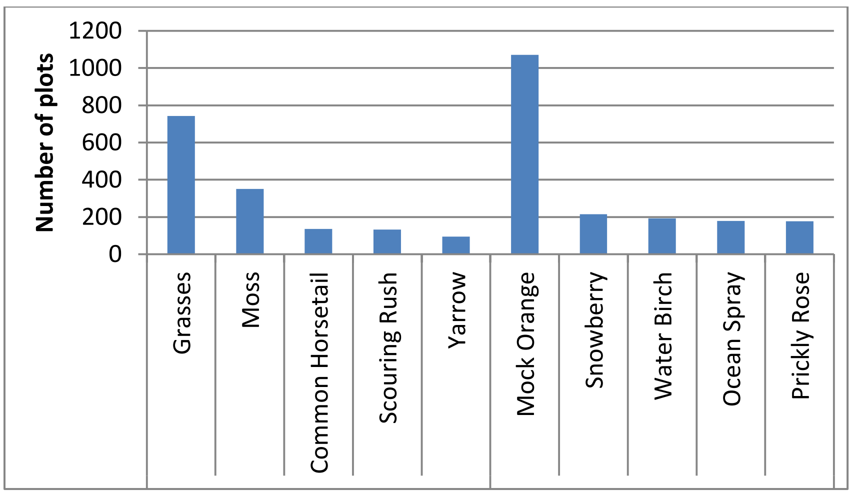

Figure 69. The top five most abundant plant species identified in the herb (<.5 m) and shrub (.5 m – 1.5 m) layers at the study streams in 2009.

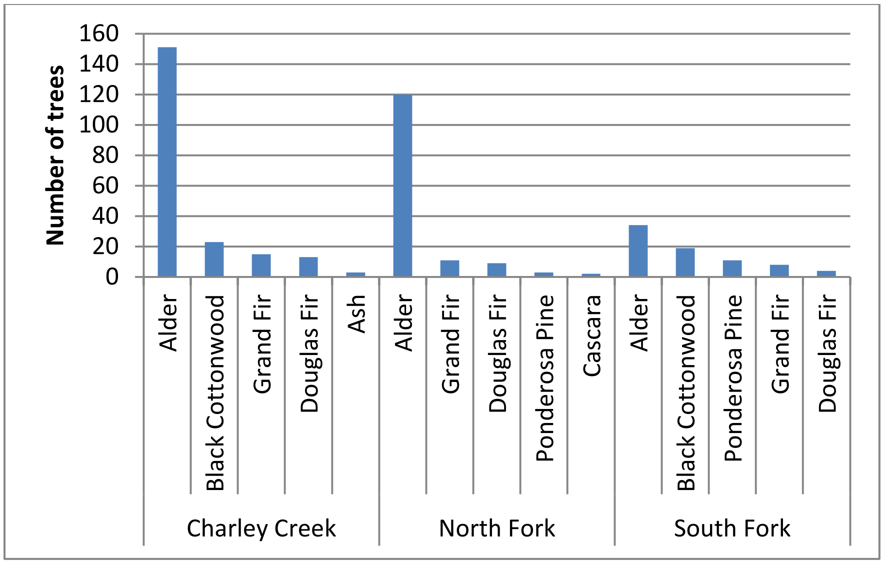

Figure 70. The total number of the top five most abundant tree species identified within habitat sites in the study stream watersheds in 2009.

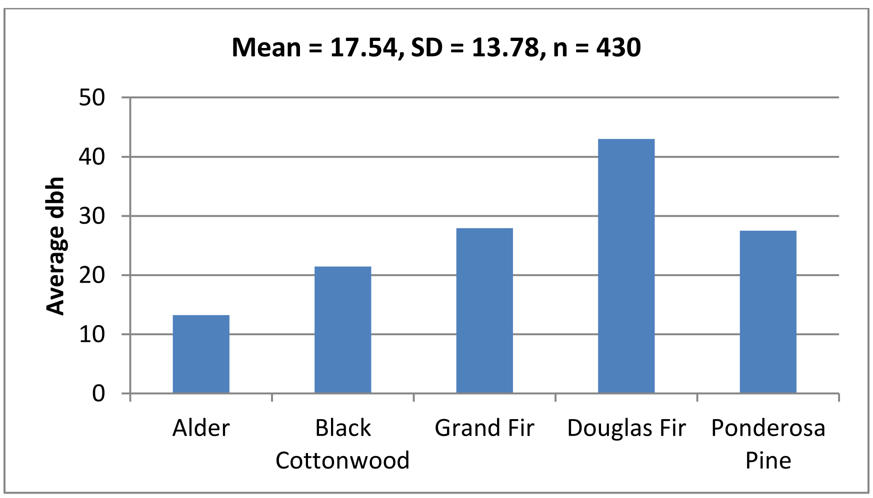

Figure 71. Average diameter at breast height (dbh) of the top five most abundant tree species identified in the three study streams in 2009.

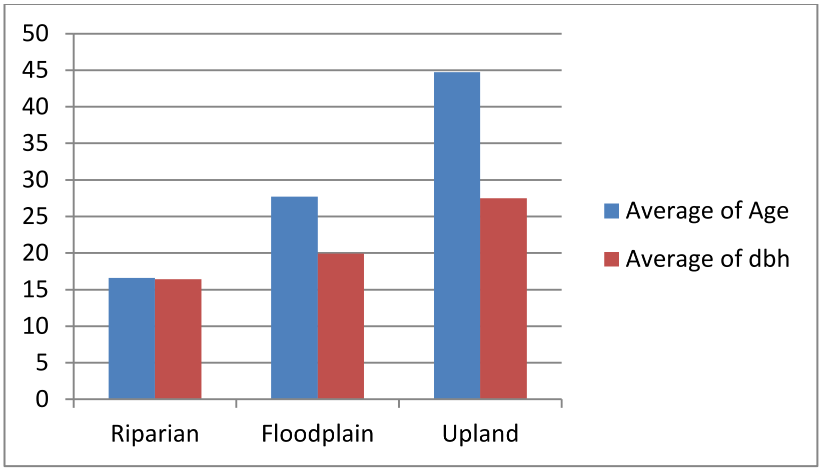

Figure 72. Average age and diameter at breast height by distance from the creek of trees cored in the study streams in 2009.

7.2.4.1 SOLAR INPUT

We used a solar pathfinder to estimate the amount of solar input at each fish site. Using a computer program we estimated the daily hours of sunlight each site receives (Table 33). A higher value for daily sun hours means there is less shade at that site. NF-F4 has the least amount of shade, receiving on average 1.02 daily sun hours annually. CC-F5 has the most amount of shade on average, receiving 0.09 daily sun hours annually. Charley Creek is more shaded than North Fork and South Fork.

Table 33. Average daily sun hours received annually by each site and stream.

Site	Daily Sun Hours
CC-F1	0.20
CC-F2	0.20
CC-F3	0.34
CC-F4	0.89
CC-F5	0.09
CC-F6	0.28
Charley Creek Ave.	**0.33**
NF-F1	0.33
NF-F4	1.02
NF-F6	0.84
North Fork Ave.	**0.73**
SF-F2	0.70
SF-F3	0.56
SF-F5	0.43
South Fork Ave.	**0.56**
Streams Ave.	**0.49**

7.3 GEOMORPHIC ASSESSMENTS

We have collected elevational, geomorphic, and aerial imagery data at a variety of spatial and temporal scales. Ground based LiDAR and low elevation aerial photography was collected along sections of Charley Creek in 2009 and is reported in (Bennett et al. 2010). An aerial LiDAR survey was performed by Watershed Sciences Inc. from the mouth of Asotin Creek upstream including the first 15 km of each of the study streams (WSI 2012). As of 2011, we are now collecting detailed topographic surveys of annual habitat sites using the CHaMP habitat protocol and these data are available on **champmonitoring.org**. All of these data will be used to compare geomorphic changes within treatment and control sections throughout the extent of the IMW project. Below we provide three examples of the geomorphic analyses we conducting.

7.3.1 GEOMORPHIC CHANGE DETECTION

We have performed preliminary geomorphic change detection (GCD) on 15 trial restoration structures that were installed in 2011 (five in each stream), topographically surveyed with the CHaMP protocol, and resurveyed in the spring of 2012 after a flood event that was the largest recorded in 12 years in Asotin Creek (Wheaton et al. 2012). We subtracted the digital elevation model (DEM) created in 2012 from the DEM created in 2011 to produce a digital elevation model of difference (DoD). Figure 73Figure 73 shows two versions of the DoD; one showing changes that we are 85% confident are real and another DoD that shows all the change regardless of confidence. Confidence levels in change are derived from the propagated error from the two elevation surfaces.

We estimated the trial area in Charley Creek had a total volume of erosion (scour) of 23 m^3, compared with 5 m^3 of deposition, with 19 m^3 of erosion and 2 m^3 of deposition within channel banks. This constitutes a net sediment imbalance within the surveyed area of -12%. The majority of this change occurred along the lower reach, where structures 1 – 3 are situated. Very little sediment was deposited in this area, but significant erosion is directly related to each of the structures and moderate erosion along the thalweg. The lower three structures all had large wood placed on the posts whereas the top two structures had only posts. Similar results were also detected with this method at the other trial structures in North Fork and South Fork that will be presented in a separate report.

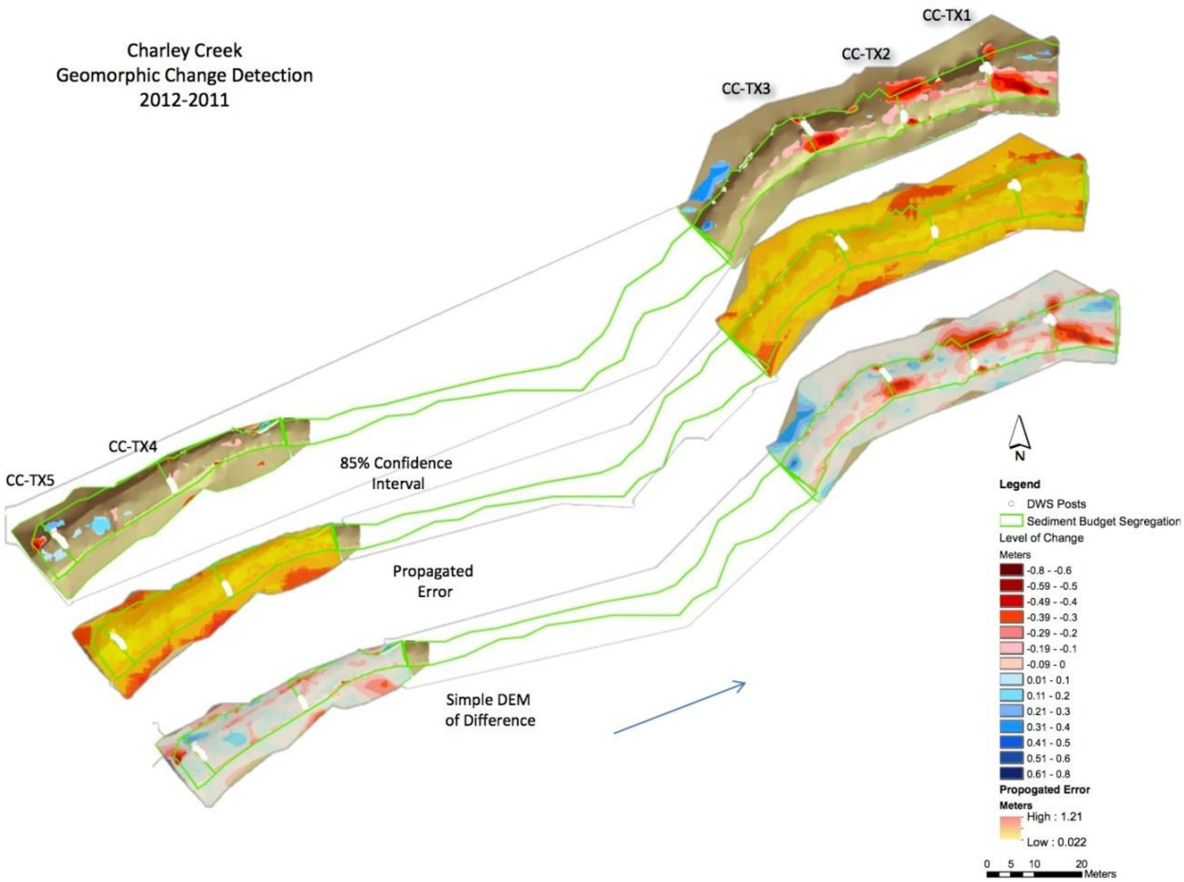

Figure 73. Geomorphic change detection analysis between 2012 and 2011 topographic surveys conducted on a section of Charley Creek where five trial dynamic woody debris structures (DWS) were installed in 2011. DWS are labeled CC-TX1 through CC-TX5 and locations are marked by white circles. Scour is represented by pink and red and deposition is blue. Stream flow is from left to right. Top surface is change with an 85% confidence level, middle surface is the error between the two surveys (yellow is low error, red is high error), bottom surface is all change detected.

7.3.2 BIOPHYSICAL ASSESSMENT

7.3.2.1 FLOODPLAIN CONFINEMENT

An example of these data are our analysis of the LIDAR data and the development of a biophysical assessment of the study streams. Figure 74Figure 74 shows an example of a portion of Charley Creek where we have used LIDAR to identify the floodplain extent, debris fan areas, and channel confinement features along the length of the study streams. In Figure 74Figure 74 the red areas indicate steep areas within the floodplain. The red areas along the road are the elevated bed and the red areas along the stream are high banks. These data will help us refine our predicted habitat responses to restoration and subsequently the response of fish populations within these different channel and floodplain confinement types.

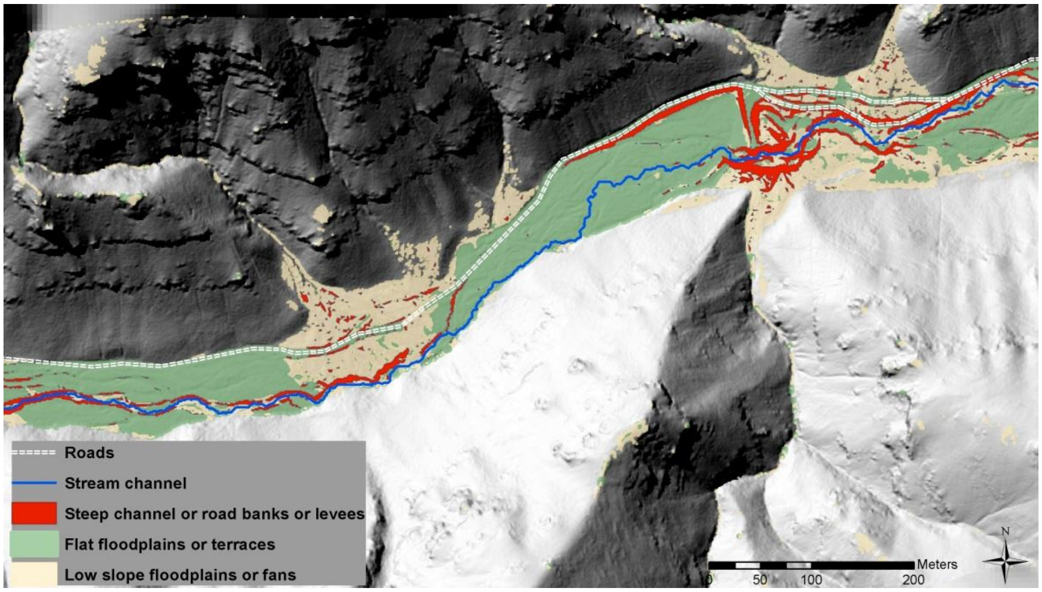

Figure 74. Example of floodplain and confinement analyses that are part of the biophysical assessment of Asotin Creek. Red areas along the stream indicate steep banks and areas where it will be more difficult for the stream to connect to the floodplain.

Charley Creek appears to have different types of confinement from the other study streams in the way the debris fans tend to be more longitudinally continuous, thus creating at least two types of alternating reaches, those pinched into effective confinement and those meandering across the valley until becoming pinched again. NF and SF also have the debris fans, but the wider valleys and greater stream powers may be allowing reworking of these sediment stores.

7.3.2.2 STREAM POWER AND REACH BREAKS

Another example of the biophysical assessment we have conducted is the generation of reach breaks and stream power profiles along the length of the study streams (Figure 75Figure 75). While gross stream-power is a useful measure of the total energy and total work done by the river at any point along its length, it is specific stream power calculated as power per unit wetted perimeter of the channel (usually expressed as per unit channel width) that is diagnostic of the power available to erode and construct individual landforms within the system. We have calculated stream power for the entire length of each study stream as part of our biophysical assessment of Asotin Creek. These data can be used to identify reach breaks and areas of rapidly changing stream power. Dramatic changes in stream power can be an indication of unique landscape units that can provide powerful insight into stream processes that will likely influence habitat responses to restoration.

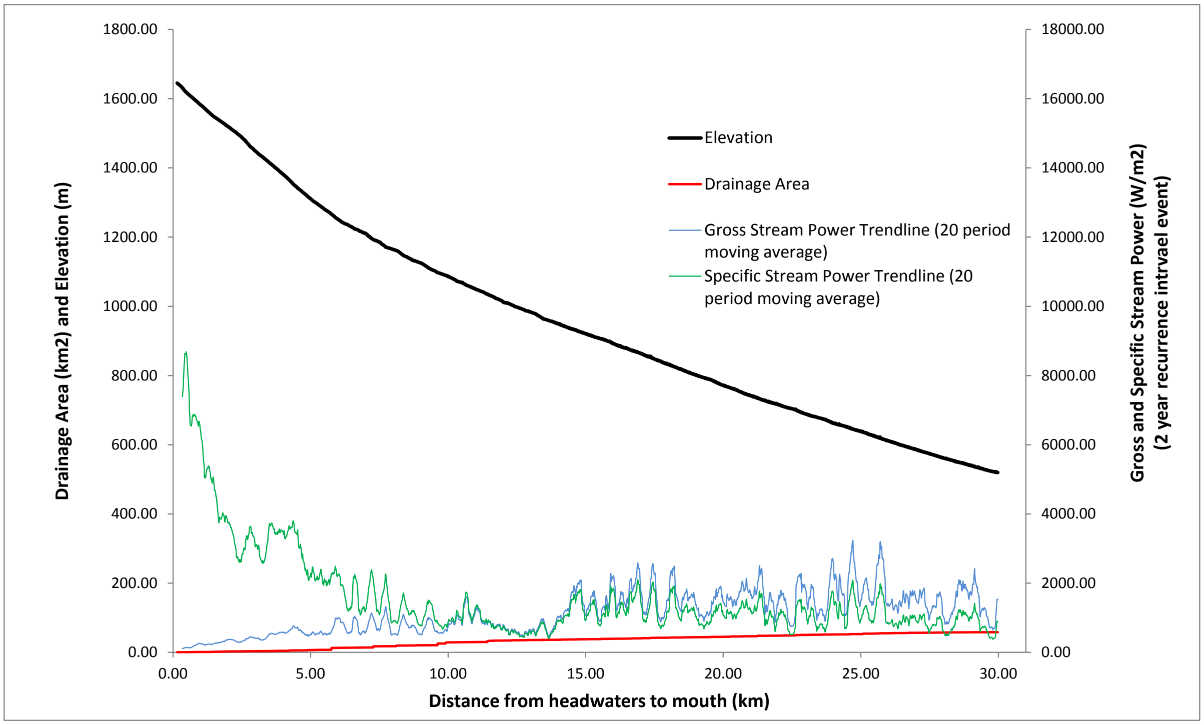

Figure 75. Charley Creek drainage area, gradient and stream power from the headwaters to the mouth. Significant changes in stream power and profile are potential reach breaks and landscape unit boundaries. Analysis based on a River Styles approach (Brierley and Fryirs 2008).

8 DISCUSSION

WDFW Steelhead Assessment

Wild adult steelhead escapement in Asotin Creek is considerable, and escapement into the study streams appears to make up a significant proportion of the main Asotin Creek population above George Creek (~ 40-45%). Efforts to enumerate this population since 2005 with an adult weir have been successful as the weir is maintained throughout the majority of the spawning season in most years (Crawford et al. 2012). Adult steelhead escapement estimates are typically very difficult to determine because of the challenging water conditions during the spring spawning (i.e., low visibility, high flows, and debris) that limit the efficiency of redd surveys and the cost/logistical constraints of maintaining a weir. However, the combination of the WDFW weir, redd surveys (with GPS locations of individual redds), and detections of PIT tagged adults at interrogation sites throughout the watershed should allow us to calculate relatively good estimates of adult escapement into the study streams.

The smolt trap is also operated at a relatively high efficiency that provides estimates of total smolt production. The smolt trap in combination with the adult escapement and age data are soon going to be providing estimates of both freshwater productivity (smolts/spawner) but also out-of-basin productivity (recruits/spawner, smolt to adult return ratio; Crawford et al. 2012). Few IMWs have these data available, or have data that is this complete, and it should allow us to compare watershed scale productivity between pre-treatment and post-treatment periods in a before-after comparison. Subsequently, we have a good chance of detecting a response to restoration as we are proposing a minimum of 12 km of LWD treatments (~ 600 structures) which is approximately 21.4% of the available spawning habitat upstream of the weir and smolt trap operations as far (i.e., 12 km treatment out of ~ 56 km of mainstem and study stream habitat). Roni et al. (2010) estimated that a minimum of 20% of the watershed (instream habitat) should be restored in order to have a reasonable chance of detecting a 25% increase in smolt production at the watershed scale. However, even this level of restoration may not produce enough of an effect in productivity at the watershed scale to detect with a high degree of statistical significance. Via our adaptive management plan, one option could be to increase the size of restoration treatments to increase our ability to detect watershed scale changes in productivity.

IMW Sampling

Biotic

We have PIT tagged a large number of juvenile steelhead within the study streams since 2008 (~ 12,500). This has allowed us to begin to characterize the abundance, distribution, growth, movement, and survival of steelhead cohorts within the study streams and Asotin watershed. It is important that we describe these basic population attributes because steelhead have one of the most complex set of life history expressions of any anadromous salmonid (Quinn 2005). The complexity of steelhead life histories makes it difficult to predict how populations will respond to habitat restoration and almost impossible to determine casual mechanisms of any response without a detailed understanding of life stage abundance, growth, survival, and movement data across multiple spatial and temporal scales.

Johnson et al. (2005) also showed how important sampling summer rearing and smolt production in control and treatment streams was to understanding steelhead response to LWD treatments and also how important it is to have a control stream that tracks the treatment stream (pre-treatment). Abundance, growth, movement, and survival in the study streams appear to track each other well based on the four years of pre-treatment data. We also found the treatment streams tracked each other reasonably well when we reviewed historic juvenile abundance and redd count data (Bennett and Bouwes 2009). This will increase our ability to detect a fish response to restoration and suggests that there are similar watershed scale influences on the juvenile populations within the study streams. The high site fidelity of juvenile steelhead we demonstrated by high recapture rates and limited movement between fish sites or streams also suggests that the sites and streams are independent and act as true replicates. However, we have identified a significant number of juveniles that leave the study streams and spend several months rearing in the mainstem of Asotin Creek before leaving the watershed. This behavior is common in many salmonid species (Quinn 2005, Tattum 2006) and could complicate survival and productivity estimates.

Abundance estimates of juvenile steelhead in the study streams appear to be similar to a wide range of steelhead and other salmon streams (Appendix N). Variability in abundance between sites within streams was high (overall CV = 39%) and there was no correlation with juvenile steelhead abundance pool or LWD frequency. We have only just begun to try to explain patterns in abundance and other population attributes, but it is already apparent that there are complex interactions between abiotic and biotic factors (Hartman et al. 1996). For example, two sites with the largest mean abundance (CC-F4 and SF-F5; Figure 31) have very different stream habitat. CC-F4 is the most degraded site we sampled with very limited riparian cover, LWD, pools, habitat diversity, and high width to depth ratio. SF-F5 is almost the exact opposite, with mature conifer and deciduous riparian habitat, deep pools, moderate levels of LWD, and complex habitat (compared to other IMW sites). These sites are an example of how it is important to understand the range of current conditions and annual fluctuations in population parameters in order to interpret any responses to restoration.

Smolt production has been linked to growth opportunity in Atlantic salmon and it has been demonstrated that a juvenile's timing of smoltification depends on accumulation of energy stores (Thorpe 1987, Horton et al. 2009). A variety of factors including water temperature, discharge, density dependence, and food availability have been shown to directly influence growth opportunity (Keeley 2003, Sauter and Connolly 2010, Van Leeuwen et al. 2011). Atlantic salmon exhibit very similar life history characteristics as steelhead and it is likely that similar mechanisms may influence smolting in steelhead (Beakes et al. 2010).

Charley Creek had the lowest average growth rates of the study streams which may, in part, be due to its cooler mean annual temperature. All the study streams had some sites that had negative growth and the summer to fall growth period had the lowest growth rates for both age classes (Figure 36). Negative growth in both length and weight have been demonstrated in both laboratory (Connolly and Petersen 2003) and field situations (Hayes et al. 2008). The summer to fall period typically has high juvenile abundance, low flows, high water temperatures and other studies have seen a similar response in growth including strong density dependence (Bouwes unpublished, Hayes et al. 2008, Horton et al. 2009). We have not seen any density dependent effects on growth rate at the current population abundances. However, high temperatures increase metabolic rates and can lead to lower growth without an increase in food availability, and low flows can lead to a decrease in both food delivery and available foraging habitat. Tattum (2006) and Hayes et al. (2008) both documented high growth rates in juvenile steelhead at temperatures well outside the thermal optimal range for steelhead (i.e., > 20-24 C) and attributed the growth rates to increased food availability.

We observed significantly lower growth in age 2+ fish compared with age 1 fish. This may be one reason a large proportion of outmigrants are age 1. We speculate that the lack of cover and suitable feeding areas for age 2+ fish (i.e., large enough slow water areas with nearby shear zones) may be contributing to poor growth rates. The addition of LWD treatments may lead to a decrease in the proportion of age 1 fish outmigrating in relation to age 2 fish, and an increase in growth and survival of age 2 fish.

We calculated true survival using the Barker model by taking advantage of re-sightings of PIT tagged fish at multiple interrogation sites within Asotin Creek and with mobile PIT tag surveys at fish sites during multiple seasons. We modeled survival at the watershed scale (i.e., from capture site to mouth of Asotin Creek). We plan to also estimate survival at the stream and treatment/control section scale if possible. This will provide an estimate of the survival of juveniles within the study streams separate from the influence of survival once they enter the mainstem of Asotin Creek.

We have not parsed out survival by age/size class because of sample size limits, but others have found increased survival of larger juveniles to the smolt stage (Beakes et al. 2010, Bell et al. 2011, Horton et al. 2011). We found the spring period had the lowest survival but we have only estimated survival for one spring period. A possible explanation for the low survival in the spring could be lack of refuge habitat in the study streams for fish to escape high velocities. This is an area of research we will pursue further as it fits well with the hypotheses we have developed for the LWD treatments and the expected geomorphic responses (Wheaton et al. 2012). Another common period of decreased survival of juvenile salmonids is winter (see review in Brown et al. 2011). Smaller juveniles, especially age 0, are usually most susceptible to harsh effects of winter and ice development including starvation, limited habitat, increased velocity, and scouring from ice flows. However, Connolly and Petersen (2003) described a situation where juveniles that are larger entering the winter period may be at a disadvantage to smaller juveniles if water temperatures increase during the winter without a corresponding increase in food availability due to increased energy demands on the larger fish. Warming periods during the winter are a common occurrence throughout the range of steelhead and again demonstrate the need to monitor a wide variety of population attributes in order to understand fish responses across a wide range of abiotic and biotic conditions that can interact together to influence the productivity of a population.

We estimated the combined result abundance, growth, and survival by summing the total production of juvenile steelhead at each site. Due to the variability we observed in the population metrics, juvenile production also varied across sites and streams. Unexpectedly, South Fork had the highest average juvenile production, but also has the highest mean annual temperatures and the longest period in the summer where temperatures exceed state recommended thermal goals. This suggests that the South Fork is not food limited. Charley Creek had very low juvenile production levels at all sites except CC-F4 which was a very open site with the highest sunlight hours recorded in Charley Creek. There was a weak correlation with juvenile production at all sites and average sunlight hours suggesting some sites have an intrinsically different potential productivity based on the aspect of the sites. Site orientation may be an important factor in how fish response to restoration that will need to be accounted for.

Invertebrate sampling is providing data on food availability, quality, and diversity. Food availability is an important input to the NREI modeling we are conducting and that may help determine the carrying capacity of the study streams pre and post restoration. We also hope to use the invertebrate data to assess the health of Asotin Creek using one the several state models of biological integrity developed based on invertebrate sampling (Huff et al. 2006). Dowdy (2002) conducted an assessment of macroinvertebrates from 2000-2002 in each of the study streams as well as areas along Asotin Creek mainstem and found that most sites had moderate to good levels of EPT indicating relatively healthy water quality. These findings are similar to ours and suggest that water quality may not be an issue restricting fish populations. However, we would like to further assess macroinvertebrate using our data and data from Dowdy (2002) as a possible way to detect changes in the macroinvertebrate community due to restoration.

Habitat

We used a variety of habitat surveys (PIBO, CHaMP, rapid surveys) over the first four years of monitoring to assess the habitat condition of the Asotin Creek IMW study streams. Much of our focus has been on determining the abundance of pools and wood, as these attributes have been regularly cited as being correlated with fish abundance (Bisson et al. 1987, Hartman et al. 1996, Roni et al. 2008) and being more frequent in reference conditions (Fox and Bolton 2007). Both our site level surveys (i.e., PIBO and CHaMP sites 0.16-0.22 km long) and our study creek wide surveys (rapid surveys over the entire 36 km of study streams) suggest these attributes occur at well below reference conditions. The low frequencies of these attributes are symptomatic of the relatively simplistic habitat conditions that are present in all the study streams that are a result of past land-use, large floods, and degradation of riparian function (ACCD 1995, 2004).

Although pool and wood frequency were a focus of our sampling, we have collected a much broader array of habitat data that will allow us to assess the effectiveness of restoration at multiple spatial scales. CHaMP topographic data and geomorphic change detection at treatment and control sites will allow us to quantify erosion and deposition of sediments at the reach and individual DWS (large woody debris structure) level and our analysis of the trial structures has already demonstrated the ability of DWS to create scour pools, eddy bars, and undercuts very similar to our predicted responses (Wheaton et al. 2012). CHaMP also allows us to generate spatially explicit maps of habitat units and directly measure if habitat diversity increases after restoration.

At the stream scale we have geo-referenced rapid habitat surveys of pools, wood, sediment bars, and sediment sources. These data will provide us with a coarser scale assessment of habitat change to put changes within our treatment and control sites in context. Finally, the LiDAR and imagery that we have collected will allow us to detect change across the floodplain and more importantly identify geomorphic controls that dictate the possible responses to restoration.

Flow and temperature are being monitored throughout the study streams and Asotin Creek watershed, and continuous measurements are available for both these important attributes. Low flow and high temperatures occur in South Fork each summer more than either Charley Creek or North Fork, but these occurrences do not seem to be impeding juvenile production. We noted that Charley Creek has larger base flows in the summer than South Fork despite having a smaller watershed area and lower stream flows than South Fork for most of the year. Flow and temperature play an important role in food and habitat availability, competition, and growth of juvenile salmonids and we expect to see different responses to restoration because of these differences in basic watershed characteristics.

The flow in Charley Creek is more constant, and the water temperature is warmer in the winter and cooler in the summer compared to North Fork and South Fork. These conditions indicate Charley Creek is more strongly influenced by ground water inputs. South Fork has the highest stream power and the North Fork has a lowest gradient, largest floodplain, and most diverse habitat. The South Fork will be a good test of the DWS treatment method to maintain large wood in position for long enough to create a geomorphic response and/or for the high density of DWS to act synergistically and maintain high levels of large wood within the treatment sections. The North Fork will be a good test of DWS to promote floodplain reconnection and side channel development since it has more floodplain to work with and lower bank heights. Charley Creek will be a good test of the ability of a relatively small stream with less flashy flows to still rework the stream channel when large wood is added. Also, the variability in the habitat and flow conditions of the study creeks may greatly enhance our ability to apply the results of the Asotin IMW to a wider variety of stream types in southeast Washington and other watersheds in the Columbia Basin with similar topographic, geologic, and climatic conditions.

9 CONCLUSIONS

The Asotin Creek IMW has a developed and tested experimental design, and is utilizing a broad array of monitoring methods to determine the effectiveness of stream restoration using large woody debris. WDFW is providing productivity estimates at the watershed scale and further IMW sampling is taking place within three tributaries where restoration will take place. Power analysis of the experimental design suggests that we have an 80% probability of detecting a 25% change in juvenile abundance. Productivity estimates at the tributary scale will require more detailed assessment of adult escapement but these data should be available with further analysis of PIT tag detections and data collected at the adult weir and from redd surveys.

Population assessments of juvenile abundance, growth, movement, and survival indicate no clear patterns between streams and suggest there are multiple factors interacting to produce variability between sites within the same stream, and between streams. Further analyses of these data are planned for the 2012-2013 annual report.

Habitat monitoring is taking place at multiple scales and confirms that the study streams have relatively simple habitat and limited high flow refugia. The proposed restoration plan is designed to increase habitat diversity with the addition of dynamic woody structures. Dynamic Woody Structures utilize wooden posts driven into the stream bottom to hold short (2-3 m) logs in place to simulate large trees. These structures can be installed by hand with limited impact on the existing riparian habitat. We have conducted a trial of the restoration method which indicated that the structures can indeed produce the desired effects and the first full restoration treatment was implemented in South Fork in the summer of 2012 (i.e., 196 structures within a 4 km long treatment area). Two more treatments will be implemented in 2013 and 2014 respectively and monitoring will continue until 2018.

10 FUTURE WORK

This report provides a summary of the experimental design, monitoring methods, and preliminary results from 2008-2011 for the Asotin IMW. Much of this analysis is still in a preliminary stage and summary in nature. This report will act as a reference for future reports to refer to designs, methods, and restoration plans, and only significant changes in any of these elements will be reported in the future. The following is a list of some of the priority analyses and data gathering we anticipate in the near future:

Analysis

- Review historic spawning records and assess distribution of spawning within study creeks
- Review recent PIT tag detections of adults entering study streams and recent redd survey data to estimate escapement
- Expand our site level fish density estimates in each study creek to estimate production at the stream scale
- Investigate methods to expand PIT tag detections of smolts leaving the study streams to total production of smolts
- Further age class analysis of juveniles to better understand age structure
- Produce estimates of survival during migration through the hydro system
- Refine biophysical assessment of Asotin Creek (i.e., River styles)
- Perform change detection analysis at treatment and control sites to determine sediment fluxes
- Develop multivariate models to explain variability in population metrics
- Summarize and partition levels of variance (CV, RMSE) at various scales (site, stream, watershed) for key metrics for comparison with other IMWs and assessment of ability to detect change

Monitoring

- Monitoring of fish habitat use during different seasons especially winter
- Mobile PIT tag surveys during smaller time periods
- Better understand distribution of spawning and zone of anadromy versus residency within the study streams
- Monitor use of structures during high flows to determine if they are providing refugia, especially for age 0 and 1 steelhead

APPENDIX A. SUMMARY OF THE CHANGES TO THE ASOTIN CREEK INTENSIVELY MONITORED WATERSHED PLAN FROM ITS INCEPTION IN 2008 TO THE END OF FOUR YEARS OF PRETREATMENT MONITORING IN 2011.

This appendix summarizes all the significant changes to the Asotin Creek Intensively Monitored Watershed Plan since the original plan was developed in 2008 (Bennett and Bouwes 2009). Many of the changes that have been made are due to new information or analyses that have become available over the course of four years of pretreatment monitoring. However, because we are implementing the restoration design over several years and across multiple spatial and temporal scales in a hierarchical-staircase design, there is built in flexibility in the year to year implementation of the IMW (experimental, restoration, and monitoring designs). For example, a fundamental requirement of the restoration action is that a fish response can be detected at the population level. If, after restoring 4 km of one creek, we have not been able to detect any population level responses, it will be possible to treat another 4 km in the same creek the next year (i.e., increase the treatment effect per creek), or complete the proposed treatment of all three creeks (i.e., 4 km per creek) and then treat a second 4 km section in a particular creek. This approach is part of the Adaptive Management strategy outlined in Section #. The following sections describe the timing, extent, and rationale for the changes we have made to the Asotin IMW project.

Table A1. Summary of the significant changes to the Asotin Creek Intensively Monitored Watershed project plan: 2008-2011.

Project Element	Description of change	Rationale for change	Timing of change
Experimental Design	Timing of restoration actions changed from 2011, 2014, and 2017 to 2012-2014	Funding was not available to initiate the restoration in 2011 and the treatments needed to be consecutive to provide a greater period of post treatment evaluation	Summer 2010
	Arrangement of restoration actions changed from 3 treatment sections in Charley Creek to 1 treatment section in Charley Creek, North Fork, and South Fork	Statistical power analysis of the initial experimental design indicated that under worst case scenario conditions (i.e., higher levels of variance) that the 1 treatment per stream design has significantly greater power to detect a change	Sept 2010

Monitoring Design	Changed stream habitat monitoring protocol from PacFish/InFish (PIBO) to the Columbia Habitat Monitoring Protocol (CHaMP)	We helped develop a new habitat protocol that was more focused on measuring attributes important to fish and that provides a greater level of habitat mapping. However, crosswalks are available between the two approaches.	August 2010
	Changed the allocation of fish monitoring sites from an emphasis on Charley Creek to an even split of sites between all three study streams (i.e., four fish sites per study stream)	Due to changes in the experimental design, we reallocated two fish sites from Charley Creek (CC-F4 and CC-F6) to the North Fork (NF-F2) and the South Fork (SF-F4). We did this so that each treatment section would have two fish sites and each control section would have one fish site.	February 2012
	Changed the allocation of habitat monitoring sites from permanent and rotating sites with an emphasis on Charley Creek to all permanent sites with either CHaMP monitoring or Rapid habitat surveys	To better survey the treatment sections and in particular the dynamic woody structures (DWS), we changed the arrangement of one permanent and two rotating habitat sites per fish site to all permanent sites (i.e., sampled ever year). In treatment sections we will survey four habitat sites using CHaMP and two habitat sites using a Rapid habitat protocol each year (2 CHaMP and 1 Rapid per fish site x 2 fish sites). In the control sections we will survey one habitat site using CHaMP and 2 sites using the Rapid protocol.	February 2012
Restoration Design	Location of restoration treatments changed (see Experimental Design above)	Increases statistical power of experiment and provides us an opportunity to assess the restoration action on a range of	

		stream types (i.e., small, spring fed, single channel stream to larger less confined stream)	
	Restoration treatment changed from a focus on engineered log structures and whole trees to "post debris catchers" with hand placed LWD	There is a significant amount of riparian vegetation along all the study streams that we want to preserve; therefore, heavy machinery is not an option for creating LWD structures in most locations. Instead we will used posts driven into the stream bottom and 2-4 m long pieces of LWD to create hand built structures which can be built without significant disruption of the existing riparian vegetation and that simulate large trees.	Spring 2011
Landowner Access	One of the two private landowners in Charley Creek (B. Koch) decided to not allow WDFW and IMW staff to access their property which contained 2 fish sampling sites (CC-F3 & CC-F4)	The landowner wanted compensation for access that we could not provide. Also, WDFW began negotiating with landowner to purchase property and the landowner did not want people working on the property while the negotiations were ongoing. ***This property has since been purchased by WDFW.	Spring 2011

APPENDIX B. DESCRIPTION OF INTERROGATION SITES INSTALLED AS PART OF THE ASOTIN CREEK INTENSIVELY MONITORED WATERSHED

In the following descriptions we define an interrogation site as any site where in-stream PIT tag antennas are installed and monitored. We define an antenna array as one or more antennas spanning the stream at a single cross-section.

Site 1: Description of Asotin Creek Mouth Interrogation Site

Site ID: ACM
Arrays: two arrays in series spanning the mainstem Asotin Creek just upstream of Hwy 129 Bridge.
Short Site Name: Mouth of Asotin Creek near the town of Asotin.
Long Site Name: Mouth of Asotin Creek 50 m upstream of the Highway 129 Bridge at the town of Asotin.
Site Description: Four muxed antennas located near the mouth of Asotin Creek 50 m upstream of the Highway 129 Bridge spanning the mainstem of Asotin Creek in two serial sets of two antennas. Campbell Scientific data logger and phone modem were installed on September 30, 2011 to upload data to ISEMP server run by Quantitative Consultants in Boise, ID.
Reference: At the mouth of Asotin Creek on the mainstem Asotin ASOTIC 522.234.000)
Latitude: 46.341368
Longitude: -117.055707
KMZ: see attached
Transceiver ID: 00
Antenna IDs: 01, 02, 03, 04
Firmware Version: 1.7

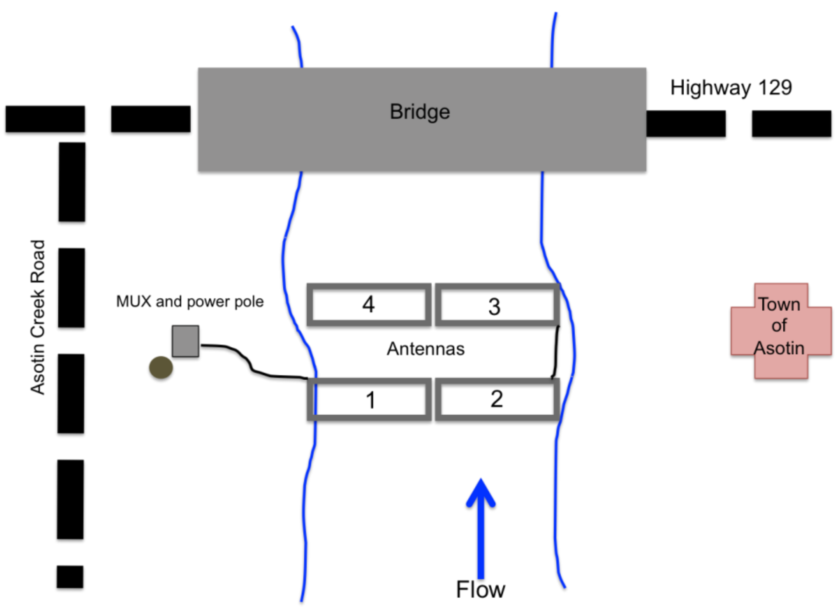

Figure 1. Antenna configuration at the Asotin Creek "Mouth" interrogation site just upstream of the Highway 129 Bridge near the town of Asotin. Antennas are 6 m long, site is 25 m upstream of bridge, and confluence with Snake River is 250 m downstream of bridge. Map not to scale.
Power Source: Wired to electrical grid with charger running four deep cycle batteries.
Frequency of Visits: Continuously monitoring with LoggerNet software.
Antenna Type: Passover
Coverage at normal high flow: 95% width, 80% depth
Timer Tag ID: 3E7.0000001D00
Timer Tag Firing Rate: 360 minutes
Site Steward:
Steve Martin, Snake River Salmon Recovery Board
410B East Main Street, Dayton, WA 99328
tel. (509 382 4115)
email. steve@snakeriverboard.org
Technical POC:
Steve Bennett, Eco Logical Research Inc.
456 South 100 West, Providence, Utah, 84332
tel. (435 757 5668)
email. Bennett.ecological@gmail.com
Additional Contacts:
Reid Camp, Eco Logical Research Inc.
1493 Northwood Drive, #104, Moscow, ID 83843
tel. (208 310 1376)
email. Reid.camp@gmail.com

Site 2: Description of Cloverland Bridge Interrogation Site

Site ID: ACB
Arrays: one array crossing mainstem Asotin Creek
Short Site Name: Asotin Creek at the Cloverland Bridge
Long Site Name: In-stream interrogation site at the Cloverland Bridge, Asotin Creek rkm 4.6
Site Description: Five muxed antennas spanning the width of the mainstem of Asotin Creek above the George Creek confluence, underneath the Cloverland Bridge. Campbell Scientific data logger and phone modem were installed in August 23, 2011 to upload data to ISEMP server run by Quantitative Consultants in Boise, ID.
Reference: 4.6 km upstream from the mouth of Asotin Creek (ASOTIC 522.234).
Latitude: 46.325450
Longitude: 117.108520
Transceiver ID: 00
Antenna IDs: 01, 02, 03, 04, 05
Firmware version: 1.7

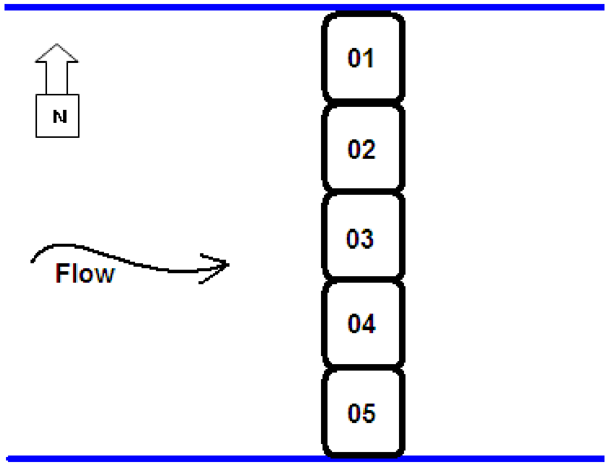

Figure 2. Antenna configuration at the Asotin Creek mainstem interrogation site at Cloverland Bridge.

Power Source: Wired to electrical grid with charger running four deep cycle batteries
Frequency of Visits: Monitored continuously as of Aug 23, 2011 with LoggerNet software.
Antenna Type: Passover
Coverage at normal high flow: 95% width, 80% depth
Timer Tag ID: 3E7.0000001D00
Timer Tag Firing Rate: 360 minutes
Site Steward:
Steve Martin, Snake River Salmon Recovery Board
410B East Main Street, Dayton, WA 99328
tel. (509 382 4115)
email. steve@snakeriverboard.org
Technical POC:
Steve Bennett, Eco Logical Research Inc.
456 South 100 West, Providence, Utah, 84332
tel. (435 757 5668)
email. Bennett.ecological@gmail.com
Additional Contacts:
Reid Camp, Eco Logical Research Inc.
1493 Northwood Drive, #104, Moscow, ID 83843
tel. (208 310 1376)
email. Reid.camp@gmail.com
First Date of Operation: 7/30/2009

Site 3: Description of Charley Creek Interrogation Site

Site ID: CCA
Arrays: two arrays spanning the mainstem of Charley Creek
Short Site Name: Lower Charley Creek, Asotin Creek watershed
Long Site Name: In-stream interrogation site at rkm 0.5 on Charley Creek, in the Asotin Creek watershed
Site Description: Changed August 23, 2011 from two antennas run on two separate FS2001 to a system with two muxed antennas arranged serially, each spanning the width of Charley Creek. Campbell

Scientific data logger and phone modem were installed in August 23, 2011 to upload data to ISEMP server run by Quantitative Consultants in Boise, ID.
Reference: 0.5 km upstream from the mouth of Charley Creek (CHARLC 522.234.022).
Latitude: 46.288458
Longitude: 117.282497
Antenna IDs: 01, 02,
Firmware version: 1.7

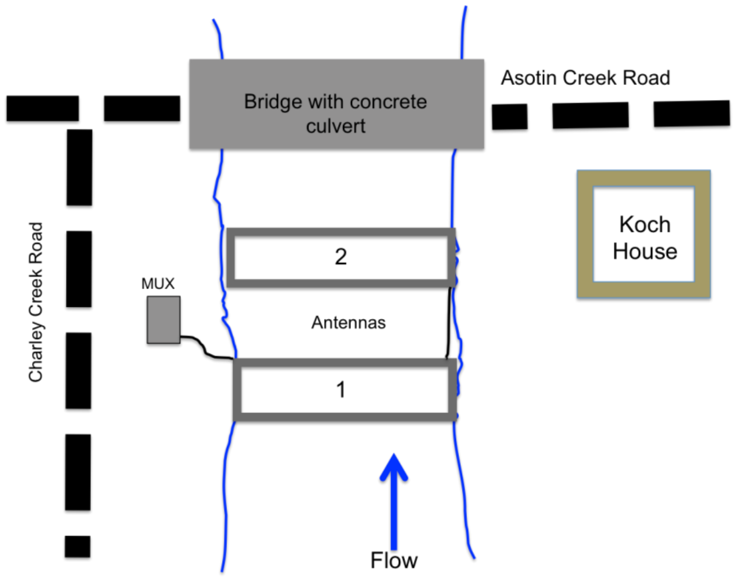

Figure 3. Antenna configuration at the Charley Creek interrogation site just upstream of the Asotin Creek Road crossing.

Power Source: Wired to electrical grid with charger running four deep cycle batteries.
Frequency of Visits: Once per week up until September 30, 2011 then switched to continuously monitoring with LoggerNet software.
Antenna Type: Passover
Coverage at normal high flow: 95% width, 80% depth
Site Steward:
Steve Martin, Snake River Salmon Recovery Board
410B East Main Street, Dayton, WA 99328
tel. (509 382 4115)
email. steve@snakeriverboard.org
Technical POC:
Steve Bennett, Eco Logical Research Inc.
456 South 100 West, Providence, Utah, 84332
tel. (435 757 5668)
email. Bennett.ecological@gmail.com
Additional Contacts:
Reid Camp, Eco Logical Research Inc.
1493 Northwood Drive, #104, Moscow, ID 83843
tel. (208 310 1376)
email. Reid.camp@gmail.com

First Date of Operation (CCA): 8/7/2009
First Date of Operation (CCB): 4/19/2010

Site 4. Description of Asotin Creek Forks Interrogation Site

Site ID: AFC
Arrays: three arrays; one spanning mouth of North Fork Asotin Creek, one spanning mouth of South Fork Asotin Creek, and one spanning the Asotin Creek mainstem just downstream from confluence of NF and SF.
Short Site Name: Junction of North and South FK Asotin Creeks
Long Site Name: In-stream interrogation site on Asotin Creek at and below the confluence of the North and South Forks.
Site Description: Six muxed antennas located at the confluence of the mainstem of Asotin Creek, North fork Asotin Creek, and South Fork Asotin Creek. Three antennas span the mainstem, two antennas span the North Fork, and one antenna spans the South Fork. Campbell Scientific data logger and phone modem were installed in August 23, 2011 to upload data to ISEMP server run by Quantitative Consultants in Boise, ID.
Reference: At the confluence of North Fork Asotin Creek and the mainstem Asotin (NFKASC 522.234.025)
Latitude: 46.272300
Longitude: 117.292430
Transceiver ID: 00
Antenna IDs: 01, 02, 03, 04, 05, 06
Firmware Version: 1.7

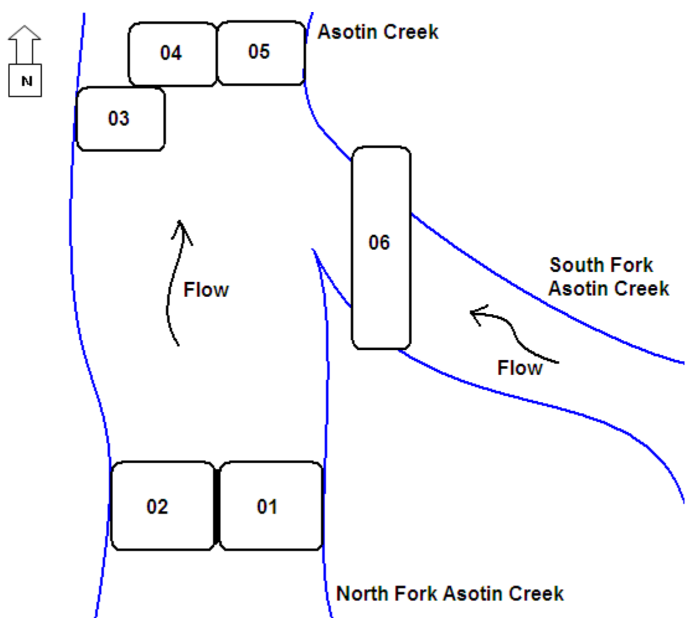

Figure 4. Antenna configuration at the Asotin Creek "Forks" interrogation site at the confluence of North Fork Asotin Creek and South Fork Asotin Creek.

Power Source: Wired to electrical grid with charger running four deep cycle batteries.

Frequency of Visits: Once per week up until September 30, 2011 then switched to continuously monitoring with LoggerNet software.
Antenna Type: Passover
Coverage at normal high flow: 95% width, 80% depth
Timer Tag ID: 3E7.0000001D00
Timer Tag Firing Rate: 360 minutes
Site Steward:
Steve Martin, Snake River Salmon Recovery Board
410B East Main Street, Dayton, WA 99328
tel. (509 382 4115)
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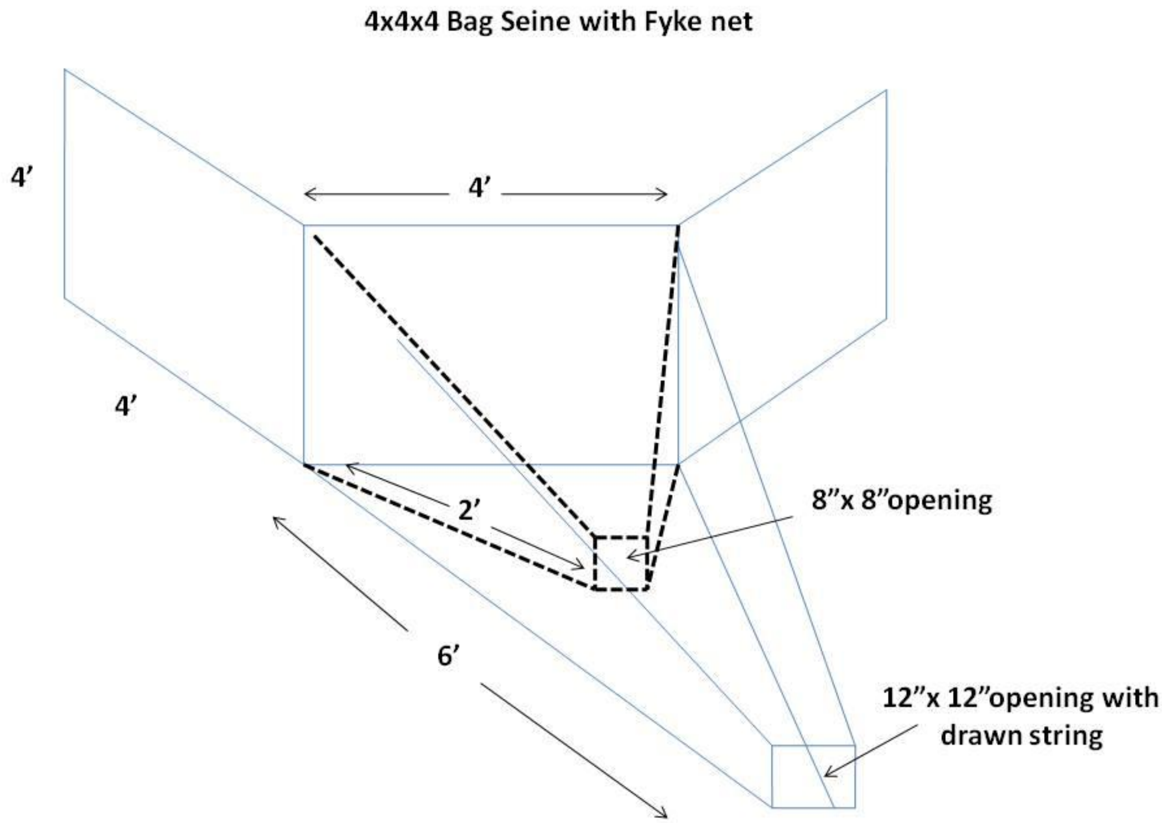
First Date of Operation: 7/30/2009

APPENDIX C. MODIFIED FYKE NET USED TO CAPTURE JUVENILE STEELHEAD DURING MARK-RECAPTURE SURVEYS IN ASOTIN CREEK AND TRIBUTARIES.



APPENDIX D. LOCATIONS OF ALL CONTROL POINTS ESTABLISHED IN 2011 TO ACT AS A CONTROL NETWORK FOR CONDUCTING CHAMP TOPOGRAPHIC SURVEYS, AERIAL PHOTOGRAPHY, LIDAR, AND RESTORATION SURVEYS IN THE ASOTIN CREEK IMW.

PtNumber	Zone	UTM_North	UTM_Easting	Elevation	Name	Comment
1	11	5124486.41	477442.55	559.74		
100	11	5126157.39	477886.75	544.31	AC100	
101	11	5126186.73	477982.75	552.25	AC101	
102	11	5126214.00	477851.94	558.92	AC102	
103	11	5126167.69	477871.98	546.62	FD	CC01BASE
104	11	5126156.74	477831.87	544.93	FD	CP-103
105	11	5126164.65	477896.13	544.49	FD	CP-104
106	11	5126168.48	476749.37	583.86	FD	CC-TX BM1
107	11	5126213.12	476760.21	589.09	FD	CC-TX BM2
108	11	5126202.30	476725.37	591.05	FD	CC-TX BM3
109	11	5125908.21	475993.81	609.74	AC103	
110	11	5125838.88	475804.87	624.74	FD	CC02 BASE
111	11	5125847.34	475798.97	628.48	AC104	
112	11	5125835.88	475752.90	630.39	AC105	
113	11	5125813.68	475614.49	622.18	AC106	
114	11	5125468.36	470845.94	804.04	FD	CP1101
115	11	5125457.30	470411.03	810.72	AC107	
116	11	5125508.83	470477.05	835.93	AC108	
117	11	5125496.88	470443.80	827.09	FD	CP501
118	11	5125493.65	470319.64	840.61	AC109	
119	11	5125484.03	470209.39	846.15	AC110	
120	11	5125429.12	470098.08	852.64	AC111	
121	11	5125358.65	470140.42	812.68	AC112	
122	11	5125408.78	470178.24	811.67	FD	CP508
123	11	5125422.99	470284.34	809.80	FD	CP506
124	11	5125450.36	470383.03	809.25	FD	CP504
125	11	5125459.10	470456.26	807.76	FD	CP502
126	11	5125445.04	469744.89	831.34	AC	CC BM1
127	11	5125325.52	468448.75	882.17	AC113	
128	11	5125381.46	468430.89	911.22	AC114	
129	11	5125313.07	468275.05	905.72	AC115	
130	11	5125339.52	468186.27	934.11	AC116	
131	11	5125242.23	468128.81	920.67	AC117	
132	11	5125239.94	468193.70	891.47	AC118	
133	11	5126159.38	476750.39	582.19	AC119	
134	11	5126271.00	476813.02	602.65	AC120	
135	11	5124299.07	477634.73	569.86	FD	BM2
136	11	5124341.22	477620.28	572.80	FD	BM1
137	11	5124330.96	477674.79	587.31	FD	BM3
138	11	5124262.97	477685.11	585.92	AC122	
139	11	5124201.72	477695.36	586.89	AC123	
140	11	5124227.35	477643.05	572.15	AC124	

141	11	5121916.89	477680.91	634.40	AC125	
142	11	5121940.01	477733.64	663.76	AC126	
143	11	5121753.84	477818.79	680.89	AC127	
144	11	5121687.70	477745.63	643.98	AC129	
145	11	5121603.25	477895.01	684.65	AC128	
146	11	5120069.28	478157.66	691.76	AC	BASE2
147	11	5120077.83	478190.86	708.56	AC130	
148	11	5120208.85	478204.59	727.91	AC131	
149	11	5119908.31	478237.67	756.06	AC132	
150	11	5119850.77	478232.03	737.53	AC133	
151	11	5119747.40	478299.06	739.83	AC134	
152	11	5119781.43	478233.59	703.31	AC135	
153	11	5118981.93	478347.58	744.56	AC	BASE3
154	11	5118057.58	477994.22	755.21	AC	BASE4
155	11	5116889.53	477166.21	798.53	AC	BASE5
156	11	5116563.92	476838.88	812.89	AC136	
157	11	5116553.02	476739.25	856.81	AC137	
158	11	5116719.69	476920.22	865.89	AC138	
159	11	5116772.27	476986.20	858.52	AC139	
160	11	5116907.89	477092.11	850.14	AC140	
161	11	5116839.98	477067.66	827.88	AC141	
162	11	5123928.21	477044.45	627.13	AC142	
163	11	5123768.32	477042.09	613.17	AC143	
164	11	5123874.13	477091.09	598.33	AC144	
165	11	5122828.62	476830.14	612.36	AC145	
166	11	5122875.64	476856.66	597.80	AC146	
167	11	5122790.39	476843.02	598.67	AC147	
168	11	5122107.54	476483.35	615.69	AC	BASE6
169	11	5121045.34	474973.06	666.41	AC	BASE7
170	11	5121200.69	473134.33	719.70	AC148	
171	11	5121208.10	473060.12	744.86	AC149	
172	11	5121271.32	473128.54	745.20	AC150	
173	11	5121256.23	473184.90	718.91	AC151	
174	11	5119861.02	471809.98	773.03	AC	BASE8
175	11	5118944.90	470224.87	813.57	AC152	
176	11	5118977.10	470166.58	838.99	AC153	
177	11	5119000.17	470306.68	848.21	AC154	
178	11	5126154.19	476651.34	586.84	AC121	

APPENDIX E. COMPARISON OF ATTRIBUTES COLLECTED DURING PACFISH/INFISH BIOLOGICAL OPINION HABITAT SURVEYS (PIBO; HEITKE ET AL. 2010) AND COLUMBIA BASIN HABITAT MONITORING PROTOCOL SURVEYS (CHAMP; BOUWES ET AL. 2011) USED TO MONITOR STREAM HABITAT IN THE ASOTIN CREEK IMW. PIBO PROTOCOL USED FROM 2008-2009 AND CHAMP PROTOCOL USED FROM 2010-2011. PART A) COMPARES PIBO AND CHAMP ATTRIBUTES, PART B) DESCRIBES ADDITIONAL ATTRIBUTES COLLECTED OR GENERATED BY CHAMP AND THE RIVER BATHYMETRY TOOLKIT (RBT).

A)

Category	Long Name	Description	Units / Format	Measured by CHaMP
Channel dimensions	Average bankfull width from riffles	Average of the bankfull widths (m) from channel cross section measurements	m	Yes
	Average bankfull width - from transects	Average of the bankfull widths (m) from the 20-25 channel transects.	m	Yes
	Length of stream reach	Reach length (measured along the thalweg)	m	Yes
	Gradient of stream reach	Elevation change of the water surface measured along the thalweg.	%	Yes
	Sinuosity of stream reach	Reach length measured along the thalweg divided by the straight valley length.	ratio	Yes
	Residual pool depth	Average of the residual pool depths for all pools.	m	Yes

	# of pools per km	Pool frequency - # of pools / km.	# / km	Yes
	% pools	Sum of all pool lengths divided by the reach length.	%	Yes
	Width-to-depth ratio at riffles	Bankfull width / Bankfull depth using average of the 10 depth measurements.	ratio	Yes
	Wetted width-to-depth at riffles	Wetted width / wetted depth using average of the 10 depth measurements.	ratio	Yes
Stream banks	Bank angle	Average of all bank angle measurements.	degrees	Yes
	% stable banks	Percent stable banks	%	No
	Average undercut depth	Sum of all undercut depths (meters) / total number of measurements.	m	Yes (2011)
	% undercut banks	Percent of banks with a bank angles < 90 degrees and an undercut depth of > 5 cm	%	Yes
	% of bank angles $<90^{o}$	Number of locations with bank angles < 90 degrees / total number of bank measurements.	%	Yes
Substrate	D16	Diameter of 16th percentile particles collected along transects(100 particles collected)	m	Yes
	D50	Diameter of 50th percentile particles collected along transects(100 particles collected)	m	Yes

	D84	Diameter of 84th percentile particles collected along transects(100 particles collected)	m	Yes
	% pool tail Fines < 2mm and < 6mm	Percent Pool tail Fines < 2mm.	%	Yes
Water chemistry	Conductivity	Conductivity	ppm	Yes
	Alkalinity	Alkalinity	ppm	Yes
	P-Alkalinity	Phenolphthalein Alkalinity	ppm	No
Wood	Large wood frequency	Number of category 1 pieces all lengths per km.	# / km	Yes
	Large wood volume	Volume of category 1 pieces (all lengths) per km.	m^3 / km	Yes

B)

Category	Metric	Description	Units / Format
Channel dimensions	Site Wetted Area	Generated by the River Bathymetry Toolkit	m2
	Site Bankfull Area	Generated by the River Bathymetry Toolkit	m2
	Wetted volume	Generated by the River Bathymetry Toolkit	m3
	Site Length Wetted	Generated by the River Bathymetry Toolkit (Site length measured using wetted centerline)	m
	Site Length Bankfull	Generated by the River Bathymetry Toolkit (Site length measured using bankfull centerline)	m
	Pool Area	Generated by the River Bathymetry Toolkit	m2
	Pool Volume	Generated by the River Bathymetry Toolkit	m3
Fish Cover	Fish Cover Composition LWD	Visually estimated percent of cover provided to fish in each habitat unit	%
Habitat Units	Fish Cover Composition Vegetation	Visually estimated percent of cover provided to fish in each habitat unit	%
	Fish Cover Composition Undercut	Visually estimated percent of cover provided to fish in each habitat unit	%

	Fish Cover Composition Artificial	Visually estimated percent of cover provided to fish in each habitat unit	%
	Fish Cover Composition None	Visually estimated percent of cover provided to fish in each habitat unit	%
Riparian	Percent Big Tree Cover	Visually estimated percent of cover on left bank and right bank	%
	Percent Coniferous Cover	Visually estimated percent of cover on left bank and right bank	%
	Percent Ground Cover	Visually estimated percent of cover on left bank and right bank	%
	Percent Non-Woody Cover	Visually estimated percent of cover on left bank and right bank	%
	Percent Understory Cover	Visually estimated percent of cover on left bank and right bank	%
	Percent Woody Cover	Visually estimated percent of cover on left bank and right bank	%
Site Characteristics	Amount of solar input at a site	Use a Solar Pathfinder and camera to measure solar input	BTU/m^2
	Air Temperature	Air temperature probe deployed at each site	C
Substrate	Ocular Substrate Measurements	Visually estimated percent of substrate size classes in each habitat unit	%

Water chemistry/Flow	Site Discharge	Hand measured discharge at top of site using a flow meter	m/s3
	Water Temperature	Stream temperature probe deployed at each site	C
Wood	Bankfull Large Wood Frequency per 100m	LWD below bankfull but not in the water	pieces/100m

APPENDIX F. DATA MANAGEMENT FRAMEWORK FOR THE ASOTIN CREEK IMW.

Data Group	Data Source	Data Collection	Data Transfer	Data Storage	Description
Fish	Capture Surveys	Data Logger with custom ISEMP PIT tag application	Direct Transfer from Logger App >>> Fish Capture Database	ISEMP AsotinRovingFish Access database	All 2-3 pass mark-recapture tagging data collected during summer and fall tagging sessions at permanent fish survey sites
	Array Detections	Biomark MUX and Campbell Scientific Data Loggers	via phone connection or manual upload >>> PTAGIS	PTAGIS and AsotinRovingFish Access database	All arrays are connected to Biomark MUX readers and Campbell Scientific data loggers and PIT tagged fish crossing the antennas are detected, data stored, and uploaded automatically
	Mobile Surveys	Data Logger with custom ISEMP PIT tag application and GPS	Transfer from Logger App >>> Excel >>> Fish Capture Database	ISEMP AsotinRovingFish Access database	all fish detected during mobile PIT tag surveys are recorded on data logger along with date/time, GPS location, and habitat unit
	WDFW	Smolt trap, adult weir, redd counts	WDFW databases and/or PTAGIS >>> IMW database	ISEMP AsotinRovingFish Access database	all captures and recaptures at WDFW sites are stored in IMW database to aid in querying movement and PIT tag detection data
	ISMEP Adults	Arrays and adult weir	via phone connection or manual upload >>> PTAGIS	PTAGIS and AsotinRovingFish Access database	ISEMP/WDFW are PIT tagging 9-10% adult steelhead and Chinook at Lower Granite dam; we are recording the number of these fish that move into the Asotin and are detected by the arrays or at the adult weir
Habitat	PIBO	standard field datasheets	Hand entered into custom IMW database	AstotinPIBO database	from 2008-2009 we used the PIBO habitat protocol to collect habitat data - we are integrating these data with the current habitat monitoring protocol (CHaMP)
	CHaMP	custom ISEMP data logger	custom upload process to champmonitoring.org	champmonitoring.org and excel spreadsheet of metric data	ISEMP collects all data collected using CHaMP and runs QAQC on the data and then posts raw data, summarized data, and site metrics. Data is also run through the River Bathymetry Toolkit to produce metrics from the topographic data
	Riparian	aerial photography, LIDAR, PIBO riparian protocol	all aerial photography and LiDAR are transferred into GIS; riparian site data was collected on data sheets and hand entered into excel spreadsheets	transferred to GIS or stored in excel	imagery is processed using GIS; site riparian data (canopy cover), species presence, etc. are summarized and stored in excel

Data Group	Data Source	Data Collection	Data Transfer	Data Storage	Description

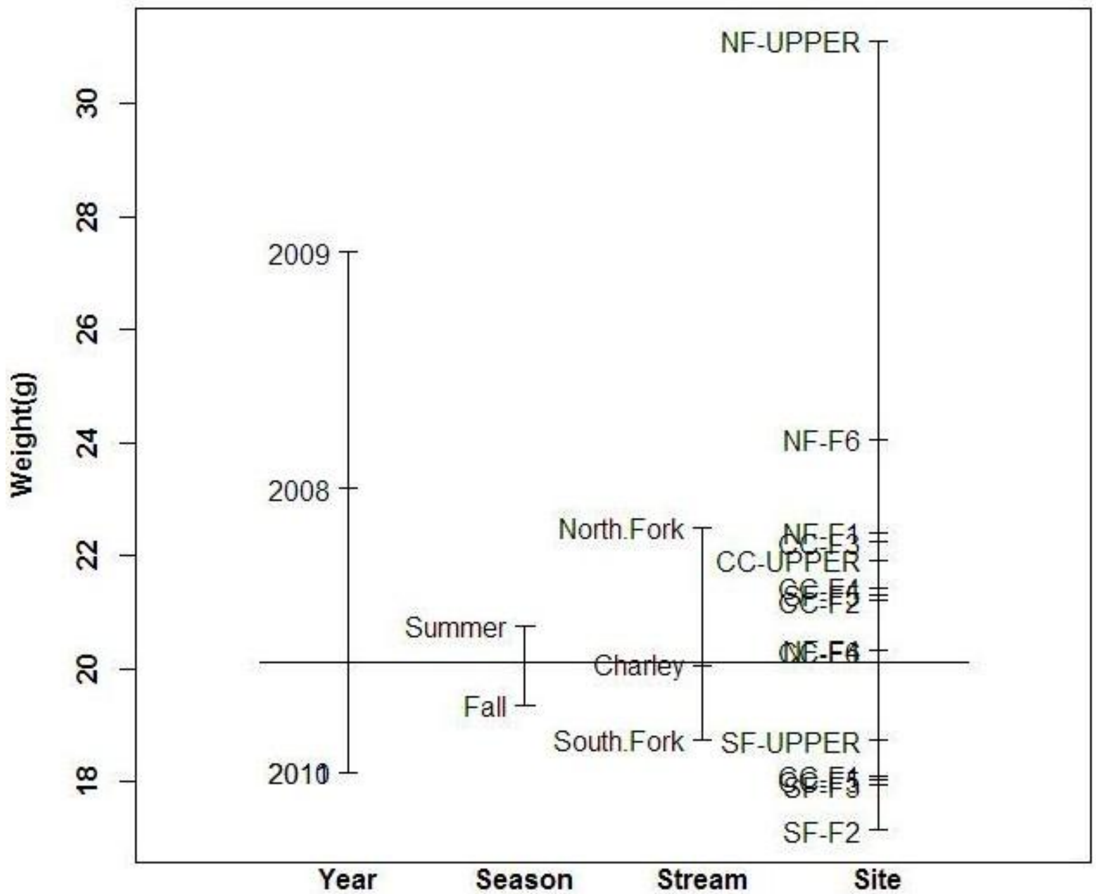
Water	Water Quality	site collection of basic water quality measures at each fish site	Direct Transfer from Logger App >>> Fish Capture Database	ISEMP AsotinRovingFish Access database	collect conductivity, pH, temperature, alkalinity, nitrogen, phosphate, turbidity annually at fish sites
	Temperature	temperature loggers recording water temperature every 15 mins at 22 sites	download 1-2 times a year to HOBO software and export to excel	custom ISMEP database	water temperature at each fish site, array location, and selected sites throughout the Asotin watershed has been collected since 2008;
	Discharge	continual water level or discharge estimates at USGS, DOE, and IMW established sites	download 1-2 times a year from internet (USGS and DOE) or manually download from IMW sites and export to excel	custom ISMEP database	use existing and IMW installed discharge monitoring sites to collect hourly discharge record of each study stream and the mainstem Asotin Creek; instantaneous discharge is also collected at each CHaMP habitat site
Watershed/ Landscape	LiDAR, aerial photography	collected every 3-5 years using contractors (i.e., Watershed Sciences or with our own UAV)	transferred from contractors or image collection devices (i.e., aerial cameras)	processed and stored in GIS geodatabase	watershed scale imagery and topographic data collected using fixed wing or unmanned aerial vehicles (UAV) every 3-5 years to detect changes in channel and floodplain condition (including riparian extent and cover).
	Watershed Attributes	soils, geology, topography, aerial imagery, climate, precipitation, basin statistics, etc.	information collect from a variety of sources online including federal, state, and university sources	processed and stored in GIS geodatabase	data collected on Columbia River Basin scale to aid in putting Asotin Creek watershed into context within CRB in a multiscalar framework (i.e., River Styles)

APPENDIX G. SUMMARY OF LENGTH, WEIGHT, AND CONDITION FACTOR ON JUVENILE STEELHEAD CAPTURED IN CHARLEY CREEK, NORTH FORK, AND SOUTH FORK BY SEASON: 2008-2011.

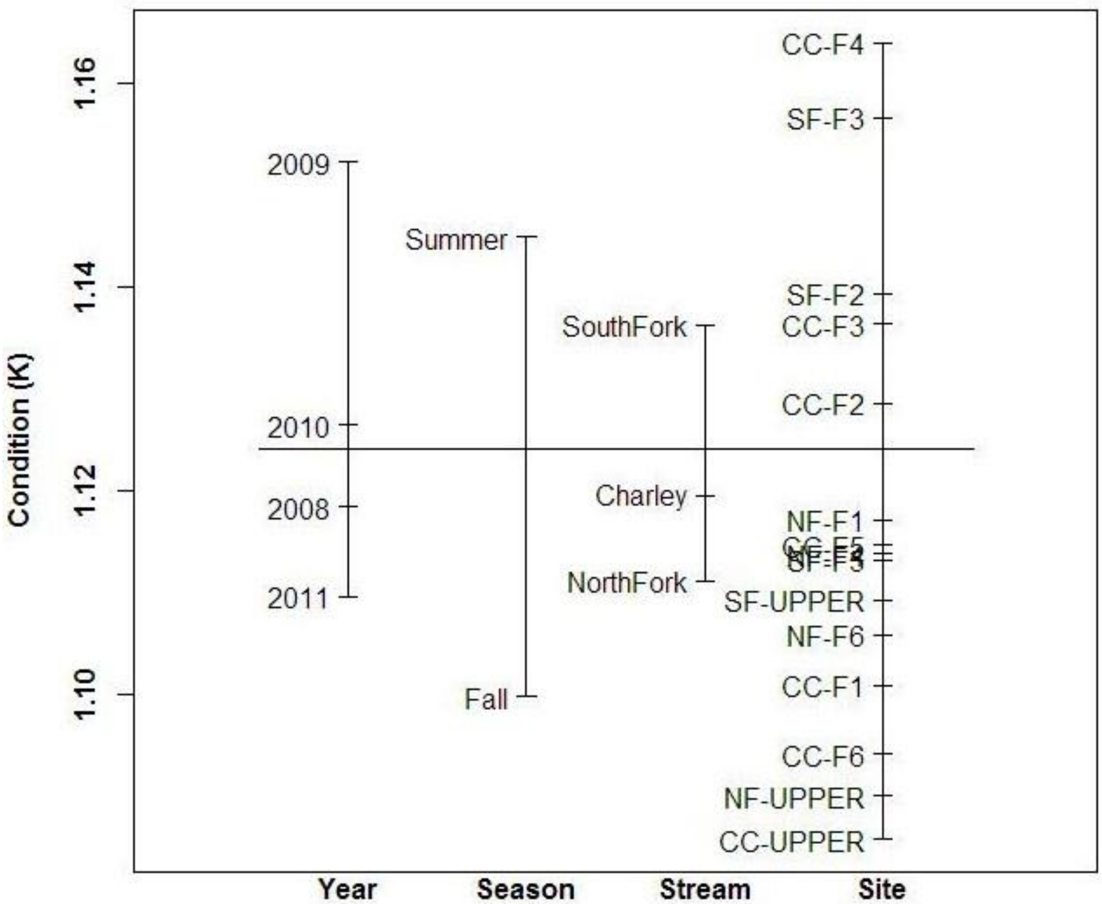
Year	Stream	Season	Mean Length (mm)	Min Length (mm)	Max Length (mm)	StDev Length (mm)	Mean Weight (g)	Min Weight (g)	Max Weight (g)	StDev Weight (g)	Mean Condition (K)	Min Condition (K)	Max Condition (K)	StDev Condition (K)	N
2008	Charley	Summer	117.9	72.0	234.0	26.2	21.8	4.2	151.1	17.2	1.14	0.44	2.90	0.14	454
2008	North Fork	Summer	126.0	80.0	247.0	27.9	25.6	5.1	140.3	20.9	1.10	0.63	1.47	0.09	410
2008	South Fork	Summer	120.2	72.0	253.0	27.2	22.6	4.2	171.3	18.5	1.11	0.80	1.53	0.08	613
2009	Charley	Summer	120.8	64.0	223.0	29.0	24.5	3.2	125.8	18.3	1.19	0.74	1.70	0.10	1091
2009	Charley	Fall	126.2	72.0	235.0	28.8	25.1	3.6	131.5	17.7	1.09	0.73	2.82	0.12	971
2009	North Fork	Summer	137.2	64.0	211.0	30.6	34.6	3.1	116.8	22.5	1.18	0.43	1.45	0.10	218
2009	North Fork	Fall	133.7	56.0	243.0	35.8	32.0	2.2	157.1	22.9	1.12	0.87	1.49	0.10	413
2009	South Fork	Summer	133.2	76.0	255.0	27.4	33.6	4.7	165.5	21.8	1.26	0.86	2.47	0.13	590
2009	South Fork	Fall	119.9	46.0	231.0	37.7	24.7	1.1	136.4	20.9	1.11	0.57	1.46	0.09	663
2010	Charley	Summer	117.4	67.0	231.0	24.0	20.7	3.2	142.5	14.1	1.14	0.69	2.16	0.10	1677
2010	Charley	Fall	113.2	65.0	200.0	27.1	18.6	2.5	96.8	13.4	1.10	0.57	1.68	0.10	1837
2010	North Fork	Summer	117.5	57.0	240.0	27.2	21.7	2.0	156.7	18.3	1.14	0.78	1.58	0.09	791
2010	North Fork	Fall	108.0	61.0	219.0	29.9	17.3	2.4	120.0	16.0	1.12	0.48	2.13	0.10	1228
2010	South Fork	Summer	104.8	63.0	224.0	24.7	15.9	2.3	155.0	14.7	1.17	0.55	1.72	0.10	1394
2010	South Fork	Fall	106.7	61.0	225.0	26.7	16.1	2.0	145.4	14.4	1.11	0.68	2.01	0.10	1747
2011	Charley	Summer	106.6	54.0	209.0	28.4	16.6	2.3	108.0	14.5	1.12	0.44	2.92	0.13	1709
2011	Charley	Fall	107.9	42.0	205.0	29.4	16.6	0.9	107.5	14.8	1.07	0.55	2.04	0.11	877
2011	North Fork	Summer	117.3	60.0	229.0	31.3	22.2	2.4	134.1	21.6	1.11	0.51	1.98	0.11	953
2011	North Fork	Fall	117.3	50.0	240.0	33.0	21.9	2.0	158.1	21.8	1.08	0.77	1.75	0.10	1146
2011	South Fork	Summer	109.6	54.0	222.0	28.2	17.8	2.4	116.5	15.5	1.14	0.51	2.04	0.11	2288
2011	South Fork	Fall	106.3	49.0	218.0	29.0	16.3	1.6	109.9	14.9	1.11	0.52	1.83	0.13	1725
Mean			**117.5**	**61.2**	**228.3**	**29.0**	**22.2**	**2.7**	**135.5**	**17.8**	**1.1**	**0.6**	**2.0**	**0.1**	**1085.5**
Median			**117.4**	**61.0**	**229.0**	**28.4**	**21.8**	**2.4**	**136.4**	**17.7**	**1.1**	**0.6**	**1.8**	**0.1**	**971.0**
Total															**22,795**

APPENDIX H. MAIN EFFECTS OF FOUR SIGNIFICANT FACTORS (YEAR, SEASON, STREAM, AND SITE) ON THE MEAN A) WEIGHT AND B) MEAN CONDITION FACTOR OF JUVENILE STEELHEAD ≥ 70 MM BASED ON TWO PASS MARK-RECAPTURE ESTIMATES IN ASOTIN CREEK.

A)



B)



Condition (K)
1.16
1.14
1.12
1.10
2009
2010
2008
2011
Summer
Fall
SouthFork
Charley
NorthFork
CC-F4
SF-F3
SF-F2
CC-F3
CC-F2
NF-F1
SF-UPPER
NF-F6
CC-F1
CC-F6
NF-UPPER
CC-UPPER
Year
Season
Stream
Site

APPENDIX I. ESTIMATES OF JUVENILE STEELHEAD ABUNDANCE ≥ 70 MM BY YEAR, SEASON, STREAM, AND SITE IN THREE TRIBUTARIES TO ASOTIN CREEK DURING THE PRETREATMENT MONITORING PHASES OF THE ASOTIN IMW: 2008-2011. ABUNDANCE WAS ESTIMATED USING TWO-PASS MARK-RECAPTURE SURVEYS. SEC = TREATMENT AND CONTROL SECTION NUMBER, RC RATIO = THE RATIO BETWEEN RECAPTURES (PASS TWO) AND TOTAL CAPTURES (PASS 1); SITE LGTH = LENGTH OF FISH SURVEY SITE IN M; WETTED WIDTH = AVERAGE WETTED WIDTH OF FISH SURVEY SITE IN M; RBT/KM = ESTIMATED NUMBER OF STEELHEAD PER KM; 90% CI = 90% CONFIDENCE INTERVALS (UPPER AND LOWER); RBT/M2 = DENSITY OF STEELHEAD PER M2.

Year	Season	Stream	Sec	Site	RC Ratio	Site Lgth	Wetted Width	RBT/ km	RBT/km 90% CI Up	RBT/km 90% CI Low	RBT/ m2	RBT/ m2 90% CI Up	RBT/m2 90% CI Low
2008	Summer	Charley	1	CC-F2	0.20	450	3.1	776	1029	522	0.25	0.33	0.17
2008	Summer	Charley	2	CC-F3	0.09	563	4.8	1557	2285	828	0.32	0.48	0.17
2008	Summer	Charley	3	CC-F5	0.13	530	3.1	975	1417	534	0.31	0.46	0.17
2008	Summer	N. Fork	1	NF-F1	0.26	210	6.9	1400	1863	938	0.20	0.27	0.14
2008	Summer	N. Fork	2	NF-F4	0.16	330	6.0	1210	1716	704	0.20	0.29	0.12
2008	Summer	N. Fork	3	NF-F6	0.19	364	6.8	986	1286	686	0.15	0.19	0.10
2008	Summer	S. Fork	1	SF-F2	0.15	585	4.6	1067	1453	682	0.23	0.32	0.15
2008	Summer	S. Fork	2	SF-F3	0.22	470	3.5	866	1031	702	0.25	0.29	0.20
2008	Summer	S. Fork	3	SF-F5	0.18	315	4.6	1470	1916	1024	0.32	0.42	0.22
2009	Summer	Charley	1	CC-F1	0.23	393	3.1	394	562	226	0.13	0.18	0.07
2009	Summer	Charley	1	CC-F2	0.34	450	3.2	478	601	355	0.15	0.19	0.11
2009	Summer	Charley	2	CC-F3	0.29	312	3.9	862	1103	621	0.22	0.28	0.16
2009	Summer	Charley	2	CC-F4	0.24	353	3.5	734	974	494	0.21	0.28	0.14
2009	Summer	Charley	3	CC-F5	0.29	530	3.5	470	588	353	0.13	0.17	0.10
2009	Summer	Charley	3	CC-F6	0.26	325	3.6	819	1026	612	0.23	0.29	0.17
2009	Summer	N. Fork	1	NF-F1	0.23	211	6.2	559	889	230	0.09	0.14	0.04
2009	Summer	N. Fork	3	NF-F6	0.10	347	7.4	919	1521	317	0.12	0.21	0.04
2009	Summer	S. Fork	1	SF-F2	0.15	585	4.4	737	1031	442	0.17	0.23	0.10
2009	Summer	S. Fork	2	SF-F3	0.19	468	4.3	783	1075	490	0.18	0.25	0.11

2009	Summer	S. Fork	3	SF-F5	0.15	370	3.9	1214	1678	750	0.31	0.43	0.19
2009	Fall	Charley	1	CC-F1	0.25	393	3.1	394	505	282	0.13	0.16	0.09
2009	Fall	Charley	1	CC-F2	0.47	450	3.2	358	427	289	0.11	0.13	0.09
2009	Fall	Charley	2	CC-F3	0.22	312	3.9	858	1167	548	0.22	0.30	0.14
2009	Fall	Charley	2	CC-F4	0.35	353	3.5	1036	1221	851	0.30	0.35	0.24
2009	Fall	Charley	3	CC-F5	0.37	530	3.5	538	637	440	0.15	0.18	0.13
2009	Fall	Charley	3	CC-F6	0.37	325	3.6	807	965	649	0.22	0.27	0.18
2009	Fall	N. Fork	1	NF-F1	0.27	211	6.2	1177	1528	826	0.19	0.25	0.13
2009	Fall	N. Fork	2	NF-F4	0.25	330	6.2	1031	1408	655	0.17	0.23	0.11
2009	Fall	N. Fork	3	NF-F6	0.27	347	7.4	685	915	456	0.09	0.12	0.06
2009	Fall	S. Fork	1	SF-F2	0.23	585	4.4	567	726	408	0.13	0.16	0.09
2009	Fall	S. Fork	2	SF-F3	0.30	468	4.3	543	679	407	0.13	0.16	0.09
2009	Fall	S. Fork	3	SF-F5	0.39	370	3.9	676	783	569	0.17	0.20	0.15
2010	Summer	Charley	1	CC-F1	0.36	380	3.8	789	944	634	0.21	0.25	0.17
2010	Summer	Charley	1	CC-F2	0.41	442	3.1	813	912	714	0.26	0.29	0.23
2010	Summer	Charley	2	CC-F3	0.35	308	4.0	1076	1284	869	0.27	0.32	0.22
2010	Summer	Charley	2	CC-F4	0.36	343	3.2	1237	1443	1032	0.39	0.45	0.32
2010	Summer	Charley	3	CC-F5	0.43	538	3.6	929	1050	807	0.26	0.29	0.22
2010	Summer	Charley	3	CC-F6	0.43	326	3.7	1292	1444	1141	0.35	0.39	0.31
2010	Summer	N. Fork	1	NF-F1	0.27	260	6.8	1600	1912	1288	0.24	0.28	0.19
2010	Summer	N. Fork	2	NF-F4	0.37	329	6.7	1321	1517	1126	0.20	0.23	0.17
2010	Summer	N. Fork	3	NF-F6	0.25	347	6.4	1504	1849	1158	0.23	0.29	0.18
2010	Summer	S. Fork	1	SF-F2	0.31	602	4.9	1138	1285	991	0.23	0.26	0.20
2010	Summer	S. Fork	2	SF-F3	0.43	469	3.9	1419	1587	1252	0.36	0.41	0.32
2010	Summer	S. Fork	3	SF-F5	0.40	371	4.3	1571	1737	1405	0.37	0.40	0.33
2010	Fall	Charley	1	CC-F1	0.50	380	3.8	856	960	752	0.23	0.25	0.20
2010	Fall	Charley	1	CC-F2	0.43	442	3.1	901	1019	784	0.29	0.33	0.25
2010	Fall	Charley	2	CC-F3	0.42	308	4.0	1097	1258	937	0.27	0.31	0.23
2010	Fall	Charley	2	CC-F4	0.41	343	3.2	1606	1797	1416	0.50	0.56	0.44
2010	Fall	Charley	3	CC-F5	0.45	538	3.6	739	827	651	0.21	0.23	0.18
2010	Fall	Charley	3	CC-F6	0.40	326	3.7	952	1078	827	0.26	0.29	0.22
2010	Fall	N. Fork	1	NF-F1	0.30	260	6.8	1966	2330	1602	0.29	0.34	0.24
2010	Fall	N. Fork	2	NF-F4	0.34	329	6.7	2512	2850	2173	0.37	0.43	0.32
2010	Fall	N. Fork	3	NF-F6	0.35	347	6.4	1709	1928	1490	0.27	0.30	0.23

2010	Fall	S. Fork	1	SF-F2	0.36	602	4.9	1381	1529	1234	0.28	0.31	0.25
2010	Fall	S. Fork	2	SF-F3	0.50	469	3.9	1584	1706	1462	0.41	0.44	0.37
2010	Fall	S. Fork	3	SF-F5	0.41	371	4.3	1412	1545	1280	0.33	0.36	0.30
2011	Summer	Charley	1	CC-F1	0.29	380	3.6	1605	1888	1321	0.45	0.53	0.37
2011	Summer	Charley	1	CC-F2	0.33	440	3.4	1027	1183	871	0.30	0.35	0.25
2011	Summer	Charley	3	CC-F5	0.34	535	3.7	948	1076	820	0.26	0.29	0.22
2011	Summer	Charley	3	CC-F6	0.46	330	3.9	966	1078	853	0.25	0.27	0.22
2011	Summer	N. Fork	1	NF-F1	0.20	270	6.9	1142	1542	742	0.17	0.22	0.11
2011	Summer	N. Fork	2	NF-F4	0.17	335	6.9	1553	2085	1022	0.23	0.30	0.15
2011	Summer	N. Fork	3	NF-F6	0.13	350	6.9	1546	2075	1017	0.23	0.30	0.15
2011	Summer	S. Fork	1	SF-F2	0.29	595	5.1	1270	1474	1066	0.25	0.29	0.21
2011	Summer	S. Fork	2	SF-F3	0.31	470	4.7	1304	1518	1089	0.28	0.32	0.23
2011	Summer	S. Fork	3	SF-F5	0.30	370	4.3	1534	1798	1271	0.36	0.42	0.30
2011	Fall	Charley	1	CC-F1	0.33	405.3	3.4	671	807	535	0.20	0.24	0.16
2011	Fall	Charley	1	CC-F2	0.32	491.7	3.4	740	886	594	0.22	0.26	0.17
2011	Fall	Charley	3	CC-F5	0.22	559.6	3.8	853	1090	616	0.22	0.29	0.16
2011	Fall	Charley	3	CC-F6	0.23	338.6	3.5	864	1164	564	0.24	0.33	0.16
2011	Fall	N. Fork	1	NF-F1	0.11	286.7	6.3	1199	1847	550	0.19	0.30	0.09
2011	Fall	N. Fork	2	NF-F4	0.18	335.9	6.7	2076	2633	1519	0.31	0.39	0.23
2011	Fall	N. Fork	3	NF-F6	0.17	360	5.7	2275	2912	1639	0.40	0.51	0.29
2011	Fall	S. Fork	1	SF-F2	0.24	587.2	4.7	791	1009	573	0.17	0.21	0.12
2011	Fall	S. Fork	2	SF-F3	0.18	413.5	4.4	1451	1854	1048	0.33	0.42	0.24
2011	Fall	S. Fork	3	SF-F5	0.36	380.6	4.1	1599	1834	1364	0.39	0.45	0.34
Mean					**0.29**	**401**	**4.6**	**1102**	**1363**	**842**	**0.25**	**0.30**	**0.19**
SD					**0.10**	**102**	**1.3**	**440**	**532**	**388**	**0.09**	**0.10**	**0.08**
Min					**0.09**	**210**	**3.1**	**358**	**427**	**226**	**0.09**	**0.12**	**0.04**
Max					**0.50**	**602**	**7.4**	**2512**	**2912**	**2173**	**0.50**	**0.56**	**0.44**

APPENDIX J. MEAN RELATIVE AND ABSOLUTE GROWTH RATES BY STREAM, SITE, AND GROWTH PERIOD FOR CHARLEY CREEK, NORTH FORK, AND SOUTH FORK: 2008-2011. GROWTH PERIODS ARE PERIODS BETWEEN MARK-RECAPTURE SURVEYS EACH SUMMER (S) AND FALL (F) WITHIN AND BETWEEN YEARS (E.G., S08-S09 = SUMMER 2008 TO SUMMER 2009).

			Rate Change in				
Stream	**Site**	**Capture Period**	**Relative Length (mm/mm/d)**	**Relative Weight (g/g/d)**	**Absolute Length (mm/d)**	**Absolute Weight (g/d)**	**N**
Charley	CC-F1	S09-F09	0.0000	-0.0010	0.0023	-0.0253	24
Charley	CC-F1	F09-S10	0.0008	0.0027	0.1263	0.1267	3
Charley	CC-F1	S10-F10	0.0004	-0.0004	0.0510	-0.0079	104
Charley	CC-F1	F10-S11	0.0013	0.0038	0.1407	0.0740	15
Charley	CC-F1	S11-F11	0.0004	0.0003	0.0518	0.0105	62
Charley	CC-F2	S08-S09	0.0005	0.0014	0.0679	0.0443	13
Charley	CC-F2	S09-F09	0.0002	-0.0009	0.0232	-0.0413	77
Charley	CC-F2	F09-S10	0.0006	0.0019	0.0839	0.0572	10
Charley	CC-F2	S10-F10	0.0003	-0.0003	0.0408	-0.0007	178
Charley	CC-F2	F10-S11	0.0010	0.0028	0.1124	0.0543	58
Charley	CC-F2	S11-F11	0.0005	0.0014	0.0500	0.0254	101
Charley	CC-F3	S08-S09	0.0005	0.0014	0.0532	0.0254	14
Charley	CC-F3	S09-F09	0.0005	0.0005	0.0540	-0.0094	63
Charley	CC-F3	F09-S10	0.0007	0.0023	0.0976	0.0648	36
Charley	CC-F3	S10-F10	0.0002	-0.0001	0.0244	-0.0036	118
Charley	CC-F4	S09-F09	0.0016	0.0036	0.1723	0.0605	73
Charley	CC-F4	F09-S10	0.0008	0.0023	0.0938	0.0437	55
Charley	CC-F4	S10-F10	0.0007	0.0017	0.0844	0.0411	145
Charley	CC-F5	S08-S09	0.0005	0.0016	0.0609	0.0384	18

Charley	CC-F5	S09-F09	0.0012	0.0022	0.1299	0.0255	80
Charley	CC-F5	F09-S10	0.0007	0.0020	0.0767	0.0363	46
Charley	CC-F5	S10-F10	0.0001	-0.0007	0.0086	-0.0112	101
Charley	CC-F5	F10-S11	0.0005	0.0016	0.0566	0.0334	75
Charley	CC-F5	S11-F11	0.0010	0.0028	0.1051	0.0328	90
Charley	CC-F6	S09-F09	0.0008	0.0013	0.0859	0.0152	96
Charley	CC-F6	F09-S10	0.0007	0.0020	0.0907	0.0459	42
Charley	CC-F6	S10-F10	0.0000	-0.0002	0.0002	-0.0080	205
Charley	CC-F6	F10-S11	0.0005	0.0016	0.0631	0.0367	69
Charley	CC-F6	S11-F11	0.0005	0.0014	0.0519	0.0129	75
North Fork	NF-F1	S08-S09	0.0008	0.0023	0.1123	0.0733	3
North Fork	NF-F1	S09-F09	0.0005	-0.0001	0.0685	-0.0008	22
North Fork	NF-F1	F09-S10	0.0012	0.0031	0.1485	0.0905	14
North Fork	NF-F1	S10-F10	0.0006	0.0013	0.0762	0.0307	80
North Fork	NF-F1	F10-S11	0.0016	0.0041	0.1813	0.0923	11
North Fork	NF-F1	S11-F11	0.0006	0.0018	0.0823	0.0577	13
North Fork	NF-F4	S08-S09	0.0010	0.0029	0.1336	0.0848	4
North Fork	NF-F4	S09-F09	0.0004	-0.0001	0.0420	-0.0294	15
North Fork	NF-F4	F09-S10	0.0010	0.0026	0.1201	0.0622	13
North Fork	NF-F4	S10-F10	0.0012	0.0031	0.1375	0.0545	117
North Fork	NF-F4	F10-S11	0.0011	0.0032	0.1224	0.0567	29
North Fork	NF-F4	S11-F11	0.0010	0.0027	0.1129	0.0381	27
North Fork	NF-F6	S08-S09	0.0008	0.0024	0.1089	0.0722	6
North Fork	NF-F6	S09-F09	0.0004	0.0008	0.0457	0.0181	24
North Fork	NF-F6	F09-S10	0.0008	0.0024	0.1191	0.0927	17
North Fork	NF-F6	S10-F10	0.0010	0.0025	0.1136	0.0440	104
North Fork	NF-F6	F10-S11	0.0010	0.0030	0.1356	0.0954	11
North Fork	NF-F6	S11-F11	0.0006	0.0011	0.0702	0.0029	22
South Fork	SF-F2	S08-S09	0.0007	0.0023	0.0941	0.0860	13
South Fork	SF-F2	S09-F09	0.0011	0.0016	0.1299	0.0284	57

South Fork	SF-F2	F09-S10	0.0008	0.0027	0.1098	0.0717	9
South Fork	SF-F2	S10-F10	0.0011	0.0024	0.1115	0.0336	195
South Fork	SF-F2	F10-S11	0.0014	0.0037	0.1596	0.0765	50
South Fork	SF-F2	S11-F11	0.0008	0.0020	0.0870	0.0348	60
South Fork	SF-F3	S08-S09	0.0007	0.0024	0.0945	0.0710	56
South Fork	SF-F3	S09-F09	0.0006	0.0003	0.0818	-0.0006	55
South Fork	SF-F3	F09-S10	0.0011	0.0030	0.1190	0.0541	35
South Fork	SF-F3	S10-F10	0.0009	0.0021	0.0986	0.0284	322
South Fork	SF-F3	F10-S11	0.0012	0.0035	0.1354	0.0671	73
South Fork	SF-F3	S11-F11	0.0008	0.0024	0.0918	0.0390	66
South Fork	SF-F5	S09-F09	0.0004	0.0004	0.0528	-0.0022	86
South Fork	SF-F5	F09-S10	0.0007	0.0020	0.0865	0.0667	41
South Fork	SF-F5	S10-F10	0.0007	0.0017	0.0757	0.0092	266
South Fork	SF-F5	F10-S11	0.0007	0.0020	0.0839	0.0405	67
South Fork	SF-F5	S11-F11	0.0009	0.0027	0.0949	0.0278	114
		Mean	0.0008	0.0018	0.0890	0.0385	64.7
		SD	0.0003	0.0012	0.0396	0.0343	62.3
		Min	0.0000	-0.0010	0.0002	-0.0413	3.0
		Max	0.0016	0.0041	0.1813	0.1267	322.0
		Median	0.0007	0.0020	0.0889	0.0382	55.5
		CV	46.1	68.2	44.5	89.1	96.3

APPENDIX K. SUMMARY OF ESTIMATES OF SURIVIVAL, CAPTURE PROBABILITY, AND SITE FIDELITY USING THE BARKER MODEL IN PROGRAM MARK BY SURVIVAL PERIOD.SITE CC = CHARLEY CREEK, NF = NORTH FORK, AND SF = SOUTH FORK.

Survival

	Survival Period (Month and Year)																					
	2008-09		Jul-Aug2009		Sep09		Oct09-Jul10		Jul10-Sep10		Sep10-Oct10		Oct10-Dec10		Dec10-Mar11		Apr11-Jun11		Jul11-Aug11			
Site	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**AVER S**	**AVE SE**
CC_F1			1.000	0.000	1.000	0.000	0.793	0.023	0.924	0.027	0.995	0.010	0.857	0.026	1.000	0.000	0.564	0.097	0.951	0.011	0.898	0.022
CC_F2	0.944	0.013	0.958	0.044	1.000	0.000	0.834	0.015	0.973	0.017	0.978	0.013	0.916	0.018	1.000	0.000	0.582	0.027	0.997	0.003	0.918	0.015
CC_F3	0.898	0.014	1.000	0.000	0.972	0.079	0.899	0.011	0.984	0.012	0.933	0.022	0.904	0.029	0.959	0.047					0.944	0.027
CC_F4			1.000	0.000	0.896	0.063	0.931	0.008	0.981	0.012	0.992	0.008	0.988	0.009	1.000	0.000					0.970	0.014
CC_F5	0.937	0.012	1.000	0.000	1.000	0.000	0.922	0.008	0.996	0.005	0.988	0.009	0.993	0.009	0.943	0.049	0.752	0.054	0.996	0.003	0.953	0.015
CC_F6			1.000	0.000	0.699	0.054	0.941	0.009	0.997	0.004	0.999	0.005	1.000	0.000	1.000	0.000	0.797	0.041	0.998	0.002	0.937	0.013
NF_F1	0.827	0.024	1.000	0.002	0.968	0.131	0.869	0.017	0.978	0.015	1.000	0.000	0.933	0.028	0.940	0.050	0.563	0.115	0.973	0.013	0.905	0.039
NF_F4	0.897	0.021	0.913	0.079	1.000	0.000	0.858	0.017	1.000	0.000	0.988	0.011	0.952	0.017	0.879	0.051	0.639	0.105	0.996	0.004	0.912	0.030
NF_F6	0.879	0.028	0.997	0.000	0.489	0.070	0.848	0.020	1.000	0.000	1.000	0.000	0.994	0.009	0.880	0.039	0.478	0.032	1.000	0.000	0.857	0.020
SF_F2	0.941	0.013	0.975	0.043	1.000	0.000	0.885	0.011	0.991	0.007	0.990	0.007	0.910	0.013	1.000	0.000	0.637	0.120	0.993	0.004	0.932	0.022
SF_F3	0.955	0.009	0.903	0.029	0.941	0.084	0.895	0.010	1.000	0.000	0.996	0.006	0.942	0.015	0.987	0.039	0.738	0.075	0.995	0.003	0.935	0.027
SF_F5	0.872	0.024	1.000	0.000	0.673	0.062	0.898	0.011	1.000	0.000	1.000	0.000	1.000	0.000	0.925	0.030	0.644	0.025	0.998	0.002	0.901	0.015
																			Mean		0.922	
																			SD		0.030	
																			Min		0.857	
																			Max		0.970	
																			Median		0.925	

Capture Probability

	Survival Period (Month and Year)																					
	2008-09		Jul09-Aug09		Sep09		Oct09-Jul10		Jul10-Sep10		Sep10-Oct10		Oct10-Dec10		Dec10-Mar11		Apr11-Jun11		Jul11-Aug11			
Site	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**AVER S**	**AVE SE**
CC_F1	NA	NA			0.049	0.024	0.235	0.047	0.273	0.122	0.000	0.000	0.497	0.047	0.236	0.035	0.213	0.034	0.417	0.256	0.237	0.067
CC_F2	NA	NA	0.296	0.083	0.155	0.032	0.358	0.049	0.311	0.082	0.407	0.038	0.582	0.042	0.130	0.022	0.275	0.032	1.000	0.000	0.379	0.041
CC_F3	NA	NA	0.361	0.098	0.000	0.000	0.295	0.042	0.419	0.061	0.250	0.038	0.471	0.053	0.082	0.020					0.268	0.044
CC_F4	NA	NA	0.000	0.000	0.411	0.041	0.403	0.050	0.378	0.044	0.227	0.025	0.424	0.030	0.104	0.014					0.278	0.029
CC_F5	NA	NA	0.418	0.099	0.000	0.000	0.344	0.037	0.415	0.049	0.284	0.032	0.461	0.042	0.000	0.000	0.000	0.000	0.534	0.180	0.245	0.044
CC_F6	NA	NA	0.000	0.000	0.180	0.030	0.548	0.056	0.534	0.059	0.000	0.000	0.423	0.029	0.000	0.000	0.000	0.000	0.428	0.083	0.211	0.026
NF_F1	NA	NA	0.286	0.133	0.028	0.020	0.306	0.068	0.274	0.079	0.094	0.020	0.265	0.031	0.062	0.014	0.048	0.014	0.321	0.239	0.173	0.063
NF_F4	NA	NA	0.087	0.051	0.000	0.000	0.291	0.065	0.338	0.086	0.018	0.008	0.330	0.029	0.000	0.000	0.000	0.000	0.329	0.222	0.139	0.046
NF_F6	NA	NA	0.177	0.088	0.028	0.016	0.507	0.098	0.597	0.125	0.000	0.000	0.396	0.063	0.000	0.000	0.000	0.000	1.000	0.000	0.271	0.039
SF_F2	NA	NA	0.359	0.115	0.000	0.000	0.278	0.042	0.183	0.046	0.407	0.031	0.416	0.031	0.516	0.030	0.157	0.017	0.408	0.269	0.288	0.060
SF_F3	NA	NA	0.375	0.056	0.646	0.047	0.309	0.043	0.376	0.057	0.460	0.030	0.541	0.031	0.186	0.018	0.152	0.021	0.292	0.123	0.349	0.045
SF_F5	NA	NA	0.000	0.000	0.100	0.023	0.516	0.061	0.498	0.065	0.246	0.030	0.690	0.048	0.000	0.000	0.000	0.000	1.000	0.000	0.305	0.023
																			Mean		0.262	
																			SD		0.068	
																			Min		0.139	
																			Max		0.379	
																			Median		0.269	

Site Fidelity

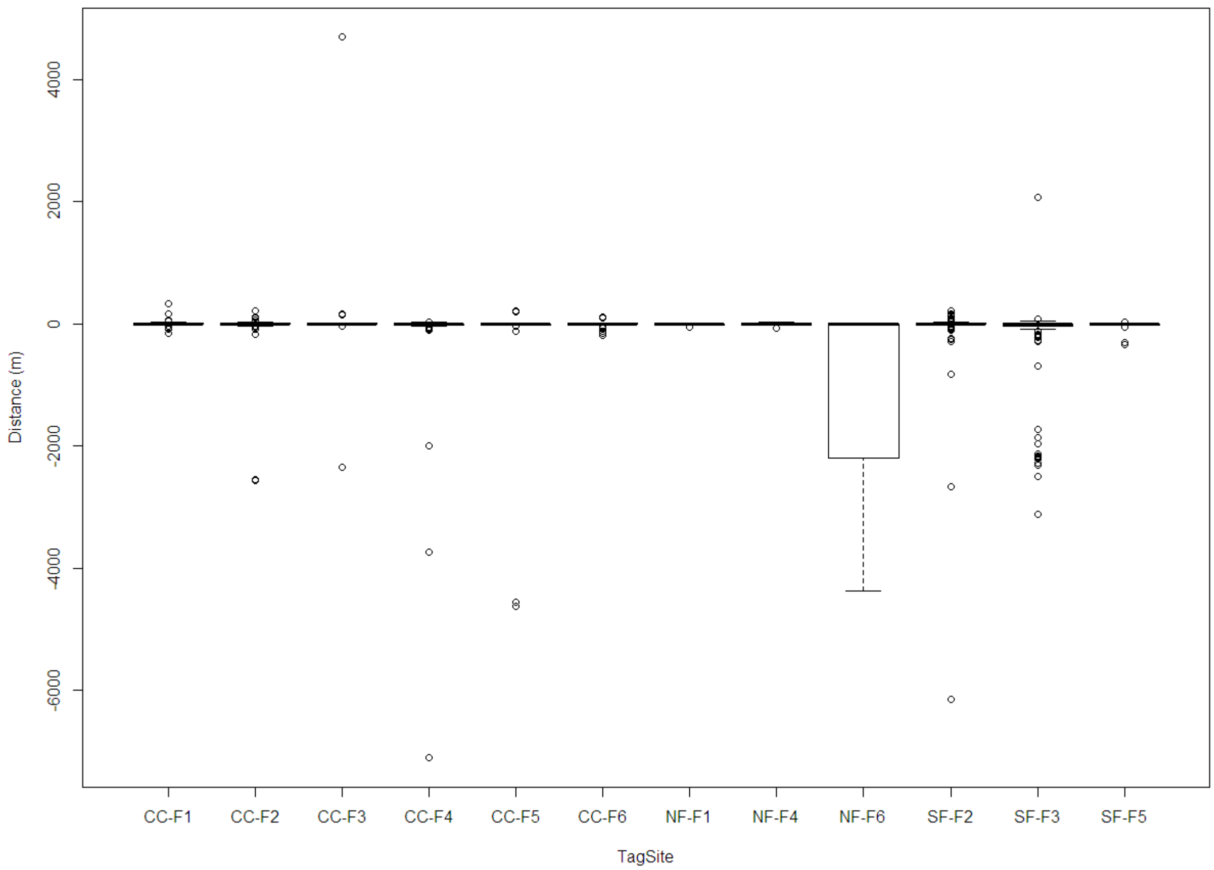
	Survival Period (Month and Year)																					
	2008-09		Jul09-Aug09		Sep09		Oct09-Jul10		Jul10-Sep10		Sep10-Oct10		Oct10-Dec10		Dec10-Mar11		Apr11-Jun11		Jul11-Aug11			
Site	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**S**	**SE**	**AVER S**	**AVE SE**
CC_F1	NA	NA	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
CC_F2	NA	NA	0.954	0.013	1.000	0.001	1.000	0.000	1.000	0.000	0.904	0.025	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.986	0.004
CC_F3	NA	NA	0.958	0.016	1.000	0.001	1.000	0.000	1.000	0.000	0.912	0.036	1.000	0.000	1.000	0.000					0.984	0.007
CC_F4	NA	NA	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000					1.000	0.000
CC_F5	NA	NA	0.945	0.015	1.000	0.001	1.000	0.000	1.000	0.000	0.886	0.031	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.983	0.005
CC_F6	NA	NA	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
NF_F1	NA	NA	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
NF_F4	NA	NA	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
NF_F6	NA	NA	0.986	0.031	1.000	0.000	1.000	0.000	1.000	0.000	0.970	0.067	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.996	0.010
SF_F2	NA	NA	0.921	0.018	1.000	0.002	1.000	0.000	1.000	0.000	0.839	0.021	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.976	0.004
SF_F3	NA	NA	0.970	0.008	1.000	0.001	1.000	0.000	1.000	0.000	0.934	0.017	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.990	0.003
SF_F5	NA	NA	0.888	0.027	1.000	0.002	1.000	0.000	1.000	0.000	0.779	0.028	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.967	0.006
																			Mean		0.990	
																			SD		0.011	
																			Min		0.967	
																			Max		1.000	
																			Median		0.993	

APPENDIX L. DETECTION OF JUVENILE STEELHEAD USING MOBILE PIT TAG ANTENNA SURVYES WITHIN FISH SITES AND UPSTREAM AND DOWNSTREAM OF FISH SITES.

Table L1. Resightings of PIT tagged juvenile steelhead at sites surveyed with a mobile PIT tag antenna in the Asotin Creek IMW study streams: 2009-2011. CC = Charley Creek, NF = North Fork, SF = South Fork. *Tag Site* refers to fish site where the fish was originally tagged and *Mobile Site* refers to site where fish was resighted with a mobile antenna. CC-F1_CCF2 = entire distance Between CC-F1 and CC-F2; CC-F1_ds = 1 km "downstream" of CC-F1; CC-F2_us = 1 km "upstream" of CC-F2.

	Tag Site											
Mobile Site	**CC-F1**	**CC-F2**	**CC-F3**	**CC-F4**	**CC-F5**	**CC-F6**	**NF-F1**	**NF-F4**	**NF-F6**	**SF-F2**	**SF-F3**	**SF-F5**
CC-F1_ds	11	2										
CC-F1	220	5		1	1					1		
CC-F1_CC-F2	1	2	1		1							
CC-F2		389	7	1	2	1						
CC-F2_us		7		1	3							
CC-F3		2	159	6	3							
CC-F4			2	327	4							
CC-F5			1	1	267	3						
CC-F6				1	3	220						
NF-F1_ds							1					
NF-F1							110	1			1	
NF-F1_us							1					
NF-F4								108	2			
NF-F4_us								2				
NF-F6_ds									6			
NF-F6								1	78			
NF-F6_us									3			
SF-F2_ds							1			29	10	4
SF-F2			1							645	14	2
SF-F2_SF-F3										24	12	3
SF-F3										11	616	2
SF-F5_ds												3
SF-F5										3		289
SF-F5_us												7
% Reisghted Off-Site	5.5	3.3	1.9	3.1	6.4	1.8	1.8	3.7	14.1	10.4	6.0	7.3
Mean	5.4											
SD	3.8											
Min	1.8											
Max	14.1											
Median	4.6											

Figure L1. Distribution of distances moved from the initial mobile detection site of PIT tagged juvenile steelhead as determined by mobile PIT tag surveys. Distances represent the distance a fish moved from its original tag site, negative numbers represent downstream movement and positive numbers represent upstream movement.



APPENDIX M. RIPARIAN VEGETATION SPECIES LIST BASED ON HABITAT SURVEYS IN 2009 ALONG CHARLEY CREEK, NORTH FORK, AND SOUTH FORK USING A MODIFIED PIBO RIPARIAN SURVEY PROTOCOL.

Species Type	Common Name	Species Name	Abundance
Forb	Chicory	Cicharium intybus	Common
Forb	Common Dandelion	Taraxacum officinale	Rare
Forb	Common Horsetail	Equisetum arvense	Abundant
Forb	Common Mullein	Verbascum thapsus	Common
Forb	Field Mint	Mentha spp.	Sparse
Forb	Goat's Beard	Tragopogon dubius	Sparse
Forb	Kentucky Bluegrass	Poa pratensis	Common
Forb	Orchard Grass	Dactylis glomerala	Common
Forb	Quack Grass	Elymus glaucus	Abundant
Forb	Reed Canary Grass	Phalaris arundinacea	Abundant
Forb	Scentless Chamomile	Matricaria perforata	Common
Forb	Scouring Rush	Equisetum hyemale	Common
Forb	Yarrow	Achillea millefolium	Common
Shrub	Bebb's Willow	Salix hebbiana	Common
Shrub	Blue Elderberry	Sambucus cerulea	Sparse
Shrub	Crab Apple	Malus spp.	Sparse
Shrub	Curly-Cup Gumweed	Grindelia squarrosa	Rare
Shrub	Mallow Ninebark	Physocarpus malvaceus	Sparse
Shrub	Mock Orange	Philadelphus Lewisii	Abundant
Shrub	Ocean Spray	Holodiscus discolor	Abundant
Shrub	Prairie Rose	Rosa woodsii	Abundant
Shrub	Prickly Rose	Rosa acicularis	Common
Shrub	Red-Osier Dogwood	Cornus stolonifera	Abundant
Shrub	Scotch Thistle	Onopordum acanthium	Abundant
Shrub	Thimbleberry	Rubus parriflorus	Abundant
Tree	Black Cottonwood	Populus balsamifera	Abundant
Tree	Hawthorn	Crataegus spp.	Common
Tree	Red Alder	Alnus rubra	Abundant
Tree	Water Birch	Betula occidentalis	Common

APPENDIX N. PRELIMINARY SUMMARY OF PRODUCTION METRICS FOR STEELHEAD AND OTHER SALMONIDS WITH SIMIALR LIFE HISTORY CHARATERISTICS.

	Study Information							Abundance		Growth		Survival		Production		Scale		
Reference	Study Period	Watershed	State	Species	Location	Site Type	Age Class	range	units	range	units	range	period	range	units	Temporal	Spatial	Comments
Beakes et al. 2010	2006-07	lab experiment	California	Wild Steelhead*	Coastal	-				0.1-0.8	mm /d					Monthly		Smolts grew 33% quicker than non-smolts
Bell et al. 2011	2008-10	Topanga Creek	California	Wild Steelhead	Coastal		1			57	mm /yr					Monthly		early fast growth and larger fish more likely to survive;
Bell et al. 2011	2008-10	Topanga Creek	California	Wild Steelhead	Coastal		2-3			12	mm /yr							Able to grow when water temps are high (>24C)
Hayes et al. 2008		Scott Creek	California	Wild Steelhead	Coastal	Estuary Pond	1+			0.2-1.6	%wgt /day							highest growth in spring and during non-optimal temps (i.e., 15-24 C)
Hayes et al. 2008		Scott Creek				Headwaters	1+			0.01-0.2	%wgt /d							density dependent growth in estuary
Hayes et al. 2010		Scott Creek					0+			0.11-0.14	mm /d							decrease in FL observed
Tattum 2006	2004-06	Murderers Creek	Oregon	Wild Steelhead	Interior	Pre	1+	3-600	100 m	0.1-0.6	mm /mm /d	0.4-0.95				Season		highest growth in spring;
Bouwes et al. unpubl.	2004-12	Bridge Creek	Oregon	Wild Steelhead	Interior	Trt	0+	0.05-1.00	m2	0.00-35.0	g /season	0.35-0.99	Season	20-400	100m2 /season			density dependent growth
Bouwes et al. unpubl.	2004-12	Murderers Creek	Oregon	Wild Steelhead	Interior	Cntrl	0+	0.05-0.20	m2	0.00-18.0	g /season	0.50-0.99	Season	20-225	100m2 /season			density dependent growth
Viola et al. 1989	1983-89	Tucannon River	Washington	Hatchery Steelhead	Interior	Trt & Cntrl	0+	0.03-0.21	m2									short-term reponse in treatment after 1 year but not 5 years
Viola et al. 1989	1983-89	Tucannon River	Washington	Hatchery Steelhead	Interior	Trt & Cntrl	>0+	0.01-0.13	m2					37.7-1508.3	g /100 m2			significant increase in numbers and biomass in treatments 5 years after treatment
Viola et al. 1989	1983-89	NF, SF Asotin Creek	Washington	Wild Steelhead	Interior	Trt & Cntrl	0+	0.06-0.41	m2									
Viola et al. 1989	1983-89	NF, SF Asotin Creek	Washington	Wild Steelhead	Interior	Trt & Cntrl	>0+	0.06-0.55	m2					105.9-405.2	*			

Appendix N continued.

	Study Information							Abundance		Growth		Survival		Production		Scale		
Reference	Study Period	Watershed	State	Species	Location	Site Type	Age Class	range	units	range	units	range	period	range	units	Temporal	Spatial	Comments
Canjak et al. 1998				Atlantic Salmon			0+					0.1-0.70	annual					survival correlated to discharge in winter
Canjak et al. 1998				Atlantic Salmon			1+					0.20-0.45	annual					ice scour a big cause of mortality
McCubbing and Ward 2000	1995-99	Keogh River		Wild Steelhead	Coastal	Trt	0+	140	100 m2									
McCubbing and Ward 2000	1995-99	Keogh River		Wild Steelhead	Coastal	Cntrl	1+	4-38	100 m2									
McCubbing and Ward 2000	1995-99	Keogh River		Wild Steelhead	Coastal	Trt	1+	55-126	100 m2									treatment includes LWD, Fertlizer, and Both
McCubbing and Ward 2000	1995-99	Keogh River		Coho	Coastal	Trt	0+	500	100 m2									increase in mean length at smolting
McCubbing and Ward 2000	1995-99	Keogh River		Coho	Coastal	Cntrl	0+	173	100 m2									
Quinn and Petersen 1996	1990-92			Coho	Coastal		1+					0.25-0.46				over winter		larger juveniles had increased survival to smolt stage
Horton et al. 2011		West, Shorey Brooks		Atlantic Salmon								0.65-0.95				Season		
Horton et al. 2009		West, Shorey Brooks		Atlantic Salmon	Coastal		0+, 1+			0.0-0.10	mm /day	0.79-0.99	monthly			Sum, Fall, Wint		high seasonal variability in growth rate
Horton et al. 2009		West, Shorey Brooks		Atlantic Salmon	Coastal		0+, 1+			0.30-0.53	mm /day	0.79-0.99				Spring		density dependence on growth but not survival; Smolt Production is dependent on **Growth Opportunity**
Johnson et al. 2005	1991-2000	Tenmile Creek	Oregon	Wild Steelhead	Coastal	Trt	0+	0.10-0.40				0.04-0.20	% 0+ - smolt					
Johnson et al. 2005		Cummins Creek	Oregon	Wild Steelhead	Coastal	Cntrl	0+					0.12-0.25	% 0+ - smolt					
Solazzi et al. 2000				Wild Steelhead														

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