# Salmon Recovery Funding Board Reach-Scale Project Effectiveness Monitoring Program

## 2018 Final Report


WASHINGTON STATE
RECREATION AND CONSERVATION OFFICE
Salmon Recovery Funding Board

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# REACH-SCALE PROJECT EFFECTIVENESS MONITORING PROGRAM

## 2018 Final Report

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# EXECUTIVE SUMMARY

In 1999, the Washington State legislature created the Governor's Salmon Recovery Office (GSRO) to provide a statewide salmon recovery plan and the Salmon Recovery Funding Board (SRFB) to distribute funds earmarked for salmon habitat restoration and protection. Since 2000, the SRFB has invested more than 1 billion dollars in salmon recovery and habitat restoration efforts. In 2004, the SRFB established a standardized effectiveness monitoring program to consistently assess the response of stream habitat and localized salmon populations to restoration efforts. The SRFB Project Effectiveness Monitoring (PE) Program originally included monitoring and evaluation for ten discrete categories including fish passage (MC-1), instream habitat (MC-2), riparian planting (MC-3), livestock exclusion (MC-4), constrained channel (MC-5), channel connectivity (MC-6), spawning gravel (MC-7), diversion screening (MC-8), estuary restoration (MC-9), and habitat protection (MC-10). In 2010 the constrained channel and channel connectivity categories and protocols were combined into a single category, floodplain enhancement (MC-5/6). By 2016, fish passage, riparian planting, spawning gravel, diversion screening, estuary restoration, and habitat protection categories were discontinued or completed. Final sampling of MC-2 instream habitat (placement of rock or wood in the active channel), MC-4 livestock exclusion (livestock exclusion to protect riparian zone and reduce erosion), and MC-5/6 floodplain enhancement (floodplain connectivity, reconnection/creation of off-channel habitat, removal of bank armor) was completed in 2017 and 2018. In this document, we report the final results and analysis for MC-2, MC-4, and MC-5/6 project types. In addition, we reviewed and synthesized the monitoring results from 2004 to 2018 for all PE project categories and provide recommendations for future monitoring.

The goal of SRFB PE monitoring of MC-2, MC-4, and MC-5/6 projects is to determine if actions specific to the category are improving stream morphology and habitat and increasing reach-scale juvenile salmonid abundance. A multiple before-after control-impact (MBACI) study design was used for monitoring of all project types. The MBACI design includes data collection in impact (restored) and control (unrestored) reaches before project implementation (Year 0), and after project implementation (Years 1, 3, 5, and 10). Monitoring followed protocols, objectives, analysis, and study design developed by the SRFB for each project type. SRFB monitoring protocols were adapted from U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program. Metrics calculated for MC-2 and MC-5/6 projects included vertical pool profile area, mean residual profile depth, large woody debris (LWD) volume, and juvenile fish densities. In addition, monitoring at MC-5/6 sites included measuring bank canopy cover, riparian vegetation structure, channel capacity, and floodprone width, while MC-4 sites included riparian vegetation structure, bank canopy cover, bank erosion, and pool tail fines. Projects were initially selected for monitoring from those that had been funded but not implemented for the given baseline sampling year. Beginning in 2004, data from 23 instream, 12 livestock, and 23 floodplain projects were collected on a rotating schedule across a range of rivers. Monitoring start dates were staggered depending upon date of restoration (impact) implementation. Data from all years of monitoring of projects were analyzed using a combination of paired *t*-tests and regression analysis. Selection of study sites and impact and control reaches, as well as data collection prior to 2017, were conducted by Tetra Tech. Cramer Fish Sciences was contracted in the fall of 2016 to finish data collection in 2017 and 2018, analyze data, and provide recommendations for future PE monitoring.

For instream habitat projects, results to date indicate significantly increased large woody debris in all years of post-treatment monitoring, while other physical habitat metrics (vertical pool profile area, mean residual profile depth) showed significant improvements in some years but not others, largely depending upon sample sizes. Fish densities have not yet significantly increased across years when compared to Year 0 or met management targets (20% increase). Large woody debris volume increases were expected due to project type (LWD additions, engineered log jams), though wood volume varied among sites, likely due to individual project variables such as funding and goals. Increases in vertical pool profile area and mean residual profile depth, though small and variable, are consistent with previous studies that document geomorphic response to wood placement and recruitment. Many studies on LWD placement have reported increases in juvenile salmonids, particularly coho salmon *Oncorhynchus kisutch* and steelhead *O. mykiss*. The lack of a significant increase in juvenile fish response to SRFB projects may simply be due to the low number of projects that have been monitored five or more years post-treatment. It may also be due to the sample timing, variability in treatments, the lack of geographic stratification, poorly matched control and impact reaches, or the chosen fish abundance metric. Given that several other studies have evaluated instream habitat projects throughout the region, we do not recommend additional monitoring of this category. However, a focused well-controlled study examining different levels of wood placement on project success may be warranted to assist with specific project design questions.

Results for livestock exclusion projects indicate significantly reduced bank erosion and improved riparian structure by Year 10, but we found no significant effects of livestock exclusion on bank canopy cover or pool tail fines. However, the mean percentage of pool tail fines was lower in all impact reaches. The reduction in bank erosion is consistent with previous studies on livestock exclusions, which have generally shown decreases in bank erosion and increases in riparian vegetation structure and shade. It is possible that canopy cover may continue to improve in impact reaches with continued livestock exclusion. However, the lack of change in canopy cover and fine sediment are likely the results of several factors including: evidence of livestock grazing in many impact reaches, livestock exclusion in control reaches, limitations of the riparian sampling protocols, and additional noise due to some control reaches that were not well matched with impact reaches. Many projects had intact fencing, but there were several instances where gates were left open, the fence was in the lay down position, or cattle were accessing the reach from upstream or downstream of the project location. Despite these limitations, livestock exclusions projects appear to be effective. Given that maintenance of livestock exclusion appears to be the main factor determining project effectiveness, future monitoring should focus on simple compliance rather than effectiveness monitoring.

While 23 floodplain enhancement projects were monitored, data from ten sites were excluded from the analysis due to inconsistencies with impact or control reaches or previous data collection. Results for the remaining floodplain enhancement projects were highly variable by metric and year with significant changes in vertical pool profile area in Year 1 and 10, mean residual profile depth in all years except Year 3, average channel capacity in Year 3, and juvenile coho salmon in Year 1 and 5. No significant changes were found for bank canopy cover, riparian vegetation structure, or Chinook salmon *O. tshawytscha* and steelhead densities. Adequate sample sizes were not available to analyze floodprone width. The positive changes in vertical pool profile area, mean residual profile depth, and coho salmon are consistent with previous studies on floodplain restoration, though results from SRFB projects have been relatively modest. Densities for juvenile fish were low across most sites, with several sites having no fish of a particular species found across several years of sampling. Moreover, the monitoring of fish, channel capacity, and floodprone width was not done consistently within and among projects across years making detection of differences due to restoration more difficult. Because floodplain enhancement projects typically involve a large impact to the riparian conditions, more time post-restoration may be needed for riparian vegetation to establish, colonize and reach the canopy threshold height. Mixed results across all metrics and the inability to assess data using more rigorous statistical methods (mixed-effects models) may be due to a variety of other factors including: sample timing, variability in restoration treatments, need for geographic stratification, and added variability from controls that were not well matched with impact reaches. Because of inconsistencies in data collection across years including lack of fish and riparian data, sampling in different seasons, and in some cases poorly matched impact and control reaches, we did not collect additional data for floodplain projects in 2018. Floodplain enhancement projects are widespread and in need of further evaluation to determine physical and biological effectiveness. Given the population of existing floodplain projects across Washington State, we recommend additional monitoring of a subsample of all existing projects using a post-treatment design coupled with more comprehensive monitoring protocols that use a mix of remote sensing and field surveys.

In our synthesis and review of the entire SRFB PE Program, including previously completed or discontinued project categories and the three categories we completed monitoring on, we found several consistent recommendations regardless of project category. First, SRFB PE represents one of the few programmatic effectiveness monitoring programs and one of the largest multiple BACI studies implemented. The SRFB and Tetra Tech should be commended for this large effort that included sampling of more than 75 projects across all project types. It is inevitable in a large multi-year program with dozens of treatments and controls that a few projects would have to be dropped because project sponsors restored controls or land owners denied access. The broad geographic coverage across very different ecoregions (eastern and western Washington), likely added additional variation that further contributed to difficulty in detecting a response for many categories. However, we found consistent problems across project types with initial selection of treatment and controls, timing of data collection within and across years, length and area sampled, data analysis, changes in protocols, and data management. This resulted in many sites having to be dropped from the analyses and limited the ability of the PE Program to detect significant differences. Thus, the limited positive results for some project categories are more likely due to limitations in PE implementation than an indication that these techniques are not successful. Most of this can be overcome through rigorous selection of treatments and controls, utilizing protocols that are developed specifically for monitoring restoration projects, and diligent monitoring implementation, coordination, and management. It is important that those selecting sites and collecting data understand the ramifications to the study design, results, and analysis of making changes to protocols, treatments and controls, or timing of sampling. It is also important to assure that those who designed the program remain involved in data collection, analysis, and reporting. Moving forward, based on our examination of the SRFB PE Program to date, we believe that diversion screening and livestock exclusion projects should be evaluated as compliance rather than effectiveness monitoring. Similarly, while the SRFB PE Program is one of the few programs that has evaluated acquisition and habitat protection projects, this monitoring should be part of a focused status and trends monitoring program rather than an effectiveness monitoring program. Additional reach-scale project effectiveness monitoring is, however, warranted for floodplain, nearshore, and riparian planting projects and we provide recommendations for design and monitoring protocols for each of these project types. Effectiveness monitoring is also needed for estuarine projects, but because of the complexity of estuaries and diversity of projects, this is best evaluated at a watershed (estuary) and landscape scale approach.

# ACKNOWLEDGMENTS

We would like to thank numerous individuals, organizations, landowners, and project sponsors for their contributions to the SRFB Project Effectiveness Monitoring (PE) Program. Without their input, support, and permission to access sites, monitoring of such a wide array of project types and locations would not have been possible. We would like to acknowledge Tetra Tech and Natural Systems Design for the 10+ years of field work and reporting for the PE Program prior to our taking over the project in late 2016. The Oregon Watershed Enhancement Board provided detailed input and helpful review on the riparian livestock exclusion chapter. Finally, we thank Pete Bisson, Ken Currens, Dennis Dauble, Leska Fore, Jody Lando, Marnie Tyler, and Micah Wait of the Monitoring Panel, and Keith Dublanica of the Governor's Salmon Recovery Office for their input and guidance on monitoring design and implementation and helpful comments on previous versions of this report.

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# CHAPTER 1. BACKGROUND

## 1.1 Need for the Project Effectiveness Monitoring Program

Pacific salmon *Oncorhynchus* spp. are keystone species of cultural, economic, and ecological significance that historically supported large tribal, commercial, and recreational fisheries in the Pacific Northwest. Due to various factors adversely impacting salmon, including overharvest, hatchery production, impassible dams, changing environmental conditions, disease, interspecific competition, and widespread habitat degradation and loss, salmon stocks in Washington State have experienced dramatic declines in the last 100 years (Chapman 1986; Nehlsen et al. 1991; Lichatowich 2001; Collins and Montgomery 2002). In response to population declines, the federal government listed several Evolutionary Significant Units of salmonids under the Endangered Species Act during the 1990's, which provided protection for the declining populations and their critical habitat.

In 1999, the Washington State legislature created the Governor's Salmon Recovery Office (GSRO) to provide a statewide salmon recovery plan and the Salmon Recovery Funding Board (SRFB) to distribute funds earmarked for salmon habitat restoration and protection. Since 2000, the SRFB has invested more than 1 billion dollars in salmon recovery and habitat restoration efforts (GSRO 2016). Federal and state funding agencies needed a way to document success of these sponsored actions. To meet this need, in 2002, the SRFB provided criteria for the monitoring and evaluation of salmon recovery in their Washington Comprehensive Monitoring Strategy and Action Plan for Watershed Health and Salmon Recovery (MOC 2002). The monitoring strategy aimed to identify monitoring efforts and priority needs and also described the need for statewide project monitoring coordination and a succinct monitoring strategy. In 2004, Washington State established a reach-scale effectiveness monitoring program (Project Effectiveness Monitoring or PE) to assess the response of stream habitat and localized salmon populations to salmon habitat restoration efforts.

## 1.2 Monitoring Goals and Objectives

Monitoring and evaluation provide critical measures of restoration effectiveness, project execution, implementation, and intended habitat enhancements and fish response. Restoration effectiveness monitoring is an important component of a monitoring and evaluation program that determines whether the restoration action had the desired effect on the physical habitat and the impact those changes have on biota (MacDonald et al. 1991; Roni 2005). The goals of the PE Program are to address several management questions developed by the GSRO and SRFB, which include:

1. Are restoration treatments having the intended effects regarding local habitats and their use by salmon;
2. Are some treatment types more effective than others at achieving specific results; and
3. Can project monitoring results be used to improve the design of future projects?

The monitoring program is designed to provide feedback on the efficacy of restoration actions at improving stream habitat and local salmonid abundance, with the goal of informing and improving restoration science and practices. The proposed questions allow for projects receiving similar treatments, such as project types involving artificially placed instream structures or floodplain reconnection, to be evaluated using a consistent protocol. Restoration projects were categorically assigned based on the restorative action, and the expected outcomes regarding habitat and fish metrics. For example, while livestock exclusion and instream projects both aim to improve habitat, the restoration actions are different and the responses to these actions are quantified using different success indicators which constitutes different monitoring categories. Eight discrete categories of commonly implemented project types were chosen for monitoring, and can be generally described as:

- MC-1: Fish Passage (removal/replacement of culverts, bridges, and dams)
- MC-2: Instream Habitat (placement of rock or wood in the active channel)[1]
- MC-3: Riparian Planting (riparian planting to increase stream shade)
- MC-4: Livestock Exclusion (livestock exclusion to protect riparian zone and reduce erosion)[1]
- MC-5/6: Floodplain Enhancement (floodplain connectivity, reconnection/creation of off-channel habitat, removal of bank armor)[1]
- MC-7: Spawning Gravel (supplementation of natural gravels in spawning-limited systems)
- MC-8: Diversion Screening (prevention of fish entrainment into water diversions)
- MC-10: Habitat Protection (protection of high-quality habitat)

Because the monitoring is programmatic, it uses standardized protocols to measure and evaluate each project within a given restoration category. The intent of the standardization is to allow for conclusions to be drawn across entire categories of projects and collaboration with other monitoring entities in the region. Specific criteria were established for each project indicator, and the combination of indicators that meet those criteria are used to provide feedback on whether the projects as a category are achieving their overarching goals as defined by the monitoring protocols.

Elimination, consolidation, and postponement of monitoring categories occurred for five of the original restoration categories for various reasons. Constrained channel (MC-5) and channel connectivity (MC-6) were combined into a single category, floodplain enhancement (MC-5/6), in 2010. Estuary monitoring (MC-9) was never implemented. Fish passage projects (MC-1) are no longer monitored because results indicated that fish quickly recolonize upstream of a removed barrier, occupying newly available habitat. Likewise, diversion screenings (MC-8) are no longer monitored because the projects were considered to have been successfully executed and functional. Additionally, riparian planting (MC-3) and habitat protection (MC-10) were unlikely to have quantifiable effects found within the monitoring period, and as a result monitoring was discontinued. Finally, an inadequate number of spawning gravel projects (MC-7) was originally included in the sample pool to provide for a proper statistical analysis, therefore monitoring was discontinued.

Three restoration action categories (MC-2, MC-4, and MC-5/6) are currently monitored in the program (see categories noted above). Monitoring for MC-2, MC-4, and MC-5/6 sites include physical habitat and biological evaluations based on categorically specific goals. Effectiveness monitoring for instream habitat restoration projects (MC-2) aim to quantify changes in habitat as they relate to local fish abundance. The

[1] Denotes categories actively being monitored under PE in 2017 and 2018.

MC-2 monitoring goal is to determine if placement of instream structures, such as rock weirs, boulders, and engineered log jams (ELJs), improve stream morphology and local fish abundance within the restoration reach. Monitoring of MC-4 projects intends to determine if the exclusion of livestock from a stream corridor leads to improved conditions in bank and instream habitat (bank erosion, riparian vegetation, fine sediment). The goal of livestock exclusion projects (MC-4) is to improve riparian, bank, and instream conditions through removal or reduction of livestock grazing. Monitoring of floodplain enhancement projects (MC-5/6) seeks to quantify changes in habitat (morphology, hydrology, connectivity) and local fish abundance. The goal of MC-5/6 monitoring is to determine if projects which remove stream bank modifications (e.g., dikes, riprap) and/or reconnect off-channel habitats, provide additional fish habitat and increase local fish densities.

## 1.3 Monitoring Design

Each restoration category protocol contains a specific objective and target metrics used during analysis to assess project effectiveness by applying a multiple before-after control-impact (MBACI) study design (Stewart-Oaten et al. 1986; Downes et al. 2002; Crawford 2011a, 2011b). Due to the large quantity of statewide restoration projects funded each year, the program monitors a subset of restoration projects funded by the SRFB. The MBACI study design utilizes an “impact site”, which is selected for a restoration treatment (e.g., cattle exclusion, wood placement, side channel creation, etc.), and a control site located upstream that is analogous to the impact site due to its proximity within the watershed. The control site should be representative of the environmental conditions at the impact site (e.g., precipitation patterns, flow regime, channel morphology, riparian conditions, and land use), but excludes the restorative action (Downes et al. 2002). The MBACI design provides the ability to test how the impact reach has changed relative to the control reach and therefore, it is assumed that any significant difference detected between the impact and control site metrics is a result of the restoration action. Effectiveness monitoring at the control and impact sites are evaluated one year before (Year 0) and 1, 3, 5, and for some categories, 10 years after restoration. Because the MBACI design involves sampling multiple restoration projects before and after restoration and therefore extensive spatial and temporal replication, it is considered one of the more rigorous designs for evaluating restoration project effectiveness (Downes et al. 2002; Roni 2005).

## 1.4 2017 and 2018 Monitoring

Cramer Fish Sciences (CFS) was contracted to complete data collection in 2017 and 2018, analyze data, and provide recommendations to guide future SRFB project effectiveness. Tetra Tech, the previous contractor, completed all project effectiveness monitoring from 2004 through 2016. Data collected by Tetra Tech was summarized into metrics for analysis and was provided by Tetra Tech to the SRFB and CFS as summary tables in spreadsheets. CFS did not recalculate summary metrics from data collected prior to 2017, but we did review the provided summary data and metrics for outliers and examined the PE Access database to address or correct any irregularities. In addition, we examined the top of site and bottom of site coordinates for each impact and control reach and year for consistency in reach location and length throughout the monitoring timeline.

Restoration project implementation and monitoring occurred over a protracted period for MC-2, MC-4, and MC-5/6, the remaining active action categories; therefore, site visits occurred on a rotating schedule. Instream habitat (MC-2) and floodplain enhancement (MC-5/6) projects had a much longer schedule of construction, occurring from 2004 to 2014 for both restoration project types. We were contracted to complete the last two years of monitoring for all three project types. This included nine MC-2, ten MC-4 and three MC-5/6 projects monitored in 2017 and eight MC-2 and 12 MC-5/6 sites contracted to CFS for monitoring in 2018.

## 1.5 Document Organization

This report details the monitoring, analysis, and recommendations for all MC-2, MC-4, and MC-5/6 projects. The methods, results, interpretation of findings, and recommendations for future monitoring are provided in separate chapters for the three project categories. In addition, the active project category chapters are followed with summaries of all project categories and an overall summary of findings for 2004-2018 of the monitoring program. Data from the previously completed categories (MC-1, MC-3, MC-8, MC-10) were not analyzed by CFS and results reported are from previous Tetra Tech analysis and annual reports. Finally, the report closes with recommendations for the project types, design, and potential analysis for future monitoring.

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# CHAPTER 2. MC-2 INSTREAM HABITAT

## 2.1 Summary

The placement of large woody debris (LWD), boulders, and other instream structures is one of the oldest and most common stream restoration techniques used in Washington State and the Pacific Northwest. In 2004, the Salmon Recovery Funding Board (SRFB) established a standardized effectiveness monitoring (PE) program to consistently assess the response of stream habitat and localized salmon populations to restoration efforts. The SRFB PE Program includes monitoring and evaluation of instream habitat projects (MC-2) which includes placement of LWD and boulder structures. Beginning in 2004, data from 23 instream projects were collected across a range of rivers throughout Washington State using a before-after control-impact (BACI) design. Project selection, impact and control reach identification, and data collection prior to 2017 were completed by a previous contractor. Cramer Fish Sciences was contracted to complete monitoring in 2017 and 2018 and to complete the final analysis and recommendations for the MC-2 category. This chapter describes the methods, data collected, and final analysis, results, and recommendations from 2004 to 2018. Each project was monitored once before project implementation and then after project implementation on a rotating schedule (Years 1, 3, 5 and 10). Physical habitat (vertical pool profile area, mean residual profile depth, and LWD) and juvenile fish density data were collected during summer low flow using SRFB protocols. Data from all years of monitoring of instream projects were analyzed using a combination of paired *t*-tests, regression analysis, and a BACI mixed-effects model. Results indicate that instream projects have significantly increased large woody debris volume by Year 10, while vertical pool profile area, mean residual profile depth, and fish densities have not significantly increased or met management targets (20% increase) by Year 10. Large woody debris volume increases were expected due to project type (LWD additions, ELJs), though volume varied among sites likely due to individual project variables such as funding and goals and project design. Vertical pool profile area and mean residual profile depth increased significantly initially, though by Year 10 results were no longer significant even though average values were larger than Year 0 for both metrics. Many studies on LWD placement have reported increases in juvenile salmonids, particularly coho salmon *Oncorhynchus kisutch*. The lack of a significant increase in juvenile fish response to SRFB projects may be due to the low number of projects that have been monitored for ten years post-treatment. It may also be due to the sample timing, variability in treatments, the lack of geographic stratification, poorly matched treatment and control reaches, or the chosen fish abundance metric. Based on monitoring to date, future monitoring of instream projects should consider stratifying projects by ecoregion, seasonal fish sampling (summer and winter), more rigorous selection of treatment and controls, improved habitat survey methods, and the use of a post-treatment design that does not require extensive pre-project data collection. Given that several other studies have evaluated instream habitat projects throughout the region, we do not recommend additional monitoring of this category.

## 2.2 Introduction

In response to aquatic habitat degradation from human activities and the listing of many Pacific Northwest salmon populations as threatened or endangered under the Endangered Species Act, rehabilitation of salmonid habitats has become commonplace in Washington State and throughout the world (NRC 1992;

Cowx and Welcomme 1998; Roni and Beechie 2013). In an effort to mitigate for degradation and loss of fish habitat from human disturbance and to reverse declines in salmonid populations, a variety of habitat restoration actions—including instream habitat improvement projects—are often undertaken. Placement of instream structures to increase channel complexity, cover, and pool area, and improve spawning and rearing habitat for salmon and other fish is one of the oldest and most common habitat improvement techniques (Tarzwell 1934; Roni et al. 2002, 2008). Common instream habitat improvement techniques include placement of natural structures such as large woody debris (single or multiple logs), constructed or engineered logjams (ELJs), and artificial structures (e.g., weirs, deflectors). Instream structures can be effective at increasing habitat heterogeneity (complexity), pool depth, and woody debris (see Roni et al. 2008, 2015 for detailed review). Similarly, several studies have demonstrated that instream habitat restoration can result in increased reach-scale juvenile salmon and trout abundance particularly for coho salmon *Oncorhynchus kisutch* and other species that prefer pool habitats (Cederholm et al. 1997; Roni and Quinn 2001; Whiteway et al. 2010; Roni et al. 2015). Despite the long history of LWD placement and other structures in streams to improve fish habitat, they remain controversial and little long-term data exists on their effectiveness for species such as Chinook salmon *O. tshawytscha* or interior Columbia River steelhead *O. mykiss* (Roni et al. 2008, 2014; Clark and Roni 2018).

In 2004, SRFB established an effectiveness monitoring program to assess the response of stream habitat and localized salmon populations to the restoration efforts implemented throughout Washington State. Effectiveness monitoring of these restoration projects is critical to evaluate project performance and provide information to better inform future project designs and future funding decisions. As part of the program, monitoring has been conducted on projects from 2004 to the present, with the current phase of the program scheduled to be completed in 2018. Detailed study plans have been prepared for each major restoration category in the SRFB Project Effectiveness Monitoring (PE) Program, including the evaluation of instream structures (MC-2) (Crawford 2011). Here we report the results from all years of monitoring through 2018. The instream habitat project category mostly focuses on instream large woody debris (LWD) and engineered log jam (ELJ) placement, but there are some projects that also include boulder placement, deflectors, and weirs. Rather than examine these artificial instream structures (AIS) separately, we examine instream restoration structure projects collectively and refer to them as instream projects.

The primary monitoring goal is to determine the effectiveness of instream restoration projects and placement of AIS at improving habitat conditions, stream morphology, and fish densities in fish bearing streams by addressing:

1. Have AIS as designed remained in the stream following implementation;
2. Have treatments led to improved stream morphology for the benefit of salmonids; and
3. Has juvenile salmon abundance increased in the impact reach?

## 2.3 Methods

### 2.3.1 Monitoring Design and Replication

Here we provide a summary of the methods and design but refer readers to Crawford (2011) for details. Instream habitat projects were evaluated using a before-after control-impact (BACI) experimental design

(Green 1979; Stewart-Oaten et al. 1986). Each project was monitored one year before implementation (Year 0) and 1, 3, 5, and 10 years after implementation. Occasionally, some projects were monitored by the previous contractor for multiple years prior to project implementation (Year 0*, Year 0**) and in the second year post implementation (Year 2). Sites are at different stages of the monitoring schedule depending on when the restoration (impact) and monitoring was implemented (Table 1).

Projects were initially selected for monitoring from those that had been funded but not implemented for the given baseline sampling year (Figure 1). All site selection and data collection prior to 2017 were conducted by the previous contractor (Tetra Tech 2016). Study sites ranged in average wetted width from 1.2 m to 31.5 m and in elevation from 3 m to 844 m. Annual precipitation at sites varied from 69 cm to 297 cm per year and dominant geology was either sedimentary or volcanic (Table 2). Instream projects had various techniques applied within the project reach ranging from ELJs to single log placement (Table 3; Figure 2). An impact reach was selected within the project area where change was expected to result from project implementation (e.g., LWD installation). A control reach was selected upstream and within close proximity of the impact reach with assistance from project sponsors and regional experts (Figure 2). Selection of adequate controls is critical to account for natural variability occurring at a reach and watershed scale and not the result of project implementation. Monitoring in 2017 included eight instream projects: 04-1338 Lower Newaukum, 05-1533 Doty Edwards, 11-1315 Eagle Island, 11-1354 Lower Dosewallips, SF Asotin Creek Lower 1 and 2, and SF Asotin Creek Upper 1 and 2. Monitoring was not completed for 04-1589 Dungeness River because the control reach had been treated with wood. In 2018, monitoring included six instream projects: 04-1209IS Chico Creek, 04-1660IS Cedar Rapids, 12-1657 George Creek, Tucannon PA-3, Tucannon PA-14, and Tucannon PA-26. Monitoring was not completed for 02-1515 Upper Trout Creek because there was no Year 0 data collected in the impact reach. Monitoring was not completed for 07-1803 Skookum Reach because numerous additional structures were added throughout the impact reach and control reach in recent years. Data were not collected for the 11-1315 Eagle Island project in 2018 because of issues with both the historic data and treatment and control pairing that only became apparent during data collection in 2017. Monitoring in 2017 and 2018 focused primarily to obtain data for Year 5 and Year 10 post-treatment (impact).

**Table 1.** Monitoring schedule for instream projects. Light grey are years where monitoring did not occur. Cramer Fish Sciences took over monitoring in 2017. Year 0* and 0** represent additional years of pre-project data collected at some projects.

| Site ID | Site name | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 02-1444 | Little Skookum Valley | Yr 0 | | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 | | | |
| 02-1463 | Salmon Creek | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 | | | | |
| 02-1515 | Upper Trout Creek | | | | | | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 |
| 02-1561IS | Edgewater Park | Yr 0 | Yr 1 | | | Yr 3 | Yr 5 | | | | | Yr 10 | | | | |
| 04-1209IS | Chico Creek | | Yr 0 | Yr 0* | | | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 |
| 04-1338 | Lower Newaukum | | | | | Yr 0, Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 | |
| 04-1448 | PUD Bar Habitat | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 | | | |
| 04-1575 | Upper Washougal | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 | | | |
| 04-1589 | Dungeness River | | Yr 0 | Yr 0* | | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 | |
| 04-1660IS | Cedar Rapids | | Yr 0 | Yr 0* | | | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 |
| 05-1533 | Doty Edwards | | | Yr 0 | | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 | |
| 07-1803 | Skookum Reach | | | | | Yr 0 | | Yr 1 | | Yr 3 | | Yr 5 | | | | Yr 9 |
| 11-1315 | Eagle Island | | | | | | | | | | Yr 0 | | Yr 1 | | Yr 3 | |
| 11-1354 | Lower Dosewallips | | | | | | | | | | Yr 0 | | Yr 0* | | Yr0** | |
| 12-1334 | Elochoman | | | | | | | | | | Yr 0 | | | | | |
| 12-1657 | George Creek | | | | | | | | | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | | | | | | | | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 | |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | | | | | | | | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 | |
| SF-F4 P1 | SF Asotin Creek Upper 1 | | | | | | | | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 | |
| SF-F4 P2 | SF Asotin Creek Upper 2 | | | | | | | | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 | |
| Tucannon PA-3 | Tucannon PA-3 | | | | | | | | | | Yr 0 | Yr 1 | Yr 2 | Yr 3 | | Yr 5 |
| Tucannon PA-14 | Tucannon PA-14 | | | | | | | | | | Yr 0 | Yr 1 | Yr 2 | Yr 3 | | Yr 5 |
| Tucannon PA-26 | Tucannon PA-26 | | | | | | | | | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 |

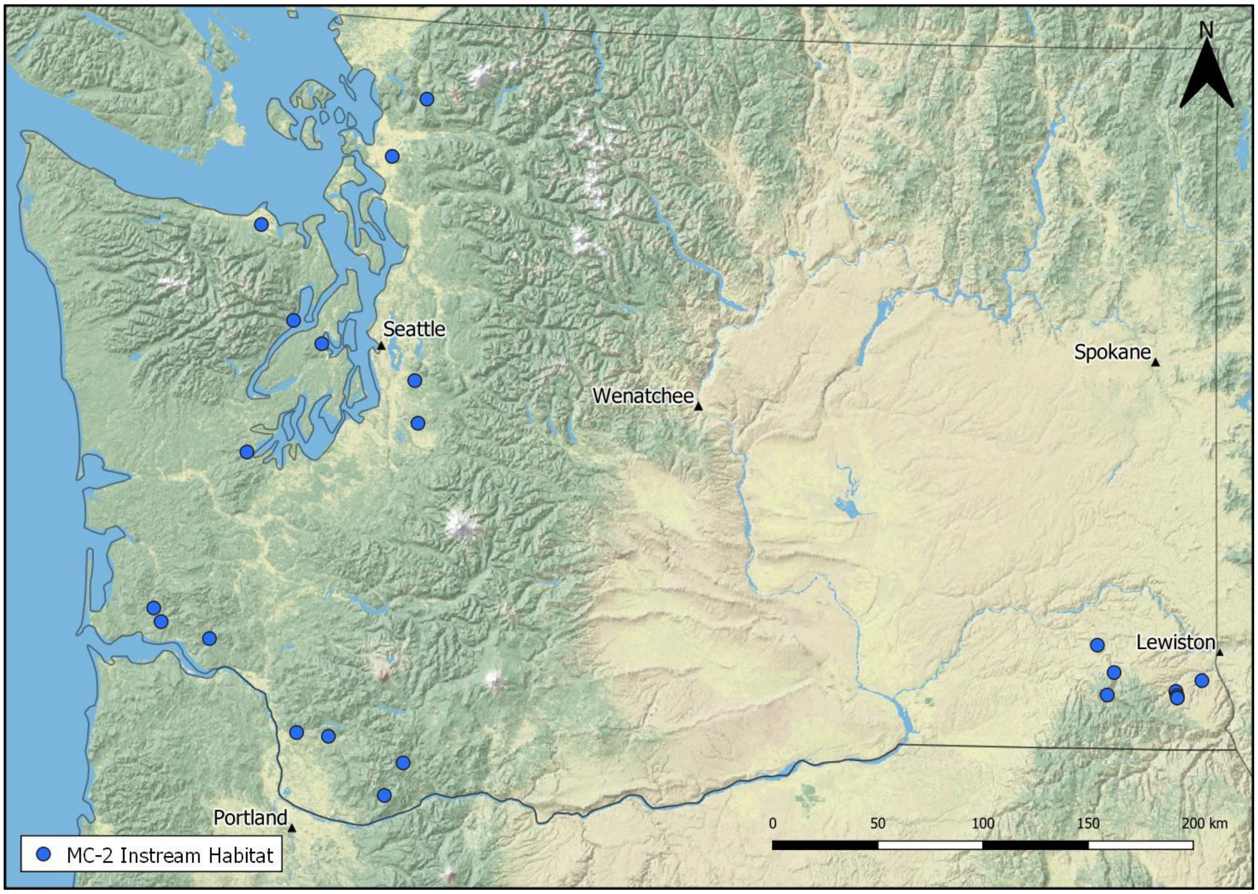


**Figure 1.** Instream habitat project locations monitored throughout Washington.

**Table 2.** Physical characteristics of instream habitat restoration sites. Geology is dominant geology (unpublished Washington State Department of Ecology) where Sed. = sedimentary and Vol. = volcanic. Average annual precipitation was obtained from the USGS StreamStats Program (https://water.usgs.gov/osw/streamstats/). Wetted width (WW) is the average wetted width over all sampling years.

| Site ID | Site name | County | Basin | Year 0 | Geology | Site elev. (m) | Precip. (cm/yr) | Wetted width (m) | Impact site length (m) | Control site length (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 02-1444 | Little Skookum Valley | Mason | Skookum | 2004 | Sed. | 25 | 152 | 1.2 | 150 | 150 |
| 02-1463 | Salmon Creek | Pacific | Naselle | 2004 | Sed. | 114 | 250 | 6.1 | 180 | 180 |
| 02-1515 | Upper Trout Creek | Skamania | Wind | --- | Vol. | 561 | 297 | 12.1 | 360 | 150 |
| 02-1561IS | Edgewater Park | Skagit | Skagit | 2004 | Sed. | 5 | 257 | 6.4 | 318 | 220 |
| 04-1209IS | Chico Creek | Kitsap | Chico | 2005 | Sed. | 12 | 135 | 6.7 | 250 | 250 |
| 04-1338 | Lower Newaukum | King | Green | 2008 | Sed. | 55 | 151 | 7.6 | 220 | 220 |
| 04-1448 | PUD Bar Habitat | Wahkiakum | Grays | 2005 | Sed. | 8 | 285 | 31.5 | 320 | 320 |
| 04-1575 | Upper Washougal | Skamania | Washougal | 2005 | Vol. | 241 | 277 | 22.2 | 500 | 500 |
| 04-1589 | Dungeness River | Clallam | Dungeness | 2005 | Sed. | 58 | 155 | 18.5 | 500 | 500 |
| 04-1660IS | Cedar Rapids | King | Cedar | 2005 | Sed. | 69 | 236 | 23.3 | 400 | 500 |
| 05-1533 | Doty Edwards | Clark | Lewis | 2006 | Sed. | 92 | 195 | 14.0 | 300 | 300 |
| 07-1803 | Skookum Reach | Whatcom | Nooksack | 2008 | Sed. | 116 | 233 | 29.6 | 500 | 500 |
| 11-1315 | Eagle Island | Clark | Lewis | 2013 | Sed. | 3 | 269 | 12.8 | 155 | 165 |
| 11-1354 | Lower Dosewallips | Kitsap | Dosewallips | 2013 | Sed. | 2 | 228 | 42.0 | 500 | 500 |
| 12-1334 | Elochoman | Wahkiakum | Elochoman | 2013 | Sed. | 98 | 246 | 28.2 | 400 | 400 |
| 12-1657 | George Creek | Asotin | Asotin | 2013 | Sed. | 372 | 56 | 5.3 | 160 | 200 |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | Asotin | Asotin | 2012 | Sed. | 570 | 70 | 3.4 | 167 | 181 |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | Asotin | Asotin | 2012 | Sed. | 576 | 70 | 4.0 | 186 | 183 |
| SF-F4 P1 | SF Asotin Creek Upper 1 | Asotin | Asotin | 2012 | Sed. | 716 | 72 | 3.8 | 166 | 178 |
| SF-F4 P2 | SF Asotin Creek Upper 2 | Asotin | Asotin | 2012 | Sed. | 753 | 74 | 4.4 | 156 | 178 |
| Tucannon PA-3 | Tucannon PA-3 | Columbia | Tucannon | 2013 | Sed. | 844 | 90 | 11.3 | 280 | 280 |
| Tucannon PA-14 | Tucannon PA-14 | Columbia | Tucannon | 2013 | Sed. | 634 | 85 | 9.7 | 240 | 280 |
| Tucannon PA-26 | Tucannon PA-26 | Columbia | Tucannon | 2013 | Sed. | 427 | 75 | 11.2 | 320 | 400 |

**Table 3.** Description of treatments implemented at each project and which sites were sampled in 2017 or 2018. 02-1515 Upper Trout Creek and 07-1803 Skookum Reach were dropped from monitoring in 2018 because of issues with impact or control reaches. Target salmonid species were Chinook salmon for the Tucannon sites, and were Chinook salmon, coho salmon, steelhead, and other present salmonids for all other projects.

| **Site ID** | **Site name** | **Description** | **2017** | **2018** |
|---|---|---|---|---|
| 02-1444 | Little Skookum Valley | LWD placement and planting on Little Skookum Creek near Shelton, WA | No | No |
| 02-1463 | Salmon Creek | Channel regrading and LWD placement in Pacific County | No | No |
| 02-1515 | Upper Trout Creek | LWD placement and riparian planting tributary on Wind River | No | No |
| 02-1561IS | Edgewater Park | Side channel creation and LWD placement on Skagit River | No | No |
| 04-1209IS | Chico Creek | LWD placement project near Shelton, WA | No | Yes |
| 04-1338 | Lower Newaukum | LWD placement on tributary to Green River near Auburn, WA | Yes | No |
| 04-1448 | PUD Bar Habitat | Wood and rock veins with planting on Grays River near Roseburg, WA | No | No |
| 04-1575 | Upper Washougal | Sediment trapping ELJs on Washougal River | No | No |
| 04-1589 | Dungeness River | ELJ placement on Lower Dungeness River in Sequim, WA | No | No |
| 04-1660IS | Cedar Rapids | LWD and ELJ placement with planting on Cedar River near Renton, WA | No | Yes |
| 05-1533 | Doty Edwards | LWD and rock placement on Cedar Creek, tributary to NF Lewis River | Yes | No |
| 07-1803 | Skookum Reach | Bank LWD structures on South Fork Nooksack River near Acme, WA | No | No |
| 11-1315 | Eagle Island | LWD and ELJ placements on a side channel of the NF Lewis River | Yes | No |
| 11-1354 | Lower Dosewallips | Levee removal and ELJ placement on the lower Dosewallips River | Yes | No |
| 12-1334 | Elochoman | LWD and rock placement and riparian planting on Elochoman River | No | No |
| 12-1657 | George Creek | LWD placement channel re-meander on tributary to Asotin Creek | No | Yes |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | LWD placement in Asotin Creek IMW | Yes | No |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | LWD placement in Asotin Creek IMW | Yes | No |
| SF-F4 P1 | SF Asotin Creek Upper 1 | LWD placement in Asotin Creek IMW | Yes | No |
| SF-F4 P2 | SF Asotin Creek Upper 2 | LWD placement in Asotin Creek IMW | Yes | No |
| Tucannon PA-3 | Tucannon PA-3 | LWD and ELJ placement in upper Tucannon River | No | Yes |
| Tucannon PA-14 | Tucannon PA-14 | LWD and ELJ placement on middle Tucannon River | No | Yes |
| Tucannon PA-26 | Tucannon PA-26 | LWD placement and levee removal on middle Tucannon River | No | Yes |


**Figure 2.** Impact (left) and control (right) reaches for (a) 04-1209 Chico Creek, (b) 04-1660 Cedar Rapids, (c) Tucannon PA-3, and (d) Tucannon PA-14.

## 2.3.2 Field Methods

The SRFB PE Program uses field sampling indicators and techniques that were adapted from the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) (Lazorchak et al. 1998; Kaufmann et al. 1999; Peck et al. 2003). Specific indicators and protocols were developed in 2003 by the SRFB and modified in 2008 and 2010 by Tetra Tech (Washington Salmon Recovery Funding Board 2003; Tetra Tech 2009; Tetra Tech 2012; Tetra Tech 2017). The detailed protocol used to monitor these projects is Crawford (2011). The protocol includes goals and objectives for the MC-2 instream habitat monitoring category, success criteria, detailed field data collection descriptions, functional assessment methods, summary statistics, and data analysis procedures. Here we provide a summary but refer readers to Crawford (2011) for details.

### *Site Layout*

Once impact and control reaches were selected, the total reach length was calculated using bankfull measurements in the impact reach (Crawford 2011). Five bankfull measurements were recorded and averaged around the center of the reach (X-site). The total reach length was calculated by multiplying the mean bankfull width by twenty (minimum of 150 m and maximum of 500 m). This same reach length was then to be used for the control reach and was to remain the same for each year of monitoring; however, there were several projects monitored by the previous contractor where reach lengths varied among years and were different between the control and impact reaches. Once a site length was calculated, the reach layout was completed by locating Transects A-K (Figure 3). Transects were placed at a distance of one-tenth the average bankfull widths (i.e., if a reach length is 150 m, the distance between transects will be 15 m).

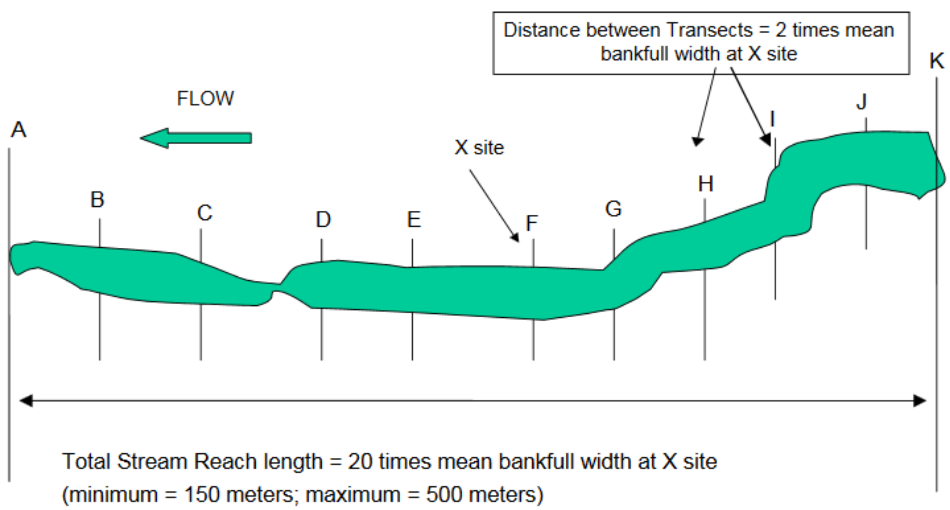


**Figure 3.** Project reach layout as adopted from Crawford (2011).

### *Habitat Surveys*

#### Large Woody Debris (LWD)

Natural and artificially placed LWD was quantified at treatment and control reaches in each site (Crawford 2011). Large woody debris was defined as all pieces within the active or bankfull channel that were greater than or equal to 1 m in length and 10 cm in diameter one-third of the way up from the base. The length, diameter, and if the piece of LWD was placed (either by noting the tag number, anchoring, or if the piece was cut at an end) were recorded for each piece. Only dead pieces were counted, and pieces embedded in the streambank were counted if the exposed portion met the length and width requirements. Between each transect, the length and diameter of the first ten pieces was estimated and measured. Following the initial ten measurements, every 5th (if fewer than 100 pieces in the entire reach) or 10th (if greater than 100 pieces in the entire reach) piece was physically measured while the length and diameter of all other pieces was visually estimated and placed into size classes. Size classes were as follows:

Diameter

- Small: 0.1 m – 0.3 m
- Medium: > 0.3 m – 0.6 m
- Large: > 0.6 m – 0.8 m
- X-Large: > 0.8 m

Length

- Small: 1.0 m < 5.0 m
- Medium: 5.0 m < 15.0 m
- Large: ≥ 15 m

The volume of LWD within the study reach was calculated for analysis using the minimum value of the assigned diameter and length classes (e.g., a small diameter size class and medium length size class were assigned a 0.1 m diameter and 5.0 m length) and the following equation as described in Crawford (2011):

$$LWD\ Volume = \pi \times (1.33 \times \left(\frac{CMD}{2}\right)^2) \times (1.33 \times CML)$$

Where *CMD* is class minimum diameter and *CML* is class minimum length. Pieces of wood that were in the small length size class (1 m to 5 m) were assigned a length of 1.5 m, rather than 1.0 m, which was initiated by the previous contractor and continued by CFS. The calculated area of the base and length are multiplied by 1.33 to account for the average piece of LWD falling somewhere between the minimum length and diameter of its class and the next largest class (Crawford 2011).

The volume of each piece of LWD is calculated using this equation and then the total nominal volume is the sum of all the pieces in the reach. The total nominal value is then multiplied by 100, divided by the total reach length, and the base 10 logarithm is taken to get the final LWD response metric used in the analyses (Crawford 2011).

### Slope and Bearing

The water surface slope and bearing between each transect (A-K) was measured to help calculate mean residual profile depth and vertical pool profile area in each reach (Kaufmann et al. 1999; Crawford 2011). One surveyor stood at the wetted edge of the downstream transect with a stadia rod at a known height. The other surveyor stood on the same bank at the next immediate upstream transect. Using a laser range finder at a known height, the upstream surveyor shot to the downstream transect and recorded the vertical and horizontal difference to calculate the slope between the two transects. Standing mid-channel at the upstream transect, the bearing to the downstream transect at mid-channel was recorded. If there was a meander bend and a full line of sight was not available between transects, a supplementary slope and bearing was recorded between transects (Crawford 2011).

## Characterizing Stream Morphology

A longitudinal thalweg profile survey was used to classify thalweg depth and habitat type (pool, riffle, glide, etc.) at 100 equally spaced intervals along the thalweg between the top and bottom of the sampling reach (Crawford 2011). Wetted widths were measured at 21 equally spaced cross-sections (at 11 primary transects A-K, plus 10 supplemental cross-sections spaced mid-way between each primary transect). For each pool encountered along the thalweg, the pool-tail crest depth, maximum pool depth, and maximum pool width was measured. If a side channel was present and contained between 16 and 49% of the total flow, secondary cross-section transects were established and wetted widths were measured. From the longitudinal profiles, average reach width, thalweg length, vertical pool profile area, and mean residual profile depth were calculated. If a stream was dry at the time of survey, vertical pool profile area, mean residual profile depth, and reach width would be zero.

Vertical pool profile area was calculated using thalweg depths of the channel, the slope of the reach, and the increment, which is the distance between depth measurement stations. At each station, the residual pool profile area was calculated, and the areas are accumulated to determine the mean residual pool vertical profile area in meters squared per reach (Kaufmann et al. 1999). The mean residual profile depth is the vertical pool profile area divided by the total length in meters of the reach, and then multiplied by 100 to get a residual depth of the thalweg (Kaufmann et al. 1999). See Kaufmann et al. (1999) for a detailed description of how these two metrics are calculated.

### *Topographic Surveys*

Beginning in 2012, the previous contractor selected new and old projects to collect topographic data using methodology adopted from the Columbia Habitat Monitoring Program (CHaMP) and available at monitoringmethods.org (e.g., Scientific Protocol for Salmonid Habitat Surveys within the Columbia Habitat Monitoring Program) (CHaMP 2013, 2016; Table 4). The River Bathymetry Toolkit console was also integrated into data processing to produce SRFB EMAP metrics that are compatible with the SRFB PE Program protocol and metrics for consistent use in data analysis (McKean et al. 2009; Tetra Tech 2013). Discrepancies were found between the provided summary tables, Access Database, and the CHaMP database in years where data was collected by the previous contractor; metric values provided in the summary tables were used for analysis in these instances.

### *Fish Surveys*

Snorkel surveys were conducted to quantify the number of fish in each impact and control reach during summer low flow (Crawford 2011). One to four divers, depending on stream width, entered the downstream end of a reach and slowly moved upstream through each transect, stopping to occasionally relay the number, sizes, fish species, and observed micro-habitat characteristics (e.g., slow or fast water, off-channel or side channel habitat, LWD or boulder association). Fish length was visually estimated to the nearest 10 mm. Prior to fish surveys, stream temperature was measured, and visibility was recorded (low, medium, high). Fish species encountered during snorkel surveys included several species of Pacific salmon *Oncorhynchus* spp., sculpin *Cottus* spp., sucker *Catostomus* spp., and dace *Rhinichthys* spp., as well as bull trout *Salvelinus confluentus*, Threespine stickleback *Gasterosteus aculeatus*, and mountain whitefish *Prosopium williamsoni*. The analysis focused on juvenile (<250 mm) Chinook salmon, coho salmon, and steelhead because these fish were the intended target species for the restoration projects (Crawford 2011).

**Table 4.** Project sites and whether they had been monitored using topographic surveys.

| Site ID | Site name | Topo implemented | Monitoring year implemented |
|---|---|---|---|
| 02-1444 | Little Skookum Valley | No | n/a |
| 02-1463 | Salmon Creek | No | n/a |
| 02-1515 | Upper Trout Creek | No | n/a |
| 02-1561IS | Edgewater Park | No | n/a |
| 04-1209IS | Chico Creek | No | n/a |
| 04-1338 | Lower Newaukum | No | n/a |
| 04-1448 | PUD Bar Habitat | No | n/a |
| 04-1575 | Upper Washougal | No | n/a |
| 04-1589 | Dungeness River | No | n/a |
| 04-1660IS | Cedar Rapids | No | n/a |
| 05-1533 | Doty Edwards | No | n/a |
| 07-1803 | Skookum Reach | No | n/a |
| 11-1315 | Eagle Island | 2015 | Year 1 |
| 11-1354 | Lower Dosewallips | 2013 | Year 0 |
| 12-1334 | Elochoman | 2013 | Year 0 |
| 12-1657 | George Creek | 2013 | Year 0 |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | 2012 | Year 0 |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | 2012 | Year 0 |
| SF-F4 P1 | SF Asotin Creek Upper 1 | 2012 | Year 0 |
| SF-F4 P2 | SF Asotin Creek Upper 2 | 2012 | Year 0 |
| Tucannon PA-3 | Tucannon PA-3 | 2013 | Year 0 |
| Tucannon PA-14 | Tucannon PA-14 | 2013 | Year 0 |
| Tucannon PA-26 | Tucannon PA-26 | 2013 | Year 0 |

## 2.3.3 Data Analysis Methods

All projects were evaluated together as a category to assess trends in indicator response from year to year and the change between pre-project (Year 0) and post-project (Year 1, 3, 5, and 10) conditions. Because monitoring began in different years for projects, some do not have the full ten years of monitoring completed as of 2018. Seventeen sites were included in the analysis, six sites were completely excluded for various reasons, and a couple sites had one or two years excluded from analysis (Table 5). Statistical analysis was not conducted on individual projects. Summary data for all individual projects can be found in Appendix B.

### *Vertical Pool Profile Area, Mean Residual Profile Depth, LWD Volume, and Fish Density*

We conducted two basic statistical methods as described in Crawford (2011), previous annual reports (Tetra Tech 2016), and required under our contract. The required analyses include a mean difference analysis and a trend analysis to test whether projects were effective each monitoring year and remained effective through Year 10 (Crawford 2011). In addition, we ran a more robust BACI style analysis where we fit multiple linear mixed-effects models with $\alpha = 0.05$ to test the effect of project implementation on our habitat and fish metrics (Underwood 1992; Downes et al. 2002; Schwarz 2015).

For the mean difference method, the Year 0 values (impact minus control) were compared to each year of post-project (Year 1, 3, 5, and 10) (impact minus control) data using a paired one-sided *t*-test with $\alpha = 0.10$. In addition, if the data was not normally distributed, a paired one-sided nonparametric *t*-test (Wilcoxon) with $\alpha = 0.10$ was used (Crawford 2011). For each response variable, our unit of analysis was the paired difference between the impact reach compared to the control reach for each sample year. The null hypothesis is that the mean of the impact metrics across sites is equal to 0. This analysis was conducted on three habitat response variables (vertical pool profile area, mean residual profile depth, $\log_{10}$ LWD volume) and three fish response variables (juvenile Chinook salmon, coho salmon, and steelhead densities). For the fish analysis, any projects without a species present during any year of monitoring were omitted from that species analysis (e.g., all projects with no Chinook observations across all years sampled were omitted from the Chinook analysis). Year 0*, Year 0**, and Year 2 were not included in this first analysis because they were only collected at a few projects and not a part of the original study design.

For the second method, the slopes of linear trend lines through time (Year 0 to Year 10) (impact minus control for each year) for each indicator, at each project site were estimated. Then, using these slopes, a *t*-test or nonparametric equivalent (Wilcoxon) test with $\alpha = 0.10$ was used to test if the average of the slopes differed from 0 for each metric (Crawford 2011; Tetra Tech 2016; O'Neal et al. 2016). All years of data were included in the second analysis. Sites were excluded from this analysis if there were only two years of data collected. The second analysis was conducted on the same three habitat response variables (vertical pool profile area, mean residual profile depth, $\log_{10}$ LWD volume) and three fish response variables (juvenile Chinook and coho salmon, steelhead densities). For the fish analysis, any projects without a species present during any year of monitoring were omitted from that species analysis (e.g., all projects with no Chinook observations across all years sampled were omitted from the Chinook analysis).

For the additional, more robust BACI style analysis, the model analyzed was:

$$Response\ Metric \sim CI + BA + (BA * CI) + Random(Site) + Random(Year)$$

Where the fixed effects included in the model were reach type (control or impact, CI), time of measurement (before or after impact, BA), and the BACI interaction term (*BA * CI*) (Underwood 1992; Downes et al. 2002; Schwarz 2015). The random effects included in the model were Site and calendar Year sampled to allow for site-to-site variation as well as year-to-year variation. A significant result of the BA*CI term indicates a difference in impact and controls before and after restoration and therefore a positive (or negative) response to restoration. To meet assumptions of normality, a log transformation was applied to the skewed vertical pool profile area and mean residual profile depth data. LWD volume did not need to be transformed. Fish density data was not normally distributed and could not be transformed to meet model assumptions for normal distribution of the model residuals (Shapiro-Wilks test, $\alpha = 0.05$). Therefore, results for fish densities are not reported for the BACI analysis.

**Table 5.** Instream projects and sampling years included in data analysis.

| Site ID | Site name | Pre sampling | Years to include in analysis | Reason for removal |
|---|---|---|---|---|
| 02-1444 | Little Skookum Valley | 2004 | 0, 1, 3 | No Year 5 or 10 since reach lengths changed from 150 to 90 m due to access issues |
| 02-1463 | Salmon Creek | 2004 | 0, 1, 3, 5, 10 | |
| 02-1515 | Upper Trout Creek | n/a | None | No Year 0 data in impact reach |
| 02-1561IS | Edgewater Park | 2004 | None | Reach locations changed since Year 0 |
| 04-1209IS | Chico Creek | 2005, 2006 | 0, 0*, 1, 3, 5, 10 | |
| 04-1338 | Lower Newaukum | 2008 | 0, 1, 3, 5, 10 | Year 5 removed from fish analysis due to inconsistent summary data |
| 04-1448 | PUD Bar Habitat | 2005 | 0, 1, 3, 5, 10 | |
| 04-1575 | Upper Washougal | 2005 | 0, 1, 3, 5, 10 | |
| 04-1589 | Dungeness River | 2005, 2006 | 0, 0*, 1, 3, 5 | No Year 10 since control reach treated |
| 04-1660IS | Cedar Rapids | 2005, 2006 | 0, 0*, 1, 3, 5, 10 | |
| 05-1533 | Doty Edwards | 2006 | None | Control reach length & location changed over time |
| 07-1803 | Skookum Reach | 2008 | 0, 1, 3, 5 | No Year 9 since impact reach re-treated |
| 11-1315 | Eagle Island | 2013 | None | Control reach treated prior to Year 0, little to no wood in impact reach |
| 11-1354 | Lower Dosewallips | 2013, 2015, 2017 | None | No post-project data; not implemented |
| 12-1334 | Elochoman | 2013 | None | No post-project data; not implemented |
| 12-1657 | George Creek | 2013 | 0, 1, 3, 5 | |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | 2012 | 0, 1, 3 | No Year 5 since control reach treated |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | 2012 | 0, 1, 3 | No Year 5 since control reach treated |
| SF-F4 P1 | SF Asotin Creek Upper 1 | 2012 | 0, 1, 3, 5 | |
| SF-F4 P2 | SF Asotin Creek Upper 2 | 2012 | 0, 1, 3, 5 | |
| Tucannon PA-3 | Tucannon PA-3 | 2013 | 0, 1, 2, 3, 5 | |
| Tucannon PA-14 | Tucannon PA-14 | 2013 | 0, 1, 2, 3, 5 | |
| Tucannon PA-26 | Tucannon PA-26 | 2013 | 0, 1, 3, 5 | Year 3 removed from LWD analysis due to inconsistent summary data |

## Decision Criteria

In addition to statistical analysis, minimum management targets (decision success criteria) defined in Crawford (2011) were used to examine project effectiveness. The management decision criteria were set for each metric and include an evaluation of the percent change in the mean differences between impact and control reaches for each analyzed metric. For physical habitat (vertical pool profile area, mean residual profile depth, $\log_{10}$ LWD) and fish metrics (Chinook and coho salmon, steelhead densities) the management decision criteria for success are: 1) a statistically significant change ($\alpha = 0.10$) between impact and control by Year 10 and 2) a positive change of $\geq 20\%$ from Year 0. Because we did not have

Year 10 data for all projects, we also examined whether projects met minimum management targets by Year 5. The following equation was used to determine if a 20% change from baseline occurred for each project:

$$\%\ diff_{site:i,year:j} = \frac{Difference_{i,0} - Difference_{i,j}}{Difference_{i,0}}$$

Percent difference was determined for each site for a given year. Then the average percent difference for a given year was computed by taking the mean of all percent differences (all sites) for a given year:

$$\%\ AvDiff_{year:j} = mean\left(\%\ diff_{i,j}\right)$$

## 2.4 Results

### 2.4.1 Physical Habitat

#### *Mean Differences and Trend Analyses*

There was a large amount of variability in all three physical habitat metrics across years (Figure 4). The impact minus the control reach of all three metrics also varied across years and among sites, with a majority of sites seeing increases when compared to Year 0 (see Appendix B). Vertical pool profile area increased significantly in Year 1 and 3 when compared to Year 0 ($P$ = 0.02 and $P$ = 0.001, respectively), though not in in Year 5 and 10 ($P$ = 0.27 and $P$ = 0.28, respectively; Table 6). Mean residual profile depth increased significantly in Year 1, 3, and 5 when compared to Year 0 ($P$ < 0.08), though not in Year 10 ($P$ = 0.28; Table 6). The linear trend analysis found a significant increase in mean residual profile depth over time ($P$ = 0.10; Table 7), but not vertical pool profile area ($P$ = 0.33; Table 7). When comparing the difference between the control and impact reaches for each year of monitoring using the mean difference analysis, there was a significant increase in $\log_{10}$ LWD volume in each year following project implementation when compared to Year 0 (Table 6). Similar results were found for LWD in the linear trend analysis, where LWD increased significantly over time ($P$ = 0.01; Table 7). Based on the management decision criteria presented in Crawford (2011), by Year 10, instream projects were effective in increasing LWD, though not vertical pool profile area and mean residual profile depth (Table 8).

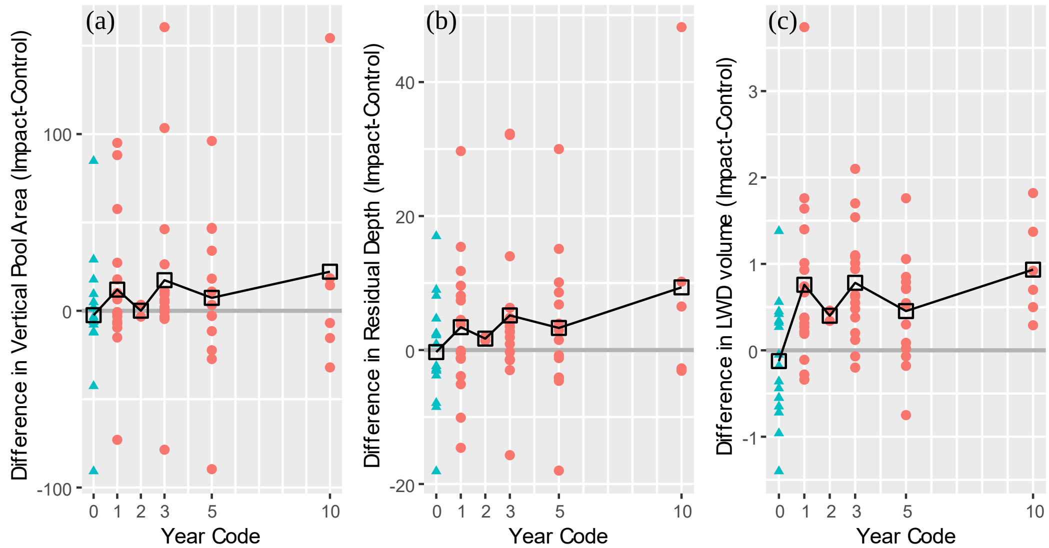


**Figure 4.** Mean difference (line and open squares) for vertical pool profile area (a), mean residual profile depth (b), and $\log_{10}$ LWD volume (c) between the impact and control reaches for instream projects. The blue triangles and red circles represent before (Year 0) and after monitoring data (Year > 0), respectively.

**Table 6.** Summary results for paired one-tailed test of the difference between the impact and control reaches for physical habitat metrics within instream projects. Bolded *P*-values indicate statistical significance (α = 0.10). The mean difference represents the average difference in response between Year 0 (impact minus control) and Year 1, 3, 5, and 10 (impact minus control) for each metric and year combination.

| Metric | Years compared | Sample size (sites) | Test | *P*-value | Mean difference |
|---|---|---|---|---|---|
| Vertical pool profile area ($m^2$) | 0↔1 | 17 | Paired Wilcoxon | **0.02** | 14.4 |
| | 0↔3 | 17 | Paired Wilcoxon | **0.001** | 19.8 |
| | 0↔5 | 14 | Paired Wilcoxon | 0.27 | 9.8 |
| | 0↔10 | 6 | Paired Wilcoxon | 0.28 | 7.8 |
| Mean residual profile depth (cm) | 0↔1 | 17 | Paired *t*-test | **0.03** | 3.7 |
| | 0↔3 | 17 | Paired Wilcoxon | **0.002** | 5.5 |
| | 0↔5 | 14 | Paired *t*-test | **0.08** | 3.2 |
| | 0↔10 | 6 | Paired Wilcoxon | 0.28 | 5.2 |
| $\log_{10}$ LWD volume ($m^3$) | 0↔1 | 17 | Paired Wilcoxon | **0.001** | 0.9 |
| | 0↔3 | 16 | Paired *t*-test | **< 0.001** | 0.9 |
| | 0↔5 | 14 | Paired *t*-test | **0.02** | 0.6 |
| | 0↔10 | 6 | Paired *t*-test | **0.003** | 1.3 |

**Table 7.** Summary results for paired one-tailed test of the linear trend analysis for physical habitat metrics within instream projects. Bolded *P*-values indicate statistical significance (α = 0.10).

| Metric | Sample size | Mean slope of differences (I-C) | Test | *P*-value |
|---|---|---|---|---|
| Vertical pool profile area ($m^2$) | 17 | 0.531 | *t*-test | 0.33 |
| Mean residual profile depth (cm) | 17 | 0.414 | *t*-test | **0.10** |
| $\log_{10}$ LWD volume ($m^3$) | 17 | 0.112 | Wilcoxon | **0.01** |

**Table 8.** Summary of instream project physical success based on management decision criteria outlined in Crawford (2011).

| Metric | Year | *t*-test or Wilcoxon test met | % change from baseline | Sample size (sites, *n*) | $n \geq 20\%$ |
|---|---|---|---|---|---|
| Vertical pool profile area ($m^2$) | 5 | No | 1 | 14 | 8 |
| | 10 | No | 104 | 6 | 3 |
| Mean residual profile depth (cm) | 5 | Yes | 85 | 14 | 8 |
| | 10 | No | 116 | 6 | 3 |
| $Log_{10}$ LWD volume ($m^3$) | 5 | Yes | 188 | 14 | 8 |
| | 10 | Yes | 225 | 6 | 6 |

### Additional Analysis – Mixed-Effects BACI Model

Results from the linear mixed-effects model for vertical pool profile area ($P = 0.02$; Table 9), mean residual profile depth ($P = 0.01$; Table 9), and LWD volume ($P < 0.001$; Table 9) show a significant BACI interaction for all three habitat metrics, with good model fit. These results indicate that there was a significant difference in vertical pool profile area, mean residual profile depth, and LWD volume at impact sites after implementation of the LWD project.

**Table 9.** Fixed effects results from the BACI analysis on vertical pool profile area, mean residual profile depth, and LWD volume. Bolded *P*-values indicate statistical significance. CI = control vs. impact. BA = before vs. after. BA*CI = interaction between CI and BA. A significant result of the BA*CI term indicates a difference in impact and controls before and after restoration and therefore a positive (or negative) response to restoration. df = degrees of freedom.

| Metric | Fixed effect | Estimate | Std. error | df | *t*-value | *P*-value |
|---|---|---|---|---|---|---|
| Vertical pool profile area ($m^2$) | Intercept | 3.215 | 0.250 | 17 | 12.87 | **< 0.001** |
| | CI | 0.187 | 0.076 | 132 | 2.47 | **0.01** |
| | BA | 0.086 | 0.105 | 132 | 0.83 | 0.41 |
| | BA*CI | -0.345 | 0.147 | 132 | -2.34 | **0.02** |
| Mean residual profile depth (cm) | Intercept | 2.235 | 0.159 | 18 | 14.06 | **< 0.001** |
| | CI | 0.241 | 0.073 | 132 | 3.28 | **0.001** |
| | BA | 0.092 | 0.102 | 132 | 0.90 | 0.37 |
| | BA*CI | -0.365 | 0.143 | 132 | -2.55 | **0.01** |
| LWD volume ($m^3$) | Intercept | 0.377 | 0.128 | 25 | 2.95 | **0.007** |
| | CI | 0.695 | 0.086 | 123 | 8.11 | **< 0.001** |
| | BA | 0.081 | 0.127 | 120 | 0.64 | 0.52 |
| | BA*CI | -0.802 | 0.167 | 123 | -4.79 | **< 0.001** |

## 2.4.2 Fish Densities

### Mean Difference and Trend Analyses

Prior to project implementation (Year 0), there was a large amount of variability in fish densities between control and impact reaches, with several sites having low densities of all three fish species analyzed in this report (see Appendix B; Figure 5). The impact minus the control reach of all three fish densities also varied across years and among sites. There were no significant increases in fish densities for any of the three species in any year following project implementation when compared to Year 0 ($P > 0.16$) (Table

10). Similarly, there were no significant changes in the three fish densities over time using the linear trend analysis (Table 11). Based on the management decision criteria presented in Crawford (2011), by Year 10, instream projects are not meeting management decision success criteria for Chinook salmon, coho salmon, or steelhead densities (Table 12).

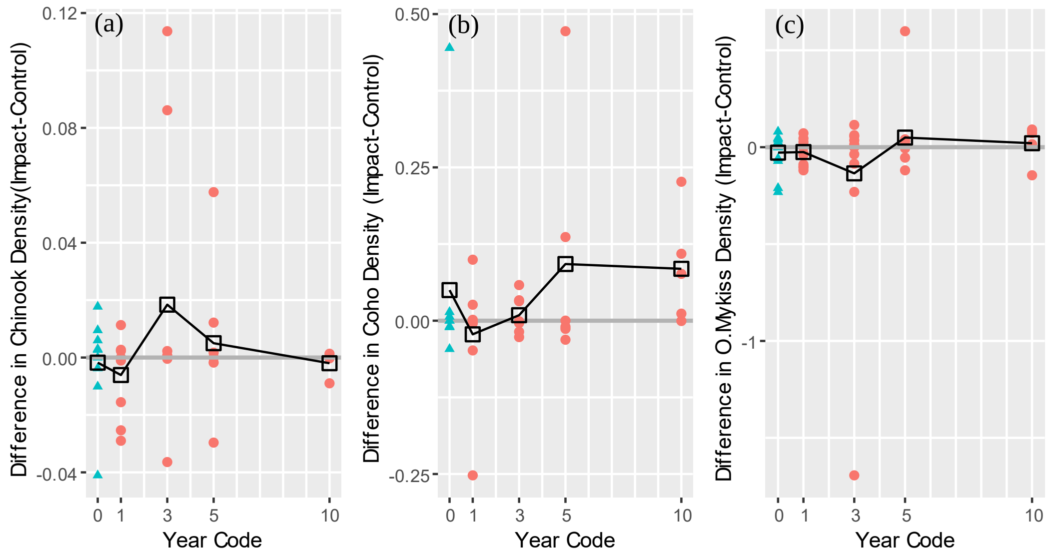


**Figure 5.** Mean difference (line and open squares) for densities of Chinook salmon (a), coho salmon (b), and steelhead (c) between the impact and control reaches. The blue triangles and red circles represent before and (Year 0) after monitoring data (Year > 0), respectively.

**Table 10.** Summary results for paired one-tailed test of the difference between the impact and control reaches for juvenile fish densities within instream projects. The mean difference represents the average difference in response between Year 0 (impact minus control) and Year 1, 3, 5, and 10 (impact minus control) for each metric and year combination.

| Metric | Years compared | Sample size (sites) | Test | *P*-value | Mean difference |
|---|---|---|---|---|---|
| Chinook density (fish/m$^2$) | 0↔1 | 9 | Paired *t*-test | 0.81 | -0.0043 |
| | 0↔3 | 9 | Paired Wilcoxon | 0.50 | 0.0202 |
| | 0↔5 | 8 | Paired Wilcoxon | 0.50 | 0.0073 |
| | 0↔10 | 4 | Paired Wilcoxon | 0.56 | -0.0025 |
| Coho density (fish/m$^2$) | 0↔1 | 8 | Paired Wilcoxon | 0.68 | -0.0721 |
| | 0↔3 | 8 | Paired Wilcoxon | 0.63 | -0.0409 |
| | 0↔5 | 6 | Paired Wilcoxon | 0.42 | 0.0254 |
| | 0↔10 | 5 | Paired Wilcoxon | 0.41 | 0.0057 |
| Steelhead density (fish/m$^2$) | 0↔1 | 17 | Paired Wilcoxon | 0.41 | 0.0078 |
| | 0↔3 | 17 | Paired Wilcoxon | 0.82 | -0.1048 |
| | 0↔5 | 13 | Paired Wilcoxon | 0.20 | 0.0720 |
| | 0↔10 | 6 | Paired Wilcoxon | 0.16 | 0.0444 |

**Table 11.** Summary results for paired one-tailed test of the linear trend analysis for juvenile fish densities within instream projects.

| **Metric** | **Sample size** | **Mean slope of differences (I-C)** | **Test** | ***P*-value** |
|---|---|---|---|---|
| Chinook density (fish/m$^2$) | 9 | 0.0029 | Wilcoxon | 0.50 |
| Coho density (fish/m$^2$) | 8 | 0.0052 | *t*-test | 0.23 |
| Steelhead density (fish/m$^2$) | 17 | -0.0006 | Wilcoxon | 0.28 |

**Table 12.** Summary of instream project biological success based on management decision criteria outlined in Crawford (2011).

| **Metric** | **Year** | ***t*-test or Wilcoxon test met** | **% change from baseline** | **Sample size (sites, *n*)** | ***n* ≥ 20%** |
|---|---|---|---|---|---|
| Chinook density (fish/m$^2$) | 5 | No | 12 | 8 | 3 |
| | 10 | No | -33 | 4 | 1 |
| Coho density (fish/m$^2$) | 5 | No | 138 | 6 | 2 |
| | 10 | No | 568 | 5 | 3 |
| Steelhead density (fish/m$^2$) | 5 | No | 195 | 13 | 6 |
| | 10 | No | -75 | 6 | 5 |

## 2.5 Discussion

A total of 23 instream habitat projects were sampled since 2004, with 17 included in the analysis. Data collection in 2017 and 2018 was focused primarily on getting data five and ten years post-treatment (Year 5 and Year 10). Significant increases in LWD volume in Year 5 and Year 10 and mean residual profile depth in Year 5 were detected. But no significant differences were detected in vertical pool profile area for either year. Moreover, no significant increase in juvenile salmonid abundance (coho and Chinook salmon, steelhead) were found when compared across years. The lack of fish results is most likely because of issues with implementation of the monitoring (e.g., selection of treatments and controls, data collection, timing of sampling), which added additional variability or resulted in several sites having to be excluded. The positive response for LWD volume is expected given that the treatment consisted of placing LWD into the impact reaches. The volume of LWD varied widely among our study streams, which is not surprising given the different amounts of LWD placed in impact reaches, as well as the large study area and variety of ecoregions. As expected, the volume of LWD was higher in impact than control reaches following project implementation, with LWD volume—averaged across post-project years—being over two and a half times higher in impact reaches compared to control reaches. The consistently significantly higher levels of LWD through Year 10 are consistent with other studies which suggest that placed LWD persists for a decade or longer (Whiteway et al. 2010; White et al. 2011; Carah et al. 2014; Roni et al. 2015). Some reaches also continued to increase in LWD volume through the study period, suggesting the recruitment of natural wood into the project reaches.

A common goal related to placement of LWD is the creation and enhancement of slow water habitat. The results for physical habitat for Year 5 are consistent with previous studies evaluating instream structure and LWD placement, which have generally shown an increase in pool depth (Roni and Quinn 2001; Jones et al. 2014, Clark and Roni 2018; see also Roni et al. 2015 for detailed review). Previous studies have documented the positive relationship between natural LWD loading and pool frequency, pool area, and residual pool depth (Beechie and Sibley 1997; Rosenfeld and Huato 2003; Collins et al. 2002; Roni et al. 2015). This type of geomorphic response to natural LWD recruitment or placed LWD may occur within the first year or two depending upon the timing of high flows (e.g., Cederholm et al. 1997; Pess et al. 2012), which is demonstrated in the significant increase measured in the first year following project implementation. Though initial trends (Years 1 and 3 post-treatment) showed a significant increase in geomorphic response to placed structures, the significant response did not remain consistent through Year 5 for vertical pool profile area and Year 10 for both vertical pool profile area and mean residual profile depth, even with LWD volume remaining significantly higher by Year 10. The magnitude of the habitat response may be linked to a variety of factors such as the size and amount of LWD, the longevity of the LWD, the LWD interaction with the active channel, and the geomorphic setting of the LWD (Beechie and Sibley 1997; Jones et al. 2014; Roni et al. 2015; Clark and Roni 2018). Additionally, the response may also be due to the metrics calculated from the SRFB EMAP protocol, which do not directly measure residual pool depth and pool area metrics. These two metrics have been shown to respond positively and consistently to LWD placement (Roni et al. 2015). However, the small sample size of projects with Year 10 data could also lead to the lack of significant increases detected in Year 10 for both vertical pool profile area and mean residual profile depth.

When comparing Year 0 to post-project implementation years, the lack of significant fish response at SRFB instream projects is somewhat surprising given that we detected changes in LWD and some habitat metrics. Pool area and LWD have been shown to be correlated with fish response to instream restoration (Roni and Quinn 2001; Roni et al. 2006; Whiteway et al. 2010; Roni et al. 2015). Failure to detect a significant fish response may simply be related to the fact that fish response is lagging behind the physical response and not enough time has elapsed since restoration has occurred. However, many other studies have found a relatively rapid response of fish to LWD and instream structure placement (Cederholm et al. 1997; Solazzi et al. 2000; Roni and Quinn 2001). Most studies report strong physical response (25 to 50% increase) to LWD placement (see Roni et al. 2015 for a review). The mean responses detected for the physical habitat metrics measured under PE were small and not consistently significant. Given the small increases in vertical pool profile area and mean residual profile depth, it is not surprising that we did not see a large significant fish response. The low sample size for sites with different fish species ($n$ = 6 to 13 for Year 5, $n$ = 4 to 6 for Year 10) may also have contributed to the difficulty in detecting a statistically significant response. If we ignore which year the final year of sampling took place for a site and compare Year 0 to the final year of sampling, sample size increases and we see a significant response from steelhead. This suggests that in addition to correcting some of issues that occurred with data collection and monitoring implementation, larger sample (15+) sizes are likely needed to detect a significant fish response at least with the current protocol and methods (see Table 13 below).

Other factors may also explain the lack of significant response to date. These include sampling only during summer low flow conditions, species and fish sizes sampled, possible issues with selection of control and impact reaches, inconsistent sample timing from year-to-year (e.g., June for one year and October for another), and the lack of stratification by geographic region. SRFB instream projects were typically sampled during summer low flow, with a few sites sampled in late fall, though not consistently across years within and among projects. Other studies that sampled during summer and winter have shown stronger responses of juvenile steelhead and coho during winter months or when examining overwinter survival (Cederholm et al. 1997; Roni and Quinn 2001). Habitat preferences of salmonid species are known to change seasonally (e.g., Bustard and Narver 1975; Nickelson et al. 1992). Thus, we might have detected an increase in fish response had we also sampled during winter or looked at additional life stages. In addition, while juvenile salmonid densities are driven in part by adult escapement and densities of salmonids varied among years and streams, the MBACI design accounts for this by examining the difference between paired treatment and controls in each site (stream). The purpose of the paired control is to help account for interannual variability in escapement and other environmental factors. Thus, it is unlikely that differences in escapement among streams and years prevented us from detected a significant fish response.

Fish response to LWD placement varies by species and life stage, presumably due to differences in habitat preferences (Roni et al. 2002, 2008). For example, juvenile coho salmon are commonly found in pool habitats and often show the largest response to LWD placement while age 1+ steelhead prefer faster water habitats and can be found in riffles and pools (Bisson et al. 1988; Roni and Quinn 2001). Habitat characteristics such as pool area, depth, and quality, and fish cover are important drivers of fish habitat selection and distribution, particularly for species like steelhead and Chinook that are less focused on slow water habitat than coho salmon (e.g., Bisson et al. 1988; Nickelson et al. 1992). Additionally, different salmonid life stages and size classes utilize wood more than others (Whiteway et al. 2010; Pess et al. 2012). For example, Pess et al. (2012) found trout utilizations of engineered log jams to vary by size class, with trout greater than 100 mm significantly associated with wood while trout less than 100 mm were not. Similarly, others have shown differences in trout response to LWD placement for different size and age classes (Cederholm et al. 1997; Solazzi et al. 2000; Roni and Quinn 2001). The SRFB protocol for fish surveys pools all fish less than 250 mm together and we were not able to separate steelhead into different size classes (Crawford 2011). Thus, there may have been differences in response to instream habitat projects among age 0 and age 1+ steelhead that we were not able to examine.

Using a BACI monitoring approach helps to account for environmental variability and temporal trends found in both impact and control reaches to better discern instream structure placement effects from natural variability (Underwood 1992; Roni et al. 2005). However, selection of appropriate controls is critical to increase the probability of detecting restoration response if one exists (Roni et al. 2013). If control and impact reaches are not selected properly and variation is not accounted for in monitoring, there is a risk that the impact might be masked by underlying natural variation (Underwood 1992; Downes et al. 2002; Roni et al. 2005). A control reach should be selected to be as similar as possible in all respects to the impact reach and considered beyond the influence of the treatment (Downes et al. 2002). The underlying assumption is that the impact reach would have behaved approximately the same as the control reach in the absence of the treatment (i.e., LWD placement) (Underwood 1992). However, there were several sites that had issues regarding the control reach selection, which could have ultimately masked significant results. In addition, there were three sites (04-1589 Dungeness River; 05-1533 Doty Edwards, 11-1315 Eagle Island) where the control reach had wood structures placed within the monitoring reach either before or after monitoring was initiated. The 04-1589 Dungeness River site had wood placed in the control sometime after Year 5, and no data after Year 5 for this site was included in the analysis. The 05-1533 Doty Edwards site had wood placed in the lower portion of the control between Year 0 and Year 1 and 11-1315 Eagle Island had wood placed in the control reach prior to any monitoring Year 0 and the impact reach included a portion of the project area with little to no wood placement. Therefore, these two sites were excluded from the analysis, decreasing the overall sample size.

SRFB instream projects monitored covered a large geographic region of Washington State and varied in stream size as well as the amount of wood placed into the stream (single log placement to engineered log jams) and fish species present. The geographic extent of instream habitat sites monitored extended throughout Washington State including east and west of the Cascade Mountains where mean rainfall varied from 56 to 297 cm/yr. Responses may have varied among ecoregions and projects that we were unable to account for, adding additional variability to the data and reducing the possibility of detecting statistically significant responses. Most projects were located in western Washington, with all projects in eastern Washington located in the Asotin and Tucannon basins. We did not have adequate representation of sites in eastern and western Washington to stratify by region, but this should be a consideration for site selection for any future project effectiveness monitoring program.

Finally, we attempted to analyze the data using three different statistical methods including: 1) a mean difference using paired *t*-tests or a non-parametric equivalent (Wilcoxon test), 2) a trend analysis using a *t*-test or a non-parametric equivalent (Wilcoxon test) on the slopes of individual sites, and 3) a mixed-effects BACI model. The first two tests were required as part of the SRFB protocols and our contract, while the mixed-effects model is a more standard approach for analyzing BACI data (Underwood 1992; Downes et al. 2002). We were not able to conduct a mixed-effects BACI model on the fish densities because the data were skewed, and no data transformations yielded an approximately normal distribution. The three analyses produced similar, but not necessarily identical results, with the mixed-effects BACI model yielding significant results for all three habitat metrics (Table 13). In the future, it would be more straightforward to use one statistical test. Each of the three potential ways of analyzing the data have strengths and weaknesses. The paired *t*-test looks only at individual years post-treatment (1, 3, 5, and 10) compared to Year 0. The analysis is structured in this way largely because there is only one year of pre-project data and the response to restoration is expected to change over time. Additionally, taking an average of all post-years and comparing it to Year 0 would mask temporal changes (improvements with time). The trend analysis seems attractive because it can provide insight into temporal changes. However, with only one year of pre-project data, it is highly dependent upon that one year of data for setting the trend. Moreover, while calculating the slope of each individual project and then running a *t*-test on the slopes is not incorrect, it is an unorthodox approach for examining trends in BACI data. The mixed-effects BACI model would appear to be the ideal approach, except that there was only one year of pre-project data. This model works best with a more balanced design and would be most appropriate if there were at least two years of pre-project data (Smokorowski and Randall 2017). Given the design used by the SRFB, we have the most confidence in the paired *t*-test analysis to compare differences between the impact and control before and after restoration. The *t*-test is a simple analysis, easily understood by managers, and is robust to violations of assumptions of normality (Zar 2009). Moreover, we feel *t*-tests are the most appropriate analysis given that there is only one year of pre-project data.

**Table 13.** Summary results (*P*-values) for the different analysis methods (mean difference, trend, and BACI analyses) for instream habitat projects. Bolded *P*-values indicate statistical significance at a 0.10 level. Values in parenthesis next to the *P*-values are the sample size for that analysis. n/a = metric not run through analysis.

| Metric | Mean difference analysis (Year 10) | Trend analysis | BACI analysis | Mean difference analysis (last year sampled) |
|---|---|---|---|---|
| Vertical pool profile area ($m^2$) | 0.28 (6) | 0.33 (17) | **0.02 (17)** | 0.13 (17) |
| Mean residual profile depth (cm) | 0.28 (6) | **0.10 (17)** | **0.01 (17)** | **0.10 (17)** |
| $Log_{10}$ LWD volume ($m^3$) | **0.003 (6)** | **0.01 (17)** | **< 0.001 (17)** | **0.002 (17)** |
| Chinook density ($fish/m^2$) | 0.56 (4) | 0.50 (9) | n/a | 0.50 (9) |
| Coho density ($fish/m^2$) | 0.41 (5) | 0.23 (8) | n/a | 0.50 (8) |
| Steelhead density ($fish/m^2$) | 0.16 (6) | 0.28 (17) | n/a | **0.08 (17)** |

In summary, we detected significant changes in LWD volume following project implementation, which is expected based on the project type. There was not a consistent significant increase in vertical pool profile area and mean residual profile depth by Year 5 and Year 10 of monitoring and no significant increases in fish abundance were detected for juvenile steelhead, coho, or Chinook salmon. While it is tempting to interpret this as the projects monitored were not effective in increasing fish numbers, the lack of results is most likely because of issues with implementation of the monitoring (e.g., selection of treatments and controls, data collection, timing of sampling), which added additional variability or resulted in several sites having to be excluded. Future monitoring of instream projects should consider stratifying projects by ecoregion, seasonal fish sampling (summer and winter), more rigorous selection of treatment and controls, improved habitat survey methods (protocols), and using a more-efficient post-treatment design that does not require collection of pre-project data. However, instream habitat projects, and wood placement in particular, have been relatively well evaluated (Roni et al. 2015; Clark and Roni 2018). A focused, well-controlled study examining different levels of wood loading may be warranted to assist with specific project design questions and guidance.

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# CHAPTER 3. MC-4 LIVESTOCK EXCLUSION

## 3.1 Summary

In 2004, the Salmon Recovery Funding Board (SRFB) established a standardized effectiveness monitoring program to consistently assess the response of stream habitat and localized salmon populations to restoration efforts. The SRFB Project Effectiveness Monitoring (PE) Program included monitoring and evaluation of livestock exclusion (MC-4). The Oregon Watershed Enhancement Board (OWEB) in partnership with the Washington Salmon Recovery Funding Board (SRFB) developed the coordinated monitoring program for livestock exclusions in 2006 to combine monitoring efforts across state jurisdictions. This partnership leverages the investment of both states to increase the sample size of livestock exclusion projects evaluated, while at the same time reducing costs for each agency. Data from 12 livestock exclusion projects was collected using a before-after control-impact design (BACI). Project selection, impact and control reach identification, and data collection prior to 2017 were done by a previous contractor. Cramer Fish Sciences collected the final year of data in 2017. This chapter summarizes the data collected and results for those projects. We used a combination of paired *t*-tests, regression analysis, and mixed-effects BACI models to analyze data. Results indicate that livestock exclusion projects significantly reduced bank erosion and improved riparian structure by Year 10, but we found no significant effects of livestock exclusion on bank canopy cover or pool tail fines. However, the mean percentage of pool tail fines was lower in all impact reaches. The reduction in bank erosion is consistent with previous studies on livestock exclusions, which have generally shown decreases in bank erosion and increases in riparian vegetation structure and shade. It is possible that canopy cover may continue to improve in impact reaches with continued livestock exclusion. However, the lack of change in canopy cover and fine sediment are likely the results of several factors including: evidence of livestock grazing in many impact reaches, livestock exclusion in control reaches, limitations of the riparian sampling protocols, and additional noise due to some control reaches that were not well matched with impact reaches. Many projects had intact fencing, but there were several instances where gates were left open, the fence was in the lay down position, or cattle were accessing the reach from upstream or downstream of the project location. Future efforts monitoring livestock exclusion projects should focus on implementation (compliance) monitoring to ensure livestock are excluded, more rigorous selection of control reaches, and improved riparian and instream sampling that more accurately measures changes in vegetation structure, shade, and channel conditions. Finally, there is fairly extensive documentation of improvement in riparian vegetation and instream habitat conditions if livestock are properly excluded, but limited information on effects of livestock exclusion on fish and other aquatic biota. Therefore, future effectiveness monitoring of livestock exclusion projects should also be designed to evaluate the response of fish, macroinvertebrates, and other aquatic biota.

## 3.2 Introduction

Livestock grazing near streams has led to the degradation of riparian and stream habitats throughout the world (Platts 1991; Belsky et al. 1999; Medina et al. 2005). Livestock grazing directly affects riparian zones by decreasing riparian vegetation through trampling and consumption, leading to increased bank erosion and fine sediment, degraded stream habitats, and impaired riparian and stream processes (Platts

1991; Belsky et al. 1999; Roni et al. 2002). Reduced shade, cover, pool area and depth, and increasing water temperatures and fine-sediment deposition from riparian grazing negatively impact salmonids and other fishes (Platts 1991; Sievers et al. 2017). Complete exclosures that are properly constructed and maintained can be effective at protecting banks and riparian vegetation from livestock grazing and other activities, leading to passive short- and long-term riparian habitat recovery and improved riparian vegetation conditions as well as reduced bank erosion, channel width, and fine sediment levels (Medina et al. 2005; Ranganath et al. 2009; Roni et al. 2014; Batchelor et al. 2015). Increased riparian vegetation, density, and structure within an exclosure provide several advantages. First, more riparian vegetation and overhanging banks are associated with a decrease in width:depth ratio (Magilligan and McDowell 1997; Clary 1999; Bayley and Li 2008). These conditions favor age-0 trout (Moore and Gregory 1988) and these improvements to water quality and bank stabilization are strongly associated with salmonid habitat quality (Walling and Webb 1992; Quinn 2005). Second, there is improved physical habitat which can provide protection from predators (Bayley and Li 2008). Finally, exclosures increase feeding opportunities due to invertebrate production in developed vegetated, undercut banks (Rhodes and Hubert 1991; Baxter et al. 2005), and increases in terrestrial invertebrate drift biomass input (Edwards and Huryn 1996). Improved riparian conditions also benefit terrestrial communities through terrestrial-aquatic linkages (e.g., Nakano et al. 1999), and benefit water quality by reducing the influx of sediment (Waters 1995).

Stream restoration efforts are conducted throughout the world to enhance or restore function of aquatic and riparian ecosystems. In the United States, more than a billion dollars is spent annually on stream restoration including livestock exclusion (Bernhardt et al. 2005). The goal of many of these projects is to help recover Pacific salmon listed as threatened or endangered under the Endangered Species Act (NOAA 2015). Restoration of streams affected by livestock access often includes installation of riparian fencing to construct exclosures and achieve maximum protection within grazed landscapes (Medina et al. 2005). Investments in the construction and maintenance of exclosures have been made to improve watershed health within Oregon, Washington, and across the western United States (Platts et al. 1991; Batchelor et al. 2015). Given the level of investment in salmon and trout habitat restoration, there is a need to track and assess the effectiveness of livestock exclusion projects to help guide future restoration and allocation of funds. Effectiveness monitoring of these restoration projects is critical to evaluate project performance and provide information to better inform future project designs through adaptive management (Rinne 1999; Medina et al. 2005).

The Oregon Watershed Enhancement Board (OWEB) and Washington Salmon Recovery Funding Board (SRFB) are both responsible for funding watershed and salmon habitat restoration projects in their respective states. The OWEB strives to conserve and restore crucial elements of natural systems that support fish, wildlife, and people, with an emphasis on restoring salmon and trout throughout the state (OCSRI 1997; OWEB 2003). This comprehensive program works to benefit watershed health and wildlife, including threatened and endangered salmonids, by implementing livestock exclusion projects that improve riparian vegetation. The SRFB provides funding for elements necessary to achieve overall salmon recovery, including habitat projects and other activities that result in sustainable and measurable benefits for salmon and other fish species (https://www.rco.wa.gov/).

The Monitoring Strategy for the Oregon Plan for Salmon and Watersheds and the Washington Comprehensive Monitoring Strategy Monitoring Oversight Committee both outline goals and objectives for monitoring aquatic habitat and the biological effects of restoration (OWEB 2003; Monitoring Oversight Committee 2002). Both states have developed comprehensive, long-term monitoring strategies to identify monitoring needs for restoration actions. A coordinated monitoring approach increases the efficiency of monitoring and results in cost savings. Comparable data collected across a region provides better information to aid resource managers in making decisions regarding listed salmon species, many of which range across state lines. With that in mind, OWEB and SRFB developed the OWEB-SRFB Coordinated Monitoring Program for Livestock Exclusion Projects in 2006 to combine efforts across state jurisdictions and produce coordinated data from a regional perspective.

The OWEB-SRFB Coordinated Monitoring Program for Livestock Exclusions focused on livestock exclusion projects in both Oregon and Washington. Livestock exclusion projects were selected for the Coordinated Monitoring Program because: 1) there was a need to increase the sample size of livestock exclusion projects monitored to improve the design and analysis; 2) there was a need in Oregon to monitor a sub-sample of the large number of livestock exclusion projects implemented; and 3) there has been significant investment by both states in livestock exclusion projects for the benefit of salmonids. Livestock exclusion projects were monitored in both Oregon and Washington, and funding for monitoring and reporting was provided jointly by both states. These data have been combined for analysis in this report, resulting in a regional representation of the effectiveness of this project type. This coordination has resulted in a larger sample size, allowing for more robust data analysis at a reduced cost to both states.

The primary goal of livestock exclusion projects is to exclude livestock from riparian areas where the animals can cause significant damage to the stream (e.g., by breaking down streambanks, increasing sedimentation, and damaging shade-producing trees and shrubs), and to allow or enhance recovery where damage has occurred. By excluding livestock, adverse impacts can be avoided, and natural recovery of vegetation can take place (Crawford 2011). The monitoring goal is to determine the effectiveness of livestock exclusions at improving riparian conditions along fish bearing streams by addressing:

1. Are livestock excluded from the riparian area;
2. Has treatment led to improvements in riparian condition including cover, shade, and structure;
3. Has bank erosion been reduced in the treatment (impact) reach; and
4. Are fine sediment levels reduced in the treated reach?

## 3.3 Methods

### 3.3.1 Monitoring Design and Replication

The details of the methods and monitoring design are provided in Crawford (2011). Here we provide a summary of the design but refer readers to Crawford for details. Livestock exclusion projects were evaluated using a before-after control-impact (BACI) experimental design (Green 1979; Stewart-Oaten et al. 1986; Downes et al. 2002). Each project (impact) and control sites were monitored before (Year 0) and after implementation on a rotating schedule (Years 1, 3, 5, and 10). The site selection and data collection for Years 0 to 5 for all projects and in Year 10 for 04-1655 Hoy and 02-1498 Abernathy were conducted by a previous contractor (Tetra Tech). Cramer Fish Sciences was contracted to complete data collection in Year 10 for remaining projects.

Projects were selected from those that had been funded by OWEB or SRFB but had not yet been implemented for the given baseline sampling year (Figure 6). Study sites ranged in wetted width from 2 m to 60 m and in elevation from 9 m to 1,463 m. Annual precipitation was highly variable among sites and dominant geology was either volcanic or sedimentary (Table 14). Livestock exclusion projects had fencing applied to a portion of the stream and occasionally were paired with riparian planting or instream work (Table 15). An impact reach was selected within the project area where change was expected to result from the project (e.g., the exclosure area). With assistance from grantees and project sponsors, a control reach was selected upstream and, when possible, in close proximity to the impact reach. These reaches were often on adjacent properties and permission to access both the impact and control reaches over time was gained prior to sampling. Potential control sites were examined, and it was determined in the field if they were suitable (similar to the impact reach prior to livestock exclusion). A control reach should be as similar as possible to the impact reach (i.e., cattle grazing should continue to occur within the control reach). Selection of adequate controls is critical to account for natural variability in riparian and stream habitat that is occurring throughout a stream and not the result of livestock exclusion. Details of site selection and identification of impact and control reaches can be found in Tetra Tech (2009).

Once the control and impact reaches were established, each reach was monitored for one year before implementation (Year 0) to collect baseline data that reflect pre-existing conditions. Following project implementation, those same reaches were surveyed on a rotating schedule (Year 1, 3, 5, and 10) to assess changes that result from the project.

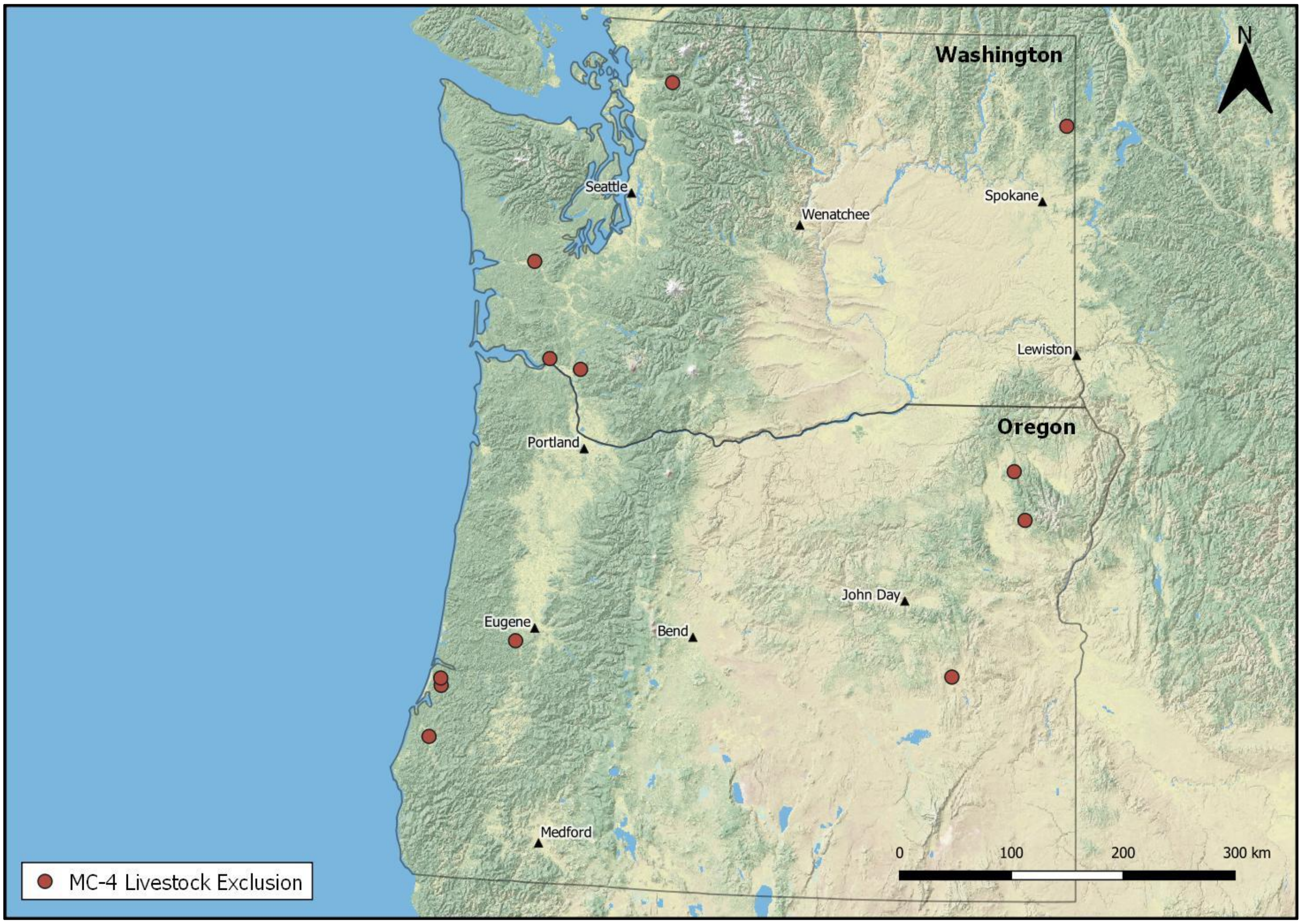


**Figure 6.** Livestock exclusion project locations monitored throughout Oregon and Washington.

**Table 14.** Physical characteristics of livestock exclusion study sites. Geology is dominant geology (unpublished Washington State Department of Ecology) where Sed. = sedimentary and Vol. = volcanic. Yearly precipitation was obtained from the USGS StreamStats Program. Wetted width (WW) is the average of the wetted width measurements over all sampling years.

| Site ID | Site name | County (State) | Basin | First year sampled | Geology | Site elev. (m) | Precip. (cm/yr) | WW (m) | Site length (m) |
|---|---|---|---|---|---|---|---|---|---|
| 02-1498 | SRFB: Abernathy | Cowlitz (WA) | Abernathy | 2004 | Vol. | 27 | 202 | 6.0 | 240 |
| 04-1655 | SRFB: Hoy Riparian | Skagit (WA) | Skagit | 2005 | Sed. | 34 | 267 | 60.0 | 210 |
| 04-1698 | SRFB: Vance | Grays Harbor (WA) | Chehalis | 2006 | Sed. | 12 | 168 | 5.0 | 150 |
| 05-1447 | SRFB: Indian Creek-Yates | Pend Oreille (WA) | Indian | 2006 | Sed. | 744 | 93 | 5.3 | 160 |
| 05-1547 | SRFB: Rauth Coweeman | Cowlitz (WA) | Coweeman | 2006 | Vol. | 73 | 151 | 2.7 | 150 |
| 205-060a | OWEB: Bottle | Union (OR) | Grande Ronde | 2006 | Vol. | 1,463 | 89 | 4.0 | 150 |
| 205-060b | OWEB: NF Clark | Union (OR) | Grande Ronde | 2006 | Vol. | 1,387 | 86 | 2.0 | 150 |
| 206-072 | OWEB: Greys | Coos (OR) | Coquille | 2006 | Sed. | 9 | 160 | 3.3 | 150 |
| 206-095 | OWEB: Jordan | Lane (OR) | Long Tom | 2006 | Sed. | 143 | 132 | 2.8 | 150 |
| 206-283a | OWEB: Johnson | Coos (OR) | Johnson | 2006 | Sed. | 21 | 193 | 4.5 | 150 |
| 206-283b | OWEB: Noble | Coos (OR) | Tenmile Lakes | 2006 | Sed. | 24 | 194 | 2.0 | 150 |
| 206-357 | OWEB: MF Malheur | Harney (OR) | Malheur | 2006 | Sed. | 1,073 | 54 | 8.0 | 375 |

**Table 15.** Description of treatments implemented at each livestock exclusion project.

| Site ID | Site name | Description |
|---|---|---|
| 02-1498 | SRFB: Abernathy | Install 5,000 ft of fencing combined with riparian plantings |
| 04-1655 | SRFB: Hoy Riparian | Install fencing and riparian plantings along 3,218 m of stream |
| 04-1698 | SRFB: Vance | Fence and plant a 25-ft buffer along 7,644 m of stream |
| 05-1447 | SRFB: Indian Creek-Yates | Fence and seed 965 m of stream bank; passage improvements |
| 05-1547 | SRFB: Rauth Coweeman | Fence 1,207 m of stream and install instream and passage improvements |
| 205-060a | OWEB: Bottle | Replace temporary electric fence with barbed wire “let-down” fence along 2,000 ft of stream |
| 205-060b | OWEB: NF Clark | Replace temporary electric fence with barbed wire “let-down” fence along 2,400 ft of stream |
| 206-072 | OWEB: Greys | Install fencing along both sides of the creek for approximately 1,981 m |
| 206-095 | OWEB: Jordan | Install fence along creek, establish off-channel watering, remove and control blackberry, revegetate with native plants |
| 206-283a | OWEB: Johnson | Install fencing along stream bank |
| 206-283b | OWEB: Noble | Fence and plant riparian area along stream |
| 206-357 | OWEB: MF Malheur | Install fencing along 1 mile of river, instream structures, bank contouring and revegetation |

## 3.3.2 Field Methods

The OWEB-SRFB Coordinated Monitoring Program for Livestock Exclusion Projects uses field sampling indicators and techniques that were adapted from the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) (Lazorchak et al. 1998; Kaufmann et al. 1999; Peck et al. 2003) and from Oregon Department of Fish and Wildlife's Methods for Stream Habitat Surveys (Moore et al. 2008). The detailed Crawford (2011) protocol includes goals and objectives for the monitoring category, success criteria, detailed field data collection descriptions, functional assessment methods, summary statistics, and data analysis procedures.

### *Site Layout*

Once impact and control reaches were selected, the total reach length was calculated using bankfull measurements in the impact reach (Crawford 2011). Five bankfull measurements were recorded and averaged around the center of the reach (X-site). The total reach length was calculated by multiplying the mean bankfull width by twenty (minimum of 150 m and maximum of 500 m). This same reach length was then used for the control reach and was to remain the same for each year of monitoring. Once a site length was calculated, the reach layout was completed by locating Transects A-K (Figure 7). Transects were placed at a distance of one-tenth the average bankfull widths (i.e., if a reach length was 150 m, the distance between transects was 15 m).

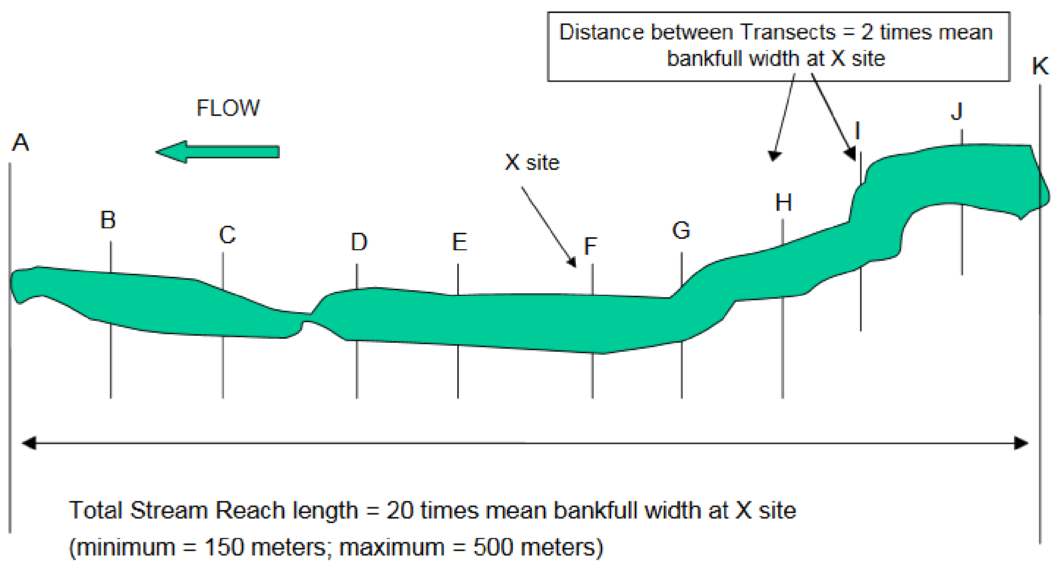


**Figure 7.** Project reach layout as adopted from Crawford (2011).

### *Bank Erosion*

The lineal distance that was actively eroding along each bank was estimated between Transects A-K (Crawford 2011). Active erosion was defined as actively eroding or collapsing banks. The percent bank erosion between each transect on both banks was then averaged across the reach.

### *Riparian Vegetation Structure*

At both the right and left banks at each Transect A-K, a plot measuring 5 m upstream and downstream and a distance 10 m back from the stream bank, into the riparian vegetation, was estimated. This created a 10-m x 10-m survey area on both banks at each transect. Within the area, vegetation was visually divided into three distinct layers: the canopy layer (>5 m high), the understory layer (0.5 to 5 m high), and the ground cover layer (<0.5 m high) (Crawford 2011).

Within the canopy layer, the dominant vegetation type was first determined as either deciduous, coniferous, broadleaf evergreen, mixed, or none. The aerial cover of large trees (>0.3 m diameter breast height (DBH)) and small trees (<0.3 m DBH) was also visually estimated in the canopy layer. Aerial cover was determined as the amount of shadow that would be cast by that particular layer of the riparian zone if the sun was directly overhead. Cover percentages were grouped into varying cover classes (0 = absent or 0%, 1 = <10%, 2 = 10%-40%, 3 = 40%-75%, or 4 = >75%) (Crawford 2011).

The dominant vegetation type was also determined in the understory layer as done in the canopy (Crawford 2011). In the understory and ground cover layers, aerial cover class was determined for woody shrubs and non-woody vegetation rather than large and small trees, as was done in the canopy layer. Cover percentages were grouped similarly to the canopy layer. Finally, in the ground cover layer, aerial cover was also estimated for bare ground and duff. All steps were repeated on the right and left bank at each transect.

Riparian vegetation structure was then summarized for analysis as the proportion of each reach containing all three layers of riparian vegetation (canopy, understory, and ground cover) (Crawford 2011). A layer was counted as containing riparian vegetation if either of the two vegetation types (canopy: small or large trees; understory/ground: woody and non-woody vegetation) were present (greater than 0%). The percentage of the 22 possible locations (right and left bank at Transects A-K) in the reach that had each of the three layers of riparian vegetation present was then calculated. If any layer at a measurement location was absent, this location did not contribute to the percentage of riparian vegetation structure within the reach.

### *Canopy Cover Density*

Canopy cover was determined at each Transect A-K using a convex spherical densiometer. The densiometer was taped so that there was a “V” at the bottom and there were 17 visible grid intersections (Mulvey et al. 1992; Figure 8). Six measurements were taken at each transect: four from mid-channel (facing upstream, river left, downstream, and river right) and one at each wetted edge facing away from the main channel (Crawford 2011). The densiometer was held level at 0.3 m above the water level with the recorder’s face just below the apex of the taped “V”. The number of grid intersection points that were covered by a tree, leaf, high branch, or any other shade-providing feature (i.e., reed canary grass *Phalaris arundinacea*, river bank, bridge or other fixed structure) was counted. The value (0-17) was then recorded. For each project and within each reach, canopy cover density was averaged across all transects, for measurements taken on the right and left banks only, to get a mean value for each monitoring year. The mean canopy cover density from each year of monitoring was then used in the statistical analysis.

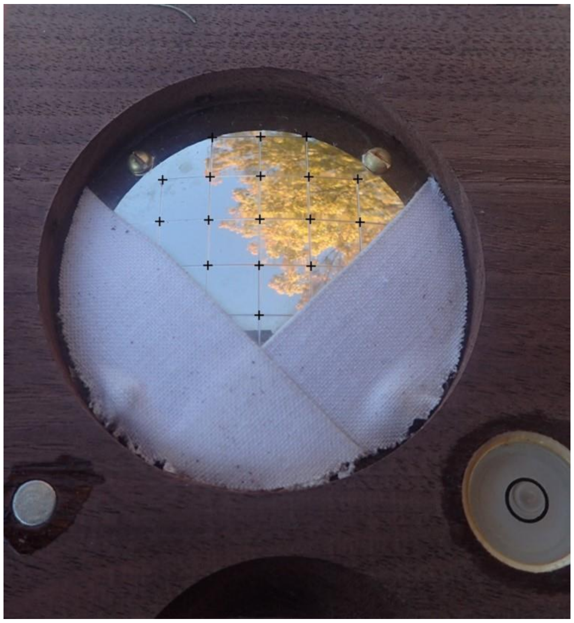

**Figure 8.** Image of modified densiometer and the remaining 17 grid intersections. In this example, 12 of the 17 intersections show canopy cover, giving a densiometer reading of 12.

### *Pool Tail Fines*

In Year 10 monitoring, measurements for percentage of fine sediment in the pool tail were taken in the first ten scour and plunge pools of each reach. If ten qualifying pools were not in the reach, the total number of qualifying pools was sampled. Pools considered for measurement had to meet the following criteria: 1) main channel pool, not a backwater or side channel; 2) span at least 50% of the wetted channel width at any one point; and 3) maximum pool depth is at least 1.5 times the pool tail depth (Crawford 2011). It should be noted that while pool tail fines are part of the protocol for livestock exclusion projects described by Crawford (2011), they were not collected prior to 2017 at any of the sites.

A 35-cm x 35-cm grid with 49 evenly distributed intersections, with the top right corner included for a total of 50 intersections, was used to measure pool tail surface fines (Crawford 2011). The grid was placed at 25, 50, and 75% of the distance across the wetted channel and upstream from the pool tail crest at a distance equal to 10% of the pool's length or one meter (Figure 9). The grid was placed following the shape of the pool tail crest, which in small streams grid placements could overlap. At each grid placement, the number of intersections that were underlain with sediment less than 2 mm in diameter and less than 6mm diameter were recorded. The number of grid intersections with sediments less than 2 mm in diameter could not exceed those with intersections less than 6 mm in diameter. Percentage of pool tail fines were summarized for analysis by averaging all pool tail fines collected in each pool across the entire reach.

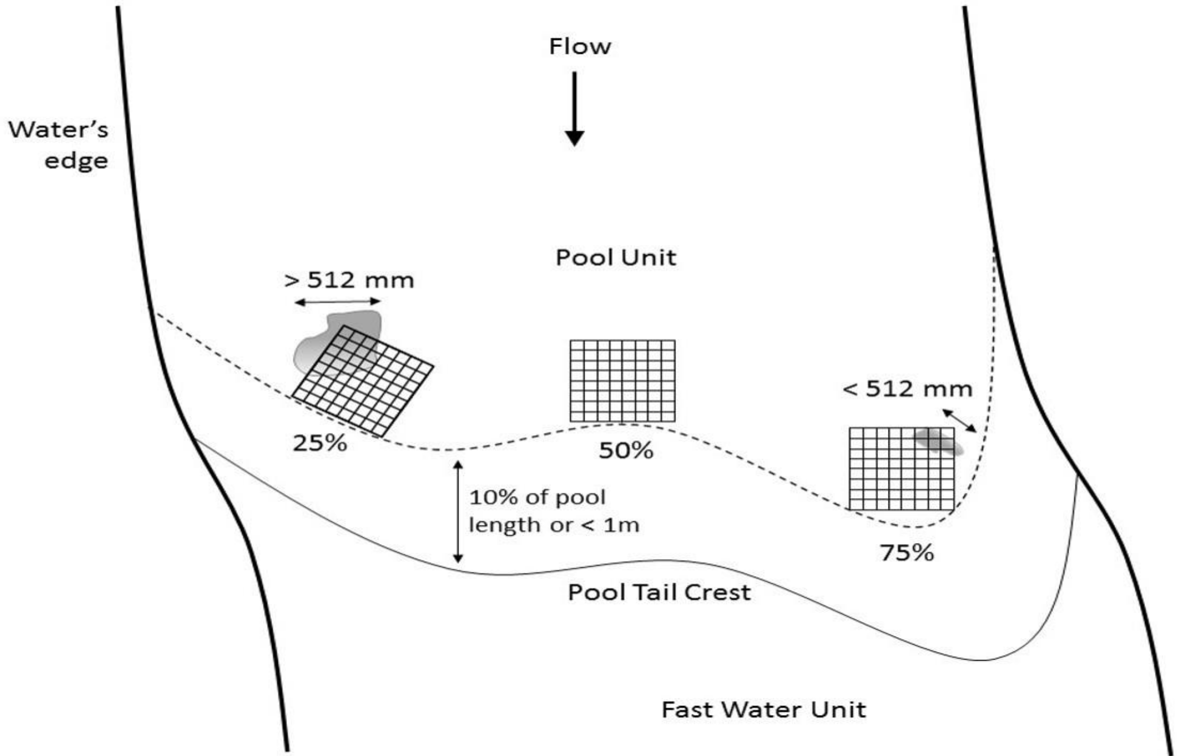


**Figure 9.** Orientation and location of grid placement for pool tail fines measurements as adapted from Crawford (2011).

### *Livestock Presence and Fencing Assessment*

Monitoring data collected at each site also included a functional assessment of the exclusion, including noting signs of livestock presence within the exclusion zone and damage to the exclusion itself. A fence could be intact with no holes or portions knocked down and could still not be functioning if a portion of the fence was not properly set-up (e.g., gates open, in the lay down position). The length of the exclusion was walked to assess for any breaks in the fence or evidence of livestock getting through the fencing. If there were signs of livestock within the exclusion, we estimated the length of the site with evidence of livestock presence and reported this as a proportion of the total site length.

## 3.3.3 Data Analysis Methods

All projects were evaluated together as a category to assess trends in indicator response from year to year, and the change between pre-project (Year 0) and post-project (Year 1, 3, 5, and 10) conditions. Statistical analysis was not conducted on individual projects. Summary data for all projects can be found in Appendix D. See 2017 Final Livestock Exclusion Report for in-depth data summaries by site (Clark et al. 2018).

Sites with data collected in all years following project implementation and two projects (206-072 Gray and 206-283b Noble) with only two or three years of after data were included in the analysis (Table 16). Sampling at the two unfinished sites did not take place because access was denied.

**Table 16.** Livestock exclusion projects and sampling years included in data analysis.

| Site ID | Project name | Year 0 sampling | Years included in analysis |
|---|---|---|---|
| 02-1498 | SRFB: Abernathy | 2004 | 0, 1, 3, 5, 10 |
| 04-1655 | SRFB: Hoy Riparian | 2005 | 0, 1, 3, 5, 10 |
| 04-1698 | SRFB: Vance Creek | 2005 | 0, 1, 3, 5, 10 |
| 05-1447 | SRFB: Indian Creek-Yates | 2006 | 0, 1, 3, 5, 10 |
| 05-1547 | SRFB: Rauth Coweeman | 2006 | 0, 1, 3, 5, 10 |
| 205-060a | OWEB: Bottle | 2006 | 0, 1, 3, 5, 10 |
| 205-060b | OWEB: NF Clark | 2006 | 0, 1, 3, 5, 10 |
| 206-072 | OWEB: Greys | 2006 | 0, 1, 3, 5 |
| 206-095 | OWEB: Jordan | 2006 | 0, 1, 3, 5, 10 |
| 206-283a | OWEB: Johnson | 2006 | 0, 1, 3, 5, 10 |
| 206-283b | OWEB: Noble | 2006 | 0, 1, 3 |
| 206-357 | OWEB: MF Malheur | 2006 | 0, 1, 3, 5, 10 |

### Bank Erosion, Riparian Structure, and Canopy Cover

We conducted both basic analyses described by Crawford (2011), previous annual reports (Tetra Tech 2016), and required under our contract, as well as additional analyses used for analyzing BACI data. The required analyses included a mean difference analysis and a trend analysis to test whether projects were effective each monitoring year and remained effective through Year 10 (Crawford 2011). For the mean difference method, the pre-project values (impact minus control) were compared to each year of post-project data (impact minus control) using a paired one-sided *t*-test with $\alpha = 0.10$. If the data was not normally distributed, a paired one-sided nonparametric *t*-test (Wilcoxon) with $\alpha = 0.10$ was used. For each response variable, our unit of analysis was the paired difference between the impact reach compared to the control reach for each sample year. The null hypothesis is that the mean of the impact metrics across sites is equal to 0. This analysis was conducted on riparian vegetation structure, bank canopy cover, and bank erosion—which were collected in all sampling years. It should be noted that, for Site 04-1655 Hoy which is located on the Skagit River, measurements were only taken on the left bank for all metrics and canopy cover was not recorded in Year 10 (2015) by the previous contractor.

For the second method, the slopes of linear trend lines through time (Year 0 to Year 10) (impact minus control for each year) for each indicator, at each project site were estimated. Then, using these slopes, a *t*-test or nonparametric equivalent (Wilcoxon) test ($\alpha = 0.10$) was used to test if the average of the slopes differed from 0 for each metric (Crawford 2011; Tetra Tech 2016; O'Neal et al. 2016).

### Additional Analysis – Mixed-Effects BACI Model

In addition to the required analysis (Crawford 2011), we ran a more robust BACI style analysis where we fit multiple linear mixed-effects models with $\alpha = 0.05$ to test the effect of cattle exclusion on bank erosion, riparian structure, and bank canopy cover (Underwood 1992; Downes et al. 2002; Schwarz 2015). The model analyzed was:

$$Response\ Metric \sim CI + BA + (BA * CI) + Random(Site) + Random(Year)$$

Where the fixed effects included in the model were reach type (control or impact, CI), time of measurement (before or after impact, BA), and the BACI interaction term (*BA * CI*). The random effects included in the model were Site and calendar Year sampled to allow for site-to-site variation as well as year-to-year variation. A significant result of the BA*CI term indicates a difference in impact and controls before and after restoration and therefore a positive (or negative) response to restoration. To meet assumptions of normality, a square root transformation was applied to the right-skewed bank erosion data. Riparian structure data did not need to be transformed. Bank canopy cover data was not normally distributed and could not be transformed to meet model assumptions for normal distribution of the model residuals (Shapiro-Wilks test, $\alpha = 0.05$). Therefore, results for bank canopy cover are not reported in the BACI analysis results.

### *Pool Tail Fines*

To test whether the mean percent fines (<2 mm and <6 mm) were significantly different between the control and impact reaches, we conducted an extensive post-treatment analysis of a paired two-sided *t*-test with $\alpha = 0.05$ for pool tail fines data collected in 2017. Sites were excluded from the analysis if either the control or impact reach of paired site did not have a pool to collect percent fines (Table 17), thus leaving five projects included in the analysis.

**Table 17.** Livestock exclusion projects sampled in 2017 for percent tail fine sediments.

| Site ID | Project name | Number of plunge and/or scour pools | |
|---|---|---|---|
| | | Impact | Control |
| 04-1698* | SRFB: Vance Creek | 0 | 0 |
| 05-1447* | SRFB: Indian Creek-Yates | 0 | 0 |
| 05-1547 | SRFB: Rauth Coweeman | 1 | 2 |
| 205-060a | OWEB: Bottle | 10 | 1 |
| 205-060b | OWEB: NF Clark | 1 | 1 |
| 206-095* | OWEB: Jordan | 0 | 1 |
| 206-283a | OWEB: Johnson | 6 | 7 |
| 206-357 | OWEB: MF Malheur | 1 | 1 |

*Excluded from the analysis due to lack of sampled plunge and/or scour pools in the control and impact reaches.

## 3.4 Results

### 3.4.1 Bank Erosion, Riparian Structure, and Canopy Cover

There was a significant reduction in bank erosion each year following project implementation when comparing the difference between the control and impact reaches pre- and post-implementation (Figure 10; Table 18). Within the impact reaches, each project either had a decrease of bank erosion or bank erosion remained about the same when comparing Year 0 to Year 10 (Figure 11). The trend analysis also found bank erosion to decrease significantly over time ($P < 0.01$).

Mean percent riparian structure remained relatively stable across the years (Figure 11) and was significantly different in Year 10 when compared to Year 0 (Table 18). The trend analysis also found a significant increase in riparian structure over time ($P = 0.03$). Of the ten projects analyzed, only one project (05-1547 Rauth) had a decrease in percent riparian structure in the impact reach from Year 0 compared to

Year 10 relative to differences found in the control reach, while three projects had no change. One project (206-357 MF Malheur) had no riparian cover in Year 0 through Year 10 (Figure 11).

Finally, mean bank canopy cover fluctuated over the years of sampling (Figure 10). However, only Year 5 was significantly different when compared to Year 0 (Table 18). The trend analysis found no significant increase in bank canopy cover over time ($P = 0.31$). Only three projects out of ten (205-060a Bottle, 206-095 Jordan, and 206-283a Johnson) had increases in bank canopy cover in the impact reaches when comparing Year 0 to Year 10 (Figure 11). Overall, there was a general positive trend in bank canopy cover.

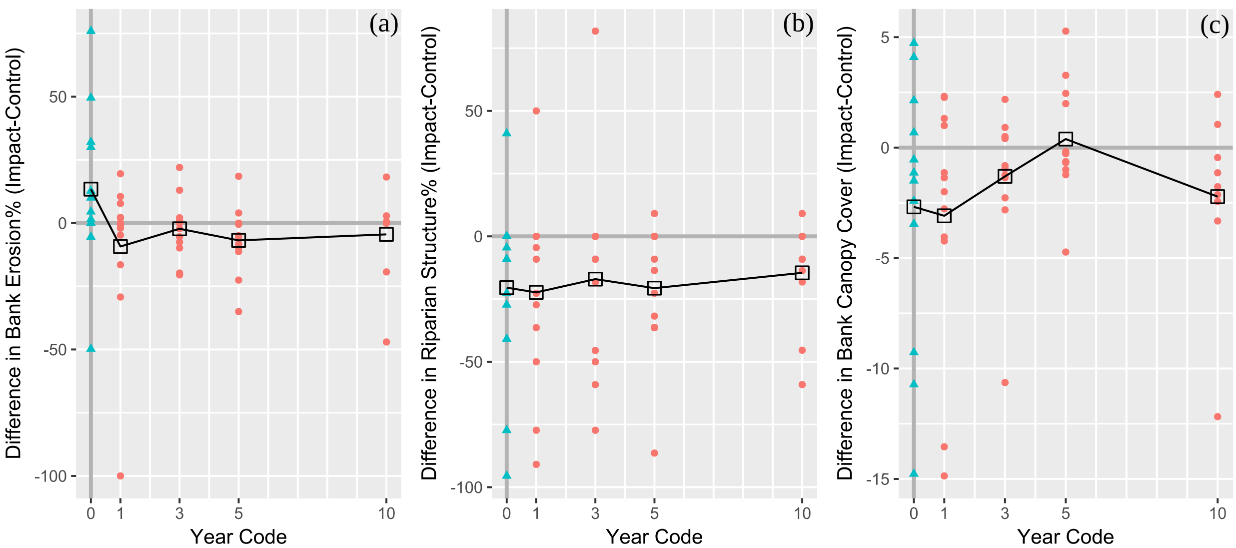


**Figure 10.** Mean difference (line and open squares) for the three measured variables between the control and impact reaches for livestock exclusion projects. The blue triangles represent pre-treatment monitoring data (Year 0) while the red circles represent post-treatment monitoring data (Year > 0).

**Table 18.** Summary results for paired one-tailed *t*-test of the difference between the impact and control reaches for livestock exclusion projects. Bolded *P*-values indicate statistical significance at a 0.10 level. The mean difference represents the average difference in response between Year 0 (impact minus control) and Year 1, 3, 5, and 10 (impact minus control) for each metric and year combination.

| Metric | Years compared | Test | *P*-value | Mean difference |
|---|---|---|---|---|
| Bank erosion (%) | 0↔1 | Paired Wilcoxon | **0.02** | -22.7 |
| | 0↔3 | Paired *t*-test | **0.04** | -15.7 |
| | 0↔5 | Paired *t*-test | **0.03** | -17.0 |
| | 0↔10 | Paired Wilcoxon | **0.01** | -20.6 |
| Riparian vegetation structure (%) | 0↔1 | Paired *t*-test | 0.81 | -1.9 |
| | 0↔3 | Paired *t*-test | 0.28 | 3.4 |
| | 0↔5 | Paired Wilcoxon | 0.82 | 5.4 |
| | 0↔10 | Paired Wilcoxon | **0.04** | 11.4 |
| Bank canopy cover (0-17) | 0↔1 | Paired Wilcoxon | 0.81 | -0.4 |
| | 0↔3 | Paired Wilcoxon | 0.45 | 1.4 |
| | 0↔5 | Paired *t*-test | **0.03** | 3.2 |
| | 0↔10 | Paired Wilcoxon | 0.50 | 0.5 |

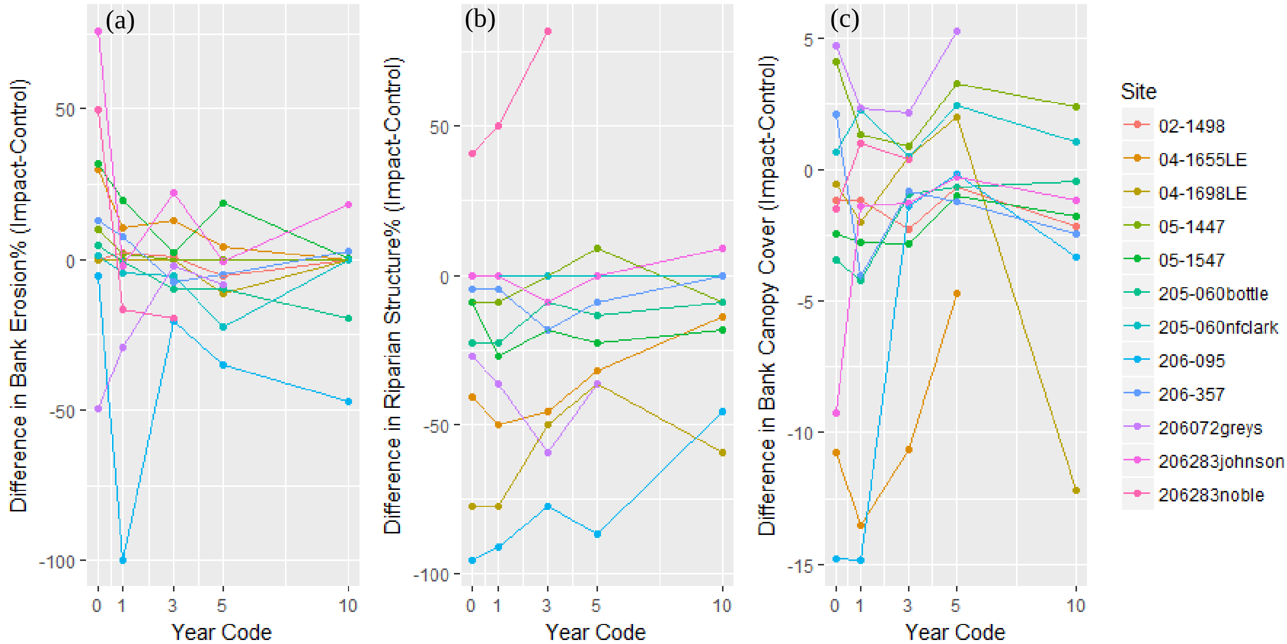


**Figure 11.** Difference between impact and control sites for bank erosion (a), canopy cover (b), and riparian structure (c) across all years sampled for each project.

## 3.4.2 Pool Tail Fines

In 2017, the percentage of fine sediment in the pool tails of the impact and control reaches was not significantly different for sediments less than 2 mm ($P$ = 0.06; Figure 12) and for sediments less than 6 mm ($P$ = 0.054; Figure 12). However, the mean percentage of pool tail fines was lower in all impact reaches than in control reaches.

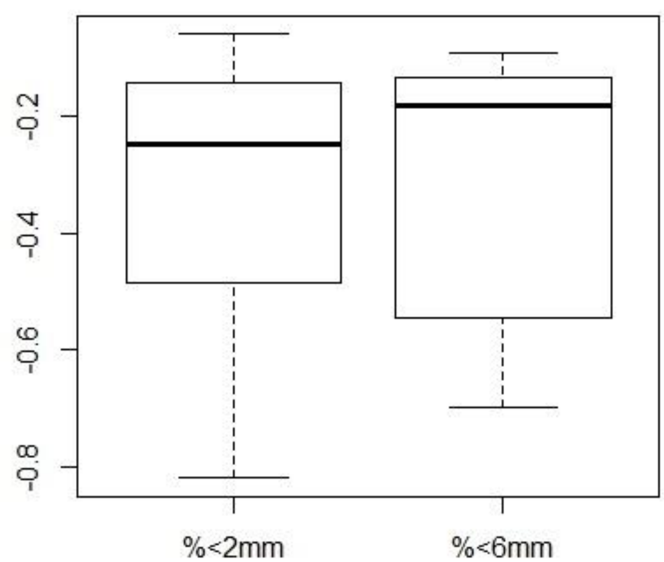


**Figure 12.** Difference in percent pool tail fines between the impact and control reaches in year 10 for sediments less than 2 mm (left) and sediments less than 6 mm (right) across all projects analyzed.

### 3.4.3 Additional Analysis – Mixed-Effects BACI Model

Results from the linear mixed-effects model for bank erosion show a significant BACI interaction ($P$ = 0.03; Table 19), with good model fit. These results indicate that there was a significant difference in bank erosion at impact sites after implementation of the exclusion fencing. Results from the linear mixed-effects model for riparian structure do not show a significant BACI interaction ($P$ = 0.29; Table 19), with good model fit. These results indicate that there was a significant difference between treatments and controls ($P < 0.01$), but no difference before or after implementation of livestock exclusion. The mixed-effects model for bank canopy cover could not be assessed because the data was not normally distributed. No standard transformations of the response variable produced a model with normally distributed residuals.

**Table 19.** Fixed effects results from the BACI analysis on bank erosion and riparian structure. Bolded *P*-values indicate statistical significance. CI = control vs. impact. BA = before vs. after. CI*BA = interaction between CI and BA. A significant result of the BA*CI term indicates a difference in impact and controls before and after restoration and therefore a positive (or negative) response to restoration. df = degrees of freedom.

| Metric | Fixed effect | Estimate | Std. error | df | *t*-value | *P*-value |
|---|---|---|---|---|---|---|
| Bank erosion (%) | Intercept | 2.978 | 0.927 | 14 | 3.21 | **0.01** |
| | CI | -0.528 | 0.478 | 72 | -1.10 | 0.27 |
| | BA | -0.280 | 1.117 | 48 | -0.25 | 0.80 |
| | BA*CI | 2.356 | 1.029 | 72 | 2.29 | **0.03** |
| Riparian structure (%) | Intercept | 76.247 | 11.80 | 10 | 6.46 | **< 0.01** |
| | CI | -21.138 | 4.087 | 89 | -5.17 | **< 0.01** |
| | BA | 1.115 | 6.239 | 89 | 0.18 | 0.86 |
| | BA*CI | -9.444 | 8.800 | 100 | -1.07 | 0.29 |

### 3.4.4 Livestock Fencing and Fencing Assessment

In each year, except for Year 0, there was at least one project with fencing that was not intact and/or functioning. Projects could have intact fencing and not be functioning if there was a gate open or if fences were in the lay down position, as was seen at several project locations. Over the ten years of post-implementation monitoring, there were several projects that had problems with fencing and showed signs of cattle present within the exclusion area (Table 20).

**Table 20.** Number of projects out of ten projects monitored through Year 10 with fencing not functioning as intended and signs of livestock.

| Exclusion assessment | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|
| Fencing not intact and/or not functioning as intended | 0 | 1 | 4 | 4 |
| Signs of livestock | 1 | 3 | 4 | 4 |

In Year 5, two of the four non-functioning project exclusions were due to fence failure; a tree had fallen on a portion of the fence (205-060a Bottle) and a part of the fence was washed away by an eroding bank (206-357 MF Malheur). The other two projects had either an open gate (206-283a Johnson) or the project was not completed because the landowner had no livestock on the property (02-1498 Abernathy). Though some sites had what looked like intact and functioning fences, there were still signs of cattle within the exclusion area (Table 21). This was seen in Year 3 of monitoring, which had more sites with signs of livestock than non-functioning fencing. It was concluded that livestock were likely entering the site from upstream of the exclosures. Projects 206-095 Jordan and 206-283a Johnson also had fencing found in the control reach, which therefore excluded cattle from the stream and therefore made these poor control reaches.

**Table 21.** Percent of total reach length where evidence of cattle presence was observed in 2017.

| Site ID | Site name | Percent of reach | |
|---|---|---|---|
| | | Impact | Control |
| 05-1447 | Indian Yates | 0 | 0 |
| 205-060a | NF Clark | 18 | 46 |
| 205-060b | Bottle | 73 | 55 |
| 206-283a | Johnson | 0 | 0 |
| 206-095 | Jordan | 62 | 0 |
| 05-1547 | Rauth Coweeman | 0 | 0 |
| 04-1698 | Vance | 0 | 0 |
| 206-357 | Malheur | 0 | 17 |

## 3.5 Discussion

A total of 10 livestock exclusion projects were sampled over the entire post-project monitoring schedule. Results suggest projects are successfully reducing bank erosion and increasing riparian structure by Year 10. However, projects are not improving canopy cover or reducing fine sediments significantly. Our results for bank stability and riparian structure are consistent with previous studies on the recovery of physical habitat following livestock exclusion. In the Pacific Northwest and beyond, livestock exclusion has been shown to increase bank stability (Platts 1991; Kauffman et al. 1997; Medina et al. 2005; Roni et al. 2008; O'Neal et al. 2016), and also to increase riparian vegetation (Sarr 2002; Archibald 2015; Batchelor et al. 2015). Additionally, bank erosion for OWEB-SRFB livestock exclusion projects decreased and riparian structure increased, on average, by more than 20% from Year 0 to Year 10. Thus, based on the Crawford (2011) management targets, livestock exclusion projects were meeting minimum management success targets for bank erosion and riparian structure, but not for any other metrics.

Though several studies demonstrate that livestock exclusion allows for riparian conditions to recover relatively rapidly (Platts 1991; Roni et al. 2002; Sarr 2002; Archibald 2015), we detected no significant change in canopy cover, except for in Year 5. There was an overall positive trend in canopy cover, suggesting that, with time and continued livestock exclusion, this metric may recover and the probability of detecting a statistically significant difference could increase. Our results may have differed from other studies due to natural environmental variables such as soil compaction (Kauffman et al. 1997), connection to a seed source (Katz et al. 2007), and channel incision (Sarr 2002), but could also be related to design issues including: limitations of sampling methods, selection of poorly matched control and impact reaches, inadequate stratification across ecoregions, or failure to adequately exclude livestock.

Percent riparian structure had a gradual response, with statistical significance only in Year 10 with the mean difference analysis, though no significant difference was detected with the more robust mixed-effects model. The inconsistent response in riparian structure may have been due to some limitations of the monitoring protocol. Riparian structure used in OWEB-SRFB monitoring differed from other studies monitoring the response of riparian vegetation to cattle exclusion. Other studies focused on densities of all plant species, plant height, leaf litter accumulation, amounts of bare substrate, and compositional changes (Sarr 2002). Though ground cover (one of the three layers of riparian structure measured in this study) was evaluated in this monitoring program, the riparian structure metric requires improvement in all riparian levels (canopy >5 m, understory 0.5-5 m, and ground cover <0.5 m) to be successful. Natural climatic and other environmental conditions may preclude the growth of vegetation in certain levels (e.g., canopy level), which would result in a conclusion of no riparian improvement even if the riparian area returned to a more natural state. Riparian vegetation structure may not have had a rapid response or improvement may not even be possible at some sites as vegetation must first establish and then grow into all the riparian levels. Moreover, the disturbance history, climate, and site conditions can affect the recovery potential and time for riparian vegetations (Wondzell et al. 2007). For example, site 206-357 MF Malheur in eastern Oregon will likely not grow a dense upper canopy level (>5 m) due to the deeply incised channel, geographic area, and arid climate. Rather, studies that focused on bare soil and overall riparian area at any height measured significant changes in vegetation and plant community development following livestock exclusion (Schulz and Leininger 1990; Robertson and Rowling 2000; Sarr 2002; Hosten and Whitridge 2007; Ranganath et al. 2009). Additionally, if livestock exclusion projects were paired with planting within the design exclosure, one may expect to see more rapid changes in canopy cover, riparian structure, and percent fines than expected with passive riparian habitat recovery.

Similar to our fine sediment results, Ranganath et al. (2009) found no significant difference in the percent fines between grazed and exclusion reaches. However, other studies have found grazed sites to have high amounts of fine sediments when compared to ungrazed sites (Platts 1991; Herbst et al. 2012). Even with decreased bank erosion, instream habitat and fine sediment improvements may be confounded by site location within a watershed, upstream processes, underlying geology, and hydrology that can affect sediment supply (Medina et al. 2005; Allan and Castillo 2007; Roni et al. 2008; Roni et al. 2013a). Fine sediment data was collected only in Year 10 of monitoring and only five sites were included in the analysis due to the low frequency of qualifying pools in both impact and control reaches. Thus, we may not have detected a difference due to low sample size, lack of pre-project data, or control and impact reach inconsistencies. Results may improve with more years of data collection and as banks continue to stabilize with time. However, it would be worth revisiting the protocol for measuring fine sediment and other in-channel features before conducting additional monitoring. Livestock exclusion leads to reduced fine sediments, typically through reduced bank erosion, but also decreased bankfull width, increased depth, and other channel features which should be part of any livestock exclusion effectiveness monitoring.

Using a BACI monitoring approach helps to account for environmental variability and temporal trends found in both impact and control reaches to better discern livestock exclusion effects from natural variability (Underwood 1992; Roni et al. 2005). However, selection of appropriate controls is critical to increase the probability of detecting a restoration response if one exists (Roni et al. 2013a). Finding sites with similar grazing strategies and physical features to serve as control reaches can be quite difficult (Medina et al. 2005). If control and impact reaches are not selected properly and variation is not accounted for in monitoring, there is a risk that the impact (livestock exclusion) might be masked by underlying natural variation (Underwood 1992; Downes et al. 2002; Roni et al. 2005). A control reach should be selected to be similar in all respects (e.g., gradient, bankfull width, channel type, flow, land use, riparian condition) to the impact reach and considered beyond the influence of the treatment (Downes et al. 2002). The underlying assumption is that the impact reach would have behaved approximately the same as the control reach in the absence of the exclusion (Underwood 1992). There were several OWEB-SRFB sites that had issues regarding the control reach selection, which could have ultimately masked significant results. There were two sites (206-095 Jordan and 206-283a Johnson) where the control reach had fencing to exclude livestock, and there were several impact and control reaches that were not impacted by livestock prior to the start of monitoring. This also suggested the need to ensure that control reaches are not treated and remain control reaches throughout the monitoring period. Additionally, control reaches for two sites (04-1655 Hoy and 206-095 Jordan) were selected in a forested area, while the impact reach was not forested. While the BACI design accounts for some of these differences, the inconsistencies among controls and treatments may have increased variability among sites and reduced the ability to detect changes due to livestock exclusion.

To assess environmental responses to livestock exclusions, the exclusions must be present and functioning. Implementation monitoring should be included in future design and monitoring programs and executed alongside any effectiveness monitoring efforts. At 40% of the projects sampled in Year 10, there was evidence of livestock within the exclosure area, suggesting projects were not effective at excluding livestock. Many projects had intact fencing, but there were several instances where gates were left open, the fence was in the lay down position, or cattle were accessing the reach from upstream or downstream of the project location. This was also apparent and reported in previous years (Tetra Tech 2012). Maintenance and repair of damaged fencing is important to continue to exclude livestock (Medina et al. 2005; Roni et al. 2013b), though it appears in several instances it is just the general function of the fencing that needs to be assessed and properly used following project implementation. In absence of detailed effectiveness monitoring of riparian and instream habitat, simple implementation monitoring may be more appropriate for many livestock exclusions projects.

Stratifying sites by geographic or climatic region, channel size, or other factors may help account for differences among livestock exclusion sites. The geographic extent of sites in this program extended from northern Washington to central Oregon and east and west of the Cascade Mountains, where mean annual rainfall varied from 86 to 267 cm/yr. Vegetation type, growing season characteristics, and regional weather patterns varied across this extent and could influence site-specific results. Similarly, land use at the sites varied considerably. For example, site 206- 283a Johnson was historically grazed by a herd of cattle, but site 05-1547 Rauth had a couple of horses that periodically grazed the area. These differences in site use could also influence results through the level of impact the practices had on the site over time. Stratifying by eco-region or site use could help alleviate some of the influences these factors may have on the results and our understanding of the effectiveness of livestock exclusions. Stratifying sites would, however, require a larger sample size and we were not able to stratify sites post-hoc given the small number of sites and broad geographic extent.

We analyzed livestock exclusion data using three different statistical methods including: 1) a mean difference using paired *t*-tests or a non-parametric equivalent (Wilcoxon test), 2) a trend analysis using a *t*-test on the slopes of individual sites, and 3) a mixed-effects BACI model. The first two tests were required as part of the livestock exclusion protocol while the mixed-effects BACI model is a more standard approach for analyzing BACI data (Underwood 1992; Downes et al. 2002). All three of these analyses produced similar, but not necessarily identical results and all have strengths and weakness (Table 22). However, in the future, it would be more straightforward to use one statistical test. The paired *t*-test looks only at individual years post-treatment (1, 3, 5, and 10) compared to Year 0.

**Table 22.** Summary results for the three analysis methods (mean difference, trend, and BACI analyses) for livestock exclusion projects. Bolded *P*-values indicate statistical significance at a 0.10 level. n/a = metric not run through analysis.

| Metric | Mean difference (Year 10) | Trend | BACI |
|---|---|---|---|
| Bank erosion (%) | **0.01** | **0.003** | **0.03** |
| Riparian vegetation structure (%) | **0.04** | **0.03** | 0.29 |
| Bank canopy cover (1-17) | 0.5 | 0.31 | n/a |

The analysis is structured in this way largely because there is only one year of pre-project data and the response to restoration (livestock exclusion) is expected to change over time. Additionally, taking an average of all post-years and comparing it to Year 0 would mask temporal changes (improvements with time). The trend analysis seems attractive because it can provide insight into temporal changes. However, with only one year of pre-project data, it is highly dependent upon that one year of data for setting the trend. Moreover, while calculating the slope of each individual project and then running a *t*-test on the slopes is not incorrect, it is an unorthodox approach for examining trends in BACI data that we have not seen used before. The mixed-effects BACI model would appear to be the ideal approach, except that there was only one year of pre-project data. This model works best with a more balanced design and would be most appropriate if there were at least two years of pre-project data (Smokorowski and Randall 2017). Given the design used by the SRFB and OWEB, we have the most confidence in the paired *t*-test analysis. The *t*-test is a simple analysis, easily understood by managers, and robust to minor violations of assumptions of normality (Zar 2009). Moreover, we feel *t*-tests are the most appropriate given that there is only one year of pre-project data. Thus, the final analysis for the monitoring design used should focus on examining the response in Year 10 compared to Year 0, using a simple paired *t*-test.

The lack of significant differences between the impact and control reaches in this study does not mean that livestock exclusion has not yielded benefits. The exclusion has been effective at decreasing active bank erosion, which overall can yield benefits to instream habitat and to the establishment and growth of riparian vegetation. Overall trends were positive for riparian structure and canopy cover, which may continue to increase with time and continued exclusion. Moving forward, it is important that fencing is maintained and properly used to allow the riparian area and stream habitat to fully recover. Furthermore, our completion of the final year of data collection and analysis of all years of data suggests several recommendations for future effectiveness monitoring of livestock exclusions projects. These include: 1) more rigorous selection of impact and control reaches, 2) improved methods for monitoring riparian vegetation and shade, 3) stratification of sites by ecoregion, and 4) monitoring additional instream morphological and biological metrics. Most studies on livestock exclusions show rapid recovery of riparian habitat if livestock are actually excluded (Dobkin et al. 1999; Platts and Nelson 1985). This suggests that long-term compliance rather than effectiveness monitoring is needed for livestock sites to ensure fencing is functioning properly. Finally, the pressing need for livestock exclusion effectiveness monitoring is data on fish and other aquatic biota, as few livestock exclusion studies have shown a direct connection and positive response for fish, macroinvertebrates, and other aquatic biota (Rinne 1999; Medina et al. 2005; Roni et al. 2014).

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# CHAPTER 4. MC-5/6 FLOODPLAIN ENHANCEMENT

## 4.1 Summary

Floodplain or off-channel habitat restoration has become a critical component of river restoration in Washington State and the Pacific Northwest. In 2004, the Salmon Recovery Funding Board (SRFB) established a standardized effectiveness monitoring program to consistently assess the response of stream habitat and local salmon populations to river restoration efforts. The SRFB Project Effectiveness Monitoring (PE) Program included monitoring and evaluation of floodplain enhancement (MC-5/6) including levee setbacks, reconnection of habitats (ponds, side channels), and creation of off-channel habitats (ponds, side channels). Beginning in 2004, data were collected for 23 floodplain enhancement projects throughout Washington State using a before-after control-impact design (BACI). Project selection, impact and control reach identification, and data collection prior to 2017 were done by a previous contractor. Cramer Fish Sciences was contracted to complete monitoring in 2017 and 2018 and complete the final analysis and recommendations for the MC-5/6 category. This chapter describes the methods, the data collected, final analysis, results, and recommendations from 2004 to 2018. Each project was monitored once before project implementation and then after project implementation on a rotating schedule. Physical habitat (vertical pool profile area, mean residual profile depth, bank canopy cover, riparian vegetation structure, channel capacity, and floodprone width) and juvenile fish density data were collected during summer low flow using SRFB protocols. Because of inconsistencies in data collection across years, including lack of fish and riparian data, sampling in different seasons, and in some cases poorly matched impact and control reaches, data collection for floodplain projects was discontinued after the 2017 field season. Data from all years of monitoring of floodplain projects were analyzed using paired *t*-tests, though data from ten sites were excluded from the analysis because of inconsistencies in data collection or impact and control reaches. Results were highly variable by metric and year with significant changes in vertical pool profile area in Year 1 and 10, mean residual profile depth in Year 1, 5, and 10, average channel capacity in Year 3, and juvenile coho salmon density in Year 1 and Year 5. No significant changes were found for bank canopy cover, riparian vegetation structure, or Chinook salmon and steelhead densities. Adequate sample sizes were not available to analyze floodprone width. The positive changes in vertical pool profile area, mean residual profile depth, and coho salmon density are consistent with previous studies on floodplain restoration. Densities for juvenile fish were low across most sites, with several sites having no fish of a particular species found across several years of sampling. Moreover, the monitoring of fish, channel capacity, and floodprone width was not done consistently within and among projects across years, making detection of differences due to restoration difficult. Because floodplain enhancement projects typically involve a large impact to the riparian conditions, more time post-restoration may be needed for riparian vegetation to establish, colonize, and reach the riparian structure canopy threshold (5 m). Mixed results across all metrics and the inability to assess data using more rigorous statistical methods (mixed-effects models) may be due to a variety of other factors including: sample timing, variability in restoration treatments, need for geographic stratification, and added variability from controls that were not well matched with impact reaches. Floodplain restoration is an important project type in need of additional monitoring. Future PE monitoring of floodplain enhancement projects should consider stratifying projects by ecoregion, seasonal fish sampling (summer, winter), more

rigorous selection of treatment and controls, improved habitat survey methods, and the use of an extensive post-treatment design that does not require extensive collection of pre-project data.

## 4.2 Introduction

Dams, levees, and the development of the floodplain for agricultural, residential, and industrial use have disrupted the natural connection between main channels and their floodplains (Ward and Stanford 1995; Ward et al. 1999). These disturbances alter floodplain inundation and frequency and the input of sediments, nutrients, and wood into the rivers and their floodplains (Junk et al. 1989; Collins et al. 2002), and reduce the availability of habitat for fishes and other aquatic biota (Collins et al. 2002). Salmonids benefit from access to floodplains and slow-water habitats for rearing and spawning, and as a refuge from high water velocities. Floodplain habitats—including off-channel ponds, side-channels, backwaters, and alcoves—are particularly important to juvenile coho salmon *Oncorhynchus kisutch* for winter rearing habitat (Peterson 1982; Nickelson et al. 1992; Rosenfeld et al. 2008) and are also used by juvenile sockeye salmon *O. nerka*, Chinook salmon *O. tshawytscha*, and steelhead *O. mykiss* (Swales and Levings 1989; Morley et al. 2005). Fish that rear in off-channel and floodplain habitats grow faster than those rearing in mainstem habitats (Jeffres et al. 2008; Limm and Marchetti 2009). This is likely due to favorable velocities, water temperatures across seasons, and increased availability of food resources (Sommer et al. 2001; Sommer et al. 2005; Urabe et al. 2010; Limm and Marchetti 2009). Thus, floodplain restoration remains a critical component of habitat restoration programs for salmon recovery.

A variety of methods have been developed to reconnect and restore floodplain habitats including side channel reconnection, culvert or dam removal, channel aggradation structures, levee removal or setback, remeandering straightened channels, constructed groundwater channels, and other methods of creating new floodplain habitats or wetlands (Cowx and Welcome 1998; Pess et al. 2005; Roni and Beechie 2013). The approaches to and scale of floodplain enhancement and restoration projects vary widely depending on project objectives, local river or stream settings, and individual techniques used. However, floodplain enhancement projects are generally designed to reconnect isolated habitat, improve channel form, increase off-channel area, and restore natural river processes to confined river systems. Baseline information on channel and floodplain form and condition is a critical foundation upon which to evaluate the effects of floodplain reconnection and enhancement efforts (Pess et al. 2005). Floodplain enhancement, creation, and connection has been shown to increase survival and provide high quality rearing habitat for young Chinook salmon, steelhead, coho salmon, and other fish species (Cederholm et al. 1988; Swales and Levings 1989; Nickelson et al. 1992; Giannico and Hinch 2003; Morley et al. 2005; Sommer et al. 2005). New floodplain channels have also been associated with high abundances and increased production of juvenile coho salmon, cutthroat trout *O. clarki*, Chinook salmon, and steelhead (Richards et al. 1992; Decker and Lightly 2004).

Numerous floodplain enhancement projects have been implemented throughout Washington State to reconnect isolated habitat, improve channel form, increase off-channel area, and restore natural river processes. Effectiveness monitoring of these restoration projects is critical to evaluate project performance and provide information to better inform future project designs and future funding decisions. In 2004, SRFB established an effectiveness monitoring program to assess the response of habitat and localized salmon populations to restoration efforts. As part of the program, monitoring has been conducted on projects from 2004 to the present, with the current phase of the program scheduled to be completed in 2018. Detailed study plans have been prepared for each major restoration category in the SRFB Project Effectiveness Monitoring (PE) plan, including the evaluation of floodplain restoration projects (MC-5/6) (Crawford 2011). Here we report the results from all years of monitoring, through the completion of the current phase of the program.

The primary monitoring goal of SRFB monitoring of floodplain enhancement projects is to determine the effectiveness of projects that are intended to restore floodplain morphology and to eliminate channel constraints in fish bearing streams. Specifically, the program was designed to answer the following questions:

1) What is the effect of floodplain enhancement on flood capacity;
2) What is the effect of floodplain enhancement on slow water habitats and habitat complexity;
3) What is the effect of floodplain enhancement on juvenile salmon and steelhead abundance; and
4) Has the removal and/or setback reduced channel constraints and increased flood flow capacity for ten years?

## 4.3 Methods

### 4.3.1 Monitoring Design and Replication

Here we provide a summary of the methods and design but refer readers to Crawford (2011) for details. Floodplain enhancement projects were evaluated using a before-after control-impact (BACI) design (Green 1979; Stewart-Oaten et al. 1986; Downes et al. 2002). Each project was monitored before implementation (Year 0) and after implementation on a rotating schedule. Occasionally, some projects were monitored for multiple years prior to project implementation (Year 0*). The post-project implementation monitoring schedule was typically Years 1, 3, 5, and 10; however, there were nine projects monitored by the previous contractor in Year 2 instead of Year 3. Sites are at different stages of the monitoring schedule depending on when they were implemented (Table 23).

Projects were initially selected for monitoring from those that had been funded but had not yet been implemented for the given baseline sampling year (Figure 13). All site selection and data collection prior to 2017 were conducted by the previous contractor (Tetra Tech 2016). Study sites ranged from 2.6 m to 135.6 m in average wetted width and in elevation from 2 m to 957 m. Annual precipitation at sites varied from 56 cm to 256 cm per year and dominant geology was either sedimentary or volcanic (Table 24). Floodplain enhancement techniques varied across projects. For example, side channel creation and/or levee removal were used in order to reconnect floodplain habitats (Table 25; Figure 7). Control reaches were selected with assistance from project sponsors and regional experts (Figure 7). Selection of adequate controls is critical to account for natural variability occurring at a reach and watershed scale that is not related to project implementation. Most sites scheduled for monitoring in 2018 had no fish data collected and inconsistent collection of other metrics in previous years, thus leaving very few additional sites to add to the total sample size for all analyzed metrics. Of the 13 floodplain enhancement sites that were scheduled for sampling in 2018, one had been dropped by the previous contractor, one control had been restored (impact), and five had clear problems with data in previous years or impact and control pairing issues. That left six projects, which would help increase samples sizes for some metrics, though fish data had not been collected on three of these projects. Therefore, due to inconsistencies in data collection across years including lack of fish and riparian data, sampling in different seasons, poorly matched impact and control reaches for some sites, and ultimately small sample sizes, no additional data was collected in 2018 for floodplain projects.

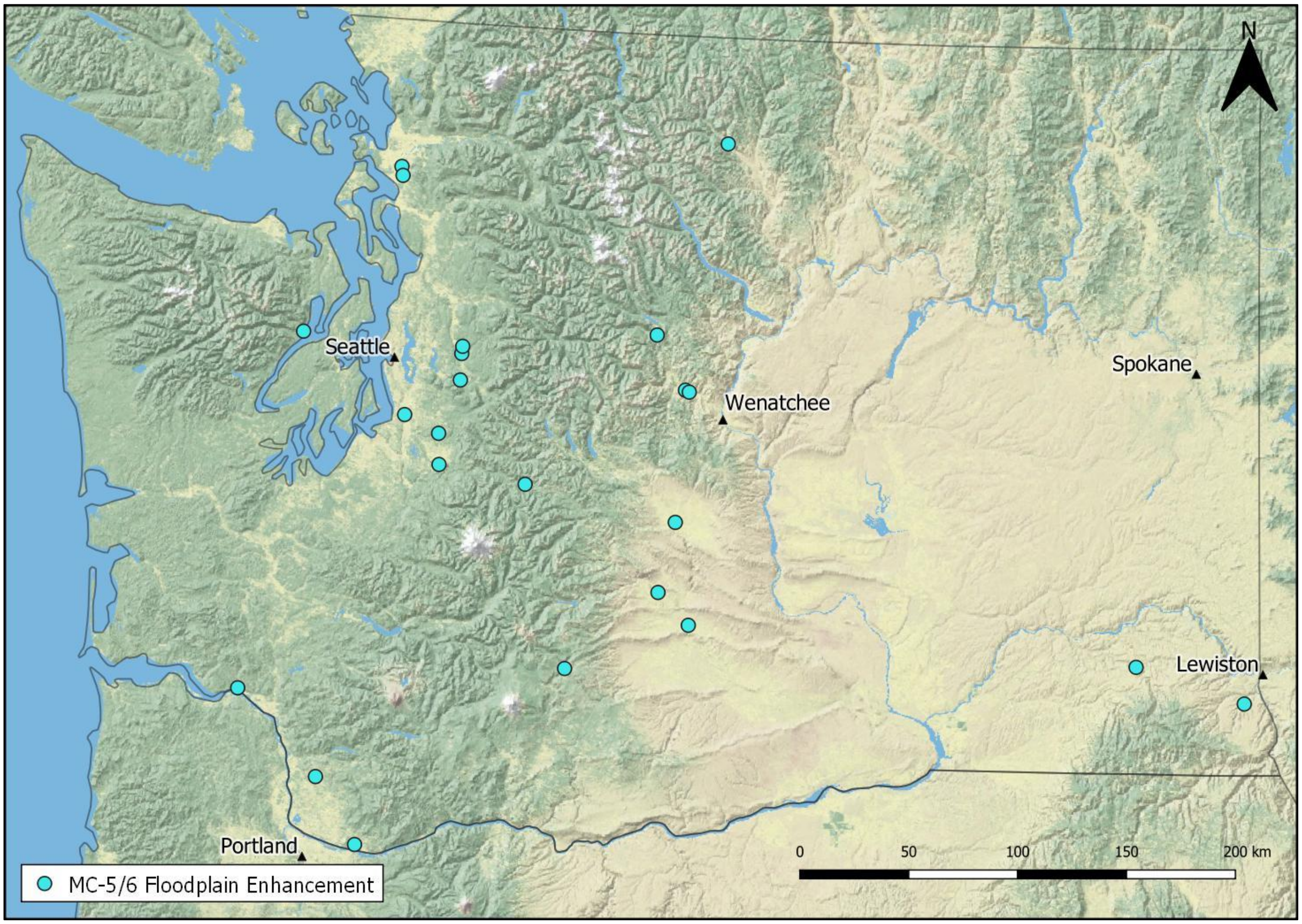


**Figure 13.** Floodplain enhancement project locations monitored throughout Washington.

**Table 23.** Monitoring schedule for floodplain enhancement projects. Light grey are years where monitoring did not occur. Cramer Fish Sciences took over monitoring in 2017. Due to inconsistencies in data collection across years including lack of fish and riparian data, sampling in different seasons, poorly matched impact and control reaches for some sites, and ultimately small sample sizes, no additional data was collected in 2018 for floodplain projects.

| Site ID | Site name | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC | Edgewater Park | Yr 0 | Yr 1 | Yr 2 | | | Yr 5 | | | | | Yr 10 | | | | |
| 02-1625 | SF Skagit Levee Setback | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 | | | | |
| 04-1461 | Dryden | | Yr 0 | | Yr 1 | Yr 2 | | | Yr 5 | | | | | Yr 10 | | |
| 04-1563 | Germany Creek | | | | | Yr 0 | Yr 1 | Yr 2 | | | Yr 5 | | | | | Yr 10 |
| 04-1573 | Lower Washougal | | Yr 0 | | Yr 1 | Yr 2 | | | Yr 5 | | | | | Yr 10 | | |
| 04-1596 | Lower Tolt River | | Yr 0 | Yr 0* | | | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 |
| 05-1398 | Fenster Levee | | | Yr 0 | | | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 |
| 05-1466 | Lower Boise Creek | | | Yr 0 | | | | | Yr 1 | | Yr 3 | | Yr 5 | | | Yr 8 |
| 05-1521 | Raging River | | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 | | |
| 05-1546 | Gagnon | | | Yr 0 | Yr 1 | Yr 2 | | | Yr 5 | | | | | Yr 10 | | |
| 06-2190 | Riverview Park | | | | Yr 0 | | | | | | Yr 1 | Yr 2 | | | Yr 5 | |
| 06-2223 | Greenwater River | | | | Yr 0 | | | | Yr 1 | | Yr 3 | | Yr 5 | | | Yr 8 |
| 06-2239CC | Fender Mill - Methow | | | | Yr 0 | | | Yr 1 | Yr 2 | | | Yr 5 | | | | Yr 9 |
| 06-2250 | Chinook Bend | | | | Yr 0 | | Yr 1 | | Yr 3 | | Yr 5 | | | | | Yr 10 |
| 06-2277 | Upper Klickitat | | | | Yr 0 | | | | Yr 1 | Yr 2 | | | Yr 5 | | | Yr 8 |
| 07-1519 | Reecer Creek | | | | | Yr 0 | | | Yr 1 | | Yr 3 | | Yr 5 | | | Yr 8 |
| 07-1691 | Lockwood Creek | | | | | Yr 0 | Yr 1 | Yr 2 | | | Yr 5 | | | | | Yr 10 |
| 10-1765 | Eschbach Park | | | | | | | | | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 |
| 11-1354 | Lower Dosewallips | | | | | | | | | | Yr 0 | | Yr 0* | | Yr0** | |
| 12-1307 | Billy's Pond | | | | | | | | | | Yr 0 | | | Yr 1 | | |
| 12-1438 | Lower Nason | | | | | | | | | | | Yr 0 | Yr 1 | | Yr 3 | |
| 12-1657 | George Creek | | | | | | | | | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 |
| Tucannon PA-26 | Tucannon PA-26 | | | | | | | | | | Yr 0 | Yr 1 | | Yr 3 | | Yr 5 |

**Table 24.** Physical characteristics of floodplain project study sites. Site lengths are determined from the latest monitoring year if lengths varied between years. Geology is dominant geology (unpublished Washington State Department of Ecology) where Sed. = sedimentary and Vol. = volcanic. Average annual precipitation was obtained from the USGS StreamStats Program (https://water.usgs.gov/osw/streamstats/). Bankfull width is from the most recent year of data collection of the impact reach. n/a = data were not collected.

| Site ID | Site name | Original protocol | County | Basin | Year 0 | Geology | Site elev (m) | Precip. (cm/yr) | Bankfull width (m) | Impact site length (m) | Control site length (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC | Edgewater Park | MC-6 | Skagit | Skagit | 2004 | Sed. | 5 | 257 | 10.6 | 318 | 220 |
| 02-1625 | SF Skagit Levee Setback | MC-5 | Skagit | Skagit | 2004 | Sed. | 3 | 79 | 146.6 | 500 | 500 |
| 04-1461 | Dryden | MC-6 | Chelan | Wenatchee | 2005 | Sed. | 271 | 172 | n/a | 175 | 150 |
| 04-1563 | Germany Creek | MC-6 | Cowlitz | Germany | 2008 | Vol. | 9 | 208 | 2.6 | 160 | 160 |
| 04-1573 | Lower Washougal | MC-6 | Clark | Washougal | 2005 | Sed. | 5 | 237 | 40.7 | 160 | 500 |
| 04-1596 | Lower Tolt River | MC-5 | King | Snoqualmie | 2005 | Sed. | 18 | 218 | 43.1 | 500 | 500 |
| 05-1398 | Fenster Levee | MC-5 | King | Green | 2006 | Sed. | 17 | 184 | 43.4 | 180 | 180 |
| 05-1466 | Lower Boise Creek | MC-5 | King | White | 2006 | Sed. | 195 | 150 | 12.3 | 200 | 200 |
| 05-1521 | Raging River | MC-5 | King | Snoqualmie | 2006 | Sed. | 116 | 200 | 18.6 | 500 | 500 |
| 05-1546 | Gagnon | MC-6 | Chelan | Wenatchee | 2006 | Sed. | 256 | 170 | n/a | 200 | 150 |
| 06-2190 | Riverview Park | MC-6 | King | Green | 2008 | Sed. | 7 | 180 | 11.0 | 230 | 350 |
| 06-2223 | Greenwater River | MC-5 | Pierce | White | 2007 | Sed. | 655 | 243 | 15.3 | 430 | 430 |
| 06-2239CC | Fender Mill | MC-6 | Okanagan | Methow | 2007 | Sed. | 585 | 114 | 5.0 | 150 | 150 |
| 06-2250 | Chinook Bend | MC-5 | King | Snoqualmie | 2007 | Sed. | 14 | 251 | 97.1 | 500 | 500 |
| 06-2277 | Upper Klickitat | MC-6 | Yakima | Klickitat | 2007 | Vol. | 957 | 158 | 8.0 | 150 | 150 |
| 07-1519 | Reecer Creek | MC-5 | Kittitas | Yakima | 2008 | Sed. | 463 | 43 | 23.7 | 170 | 170 |
| 07-1691 | Lockwood Creek | MC-6 | Clark | Lewis | 2008 | Sed. | 15 | 159 | 4.5 | 150 | 150 |
| 10-1765 | Eschbach Park | MC-5/6 | Yakima | Yakima | 2013 | Sed. | 398 | 137 | 116.6 | 173 | 189 |
| 11-1354 | Lower Dosewallips | MC-5/6 | Kitsap | Dosewallips | 2013 | Sed. | 2 | 228 | 42.1 | 500 | 500 |
| 12-1307 | Billy's Pond | MC-5/6 | Yakima | Yakima | 2013 | Sed. | 300 | 100 | 102.7 | 141 | 124 |
| 12-1438 | Lower Nason Creek | MC-5/6 | Chelan | Wenatchee | 2014 | Sed. | 601 | 173 | 4.3 | 591 | 577 |
| 12-1657 | George Creek | MC-5/6 | Asotin | Asotin | 2013 | Sed. | 372 | 56 | 13.6 | 159 | 203 |
| Tucannon PA-26 | Tucannon PA-26 | MC-5/6 | Columbia | Tucannon | 2013 | Sed. | 427 | 75 | 17.3 | 350 | 398 |

**Table 25.** Description of treatments implemented at each project. Target salmonid species were Chinook salmon for the Tucannon sites, and were Chinook salmon, coho salmon, steelhead, and other present salmonids for all other projects.

| Site ID | Site name | Original protocol | Description |
|---|---|---|---|
| 02-1561CC | Edgewater Park | MC-6 | Side channel creation and LWD placement on Skagit River in Mt. Vernon, WA |
| 02-1625 | SF Skagit Levee Setback | MC-5 | Levee setback near Conway, WA; tidally influenced |
| 04-1461 | Dryden | MC-6 | Off-channel ponds at river mile 15 on the Wenatchee River |
| 04-1563 | Germany Creek | MC-6 | Off-channel rearing habitat in Lower Columbia |
| 04-1573 | Lower Washougal | MC-6 | Convert gravel quarries to off-channel habitat near Camas, WA |
| 04-1596 | Lower Tolt River | MC-5 | Levee removal near Carnation, WA |
| 05-1398 | Fenster Levee | MC-5 | Levee setback on Green River in Auburn, WA |
| 05-1466 | Lower Boise Creek | MC-5 | Relocation of confined channel at confluence with White River |
| 05-1521 | Raging River | MC-5 | Levee removal near Preston, WA |
| 05-1546 | Gagnon | MC-6 | Creation of off-channel pond on Wenatchee River |
| 06-2190 | Riverview Park | MC-6 | Side channel creation project on Green River in Kent, WA |
| 06-2223 | Greenwater River | MC-5 | Levee removal and ELJ placement |
| 06-2239CC | Fender Mill | MC-6 | Dike/road removal and side channel initiation on Upper Methow River |
| 06-2250 | Chinook Bend | MC-5 | Levee removal on Snoqualmie River near Carnation River confluence |
| 06-2277 | Upper Klickitat | MC-6 | Side channel reconnection on Klickitat River |
| 07-1519 | Reecer Creek | MC-5 | ELJ's and rock placement in reconnected floodplain channel in Reecer Creek |
| 07-1691 | Lockwood Creek | MC-6 | Off-channel creation near La Center, WA |
| 10-1765 | Eschbach Park | MC-5/6 | Side channel creation on Naches River |
| 11-1354 | Lower Dosewallips | MC-5/6 | Levee removal, ELJ construction, and riparian planting on the Lower Dosewallips River |
| 12-1307 | Billy's Pond | MC-5/6 | Off-channel pond reconnection on Yakima River in Yakima, WA |
| 12-1438 | Lower Nason Creek | MC-5/6 | Floodplain fill removal and oxbow enhancement on Lower Nason Creek |
| 12-1657 | George Creek | MC-5/6 | Channel remeander and floodplain connection in Asotin County |
| Tucannon PA-26 | Tucannon PA-26 | MC-5/6 | Levee removal and LWD placement on Tucannon River |

MC-5: no fish or riparian data collected, except for 05-1466
MC-6: no channel constraints data collected

(a)
(b)
(c)
(d)

**Figure 14.** Impact (left) and control (right) reaches for (a) 04-1596 Lower Tolt, (b) 06-2223 Greenwater River, (c) 06-2277 Upper Klickitat, and (d) 07-1519 Reecer Creek.

## 4.3.2 Field Methods

The SRFB PE Program uses field sampling indicators and techniques that were adapted from the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) (Lazorchak et al. 1998; Kaufmann et al. 1999; Peck et al. 2003). Specific indicators and protocols were developed in 2003 by the SRFB and modified in 2008 and 2010 by Tetra Tech (Washington Salmon Recovery Funding Board 2003; Tetra Tech 2009; Tetra Tech 2012). In 2010, the two floodplain project types, MC-5 constrained channel and MC-6 channel connectivity, were combined into the single category MC-5/6 floodplain enhancement. The MC-5 protocol did not collect fish or riparian data and the MC-6 protocol did not collect channel constraints. Because of these protocol differences, not all projects have data of all response metrics. Crawford (2011) describes the combined MC-5/6 protocol for monitoring floodplain enhancement projects including goals and objectives field methods, summary statistics, data analysis procedures, and criteria for success. Here we provide a summary but refer readers to Crawford (2011) for details.

### *Site Layout*

Once impact and control reaches were selected, the total reach length was calculated using bankfull measurements in the impact reach (Crawford 2011). Five bankfull measurements were recorded and averaged around the center of the reach (X-site). The total reach length was calculated by multiplying the mean bankfull width by twenty (minimum of 150 m and maximum of 500 m). This same reach length was then to be used for the control reach and was to remain the same for each year of monitoring; however, there were several projects monitored by the previous contractor where reach lengths varied among years and were different between the control and impact reaches of the same project. Once a site length was calculated, the reach layout was completed by locating Transects A-K (Figure 15). Transects were placed at a distance of one-tenth the average bankfull widths (i.e., if a reach length is 150 m, the distance between transects will be 15 m).

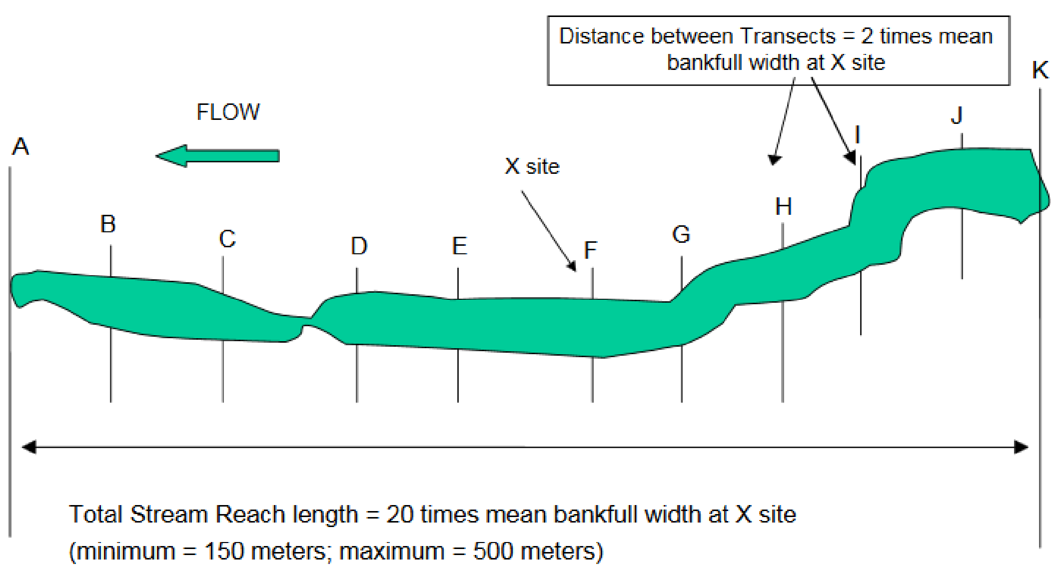


**Figure 15.** Project reach layout as adopted from Crawford (2011).

## Habitat Surveys

### Channel Constraints

Channel constrains were evaluated along the entire stream reach to assess if constraints were reduced following project implementation (Crawford 2011). First, the stream channel was classified as either predominantly single channel, anastomosing channel, or braided channel. It was then determined whether the channel was either 1) constrained within a narrow valley, 2) constrained by local features within a broad valley, 3) free to move about but within a relatively narrow valley floor, or 4) unconstrained and free to move about within a broad floodplain. Constraining features were recorded as bedrock, hillslopes, terraces/alluvial fans, and human use (e.g., road, dike, landfill, riprap, etc.).

The percent of the channel margin in contact with constraining features was estimated and the height of the constraining feature measured as the vertical distance from the wetted edge to the top of the constraining feature (Figure 16). At Transects A, F, and K, bankfull depth, bankfull height, and the floodprone width were measured. Bankfull width was also measured at each of the 21 transects (11 primary, 10 intermediate) and the entire valley width was measured. Channel constraint measurements were then used to calculate average channel capacity in the reach (Crawford 2011).

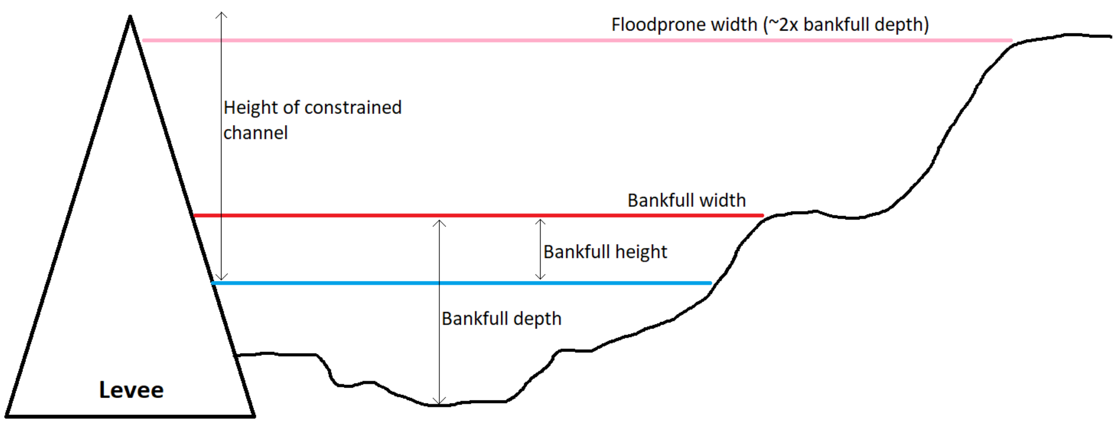


**Figure 16.** Channel survey measurements for channel constraints as adopted from Crawford (2011).

### Riparian Vegetation Structure

At both the right and left banks at each Transect A-K, a plot measuring 5 m upstream and downstream and a distance of 10 m back from the stream bank, into the riparian vegetation, was estimated. This results in a 10-m x 10-m survey area on both banks at each transect. Within the area, vegetation was visually divided into three distinct layers: the canopy layer (>5 m high), the understory layer (0.5 to 5 m high), and the ground cover layer (<0.5 m high) (Crawford 2011).

Within the canopy layer, the dominant vegetation type was first determined as either deciduous, coniferous, broadleaf evergreen, mixed, or none. The aerial cover of large trees (>0.3 m diameter breast height (DBH)) and small trees (<0.3 m DBH) was also visually estimated in the canopy layer. Aerial cover was determined as the amount of shadow that would be cast by that particular layer of the riparian zone if the sun was directly overhead. Cover percentages were grouped into varying cover classes (0 = absent or 0%, 1 = <10%, 2 = 10%-40%, 3 = 40%-75%, or 4 = >75%) (Crawford 2011).

The dominant vegetation type was also determined in the understory layer as done in the canopy (Crawford 2011). In the understory and ground cover layers, aerial cover class was determined for woody shrubs and non-woody vegetation rather than large and small trees as was done in the canopy layer. Cover percentages were grouped similarly to the canopy layer. Finally, in the ground cover layer, cover was also estimated for bare ground and duff. All steps were repeated on the right and left bank at each transect.

Riparian vegetation structure was then summarized for analysis as the proportion of each reach containing all three layers of riparian vegetation (canopy, understory, and ground cover). A layer was counted as containing riparian vegetation if either of the two vegetation types (canopy: small or large trees; understory/ground: woody and non-woody vegetation) were present (greater than 0%). The percentage of the 22 possible locations (right and left bank at Transects A-K) in the reach that had each of the three layers of riparian vegetation present was then calculated. If any layer at a measurement location was absent, this location did not contribute to the percentage of riparian vegetation structure within the reach.

### Canopy Cover Density

Canopy cover was determined at each Transect A-K using a convex spherical densiometer. The densiometer was taped so that there was a “V” at the bottom and there were 17 visible grid intersections (Mulvey et al. 1992; Figure 17). Six measurements were taken at each transect: four from mid-channel (facing upstream, river left, downstream, and river right) and one at each wetted edge facing away from the main channel. The densiometer was held level at 0.3 m above the water level with the recorder’s face just below the apex of the taped “V”. The number of grid intersection points that were covered by a tree, leaf, high branch, or any other shade providing feature (i.e., reed canary grass *Phalaris arundinacea*, river bank, bridge or other fixed structure) was counted. The value (0-17) was then recorded. For each project and within each reach, canopy cover density was averaged across all transects, for measurements taken on the right and left banks only, to get a mean value for each monitoring year. The mean canopy cover density from each year of monitoring was then used in the statistical analysis (Crawford 2011).

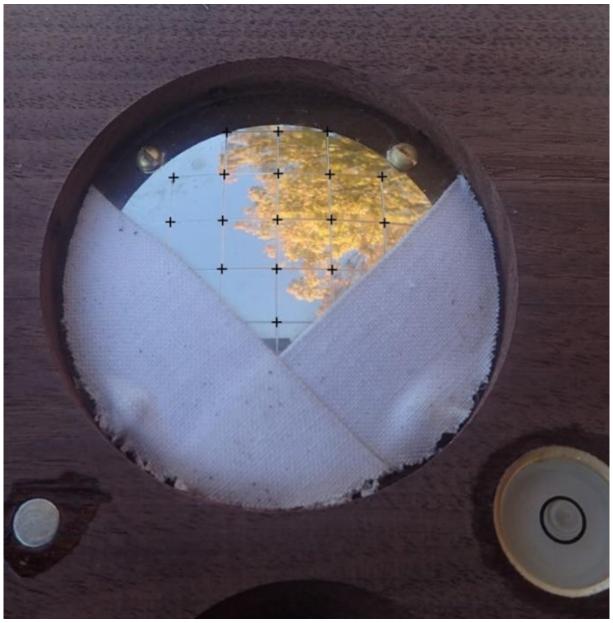

**Figure 17.** Imagine of modified densiometer reading and the remaining 17 grid intersections. In this example, 12 of the 17 intersections show canopy cover, giving a densiometer reading of 12.

## Slope and Bearing

The water surface slope and bearing between each transect (A-K) was measured to help calculate mean residual profile depth and vertical pool profile area in each reach (Kaufmann et al. 1999; Crawford 2011). One surveyor stood at the wetted edge of the downstream transect with a stadia rod at a known height. The other surveyor stood on the same bank at the next immediate upstream transect. Using a laser range finder at a known height, the upstream surveyor shot to the downstream transect and recorded the vertical and horizontal difference in order to calculate the slope between the two transects. Standing mid-channel at the upstream transect, the bearing to the downstream transect at mid-channel was recorded. If there was a meander bend and a full line of sight was not available between transects, a supplementary slope and bearing was recorded between transects (Crawford 2011).

## Characterizing Stream Morphology

A longitudinal thalweg profile survey was used to classify thalweg depth and habitat type (pool, riffle, glide, etc.) at 100 equally spaced intervals along the thalweg between the top and bottom of the sampling reach (Crawford 2011). Wetted widths were measured at 21 equally spaced cross-sections (at 11 primary transects A-K, plus 10 supplemental cross-sections spaced mid-way between each primary transect). For each pool encountered along the thalweg, the pool-tail crest depth, maximum pool depth, and maximum pool width were measured. If a side channel was present and contained between 16 and 49% of the total flow, secondary cross-section transects were established and wetted widths were measured. From the longitudinal profiles, average reach width, thalweg length, vertical pool profile area, and mean residual profile depth was calculated. If a stream were dry at the time of survey, vertical pool profile area, mean residual profile depth, and reach width would be zero.

Vertical pool profile area was calculated using thalweg depths of the channel, the slope of the reach, and the increment, which is the distance between depth measurement stations. At each station, the residual pool profile area was calculated, and the areas are accumulated to determine the mean residual pool vertical profile area in meters squared per reach (Kaufmann et al. 1999). The mean residual profile depth is the vertical pool profile area divided by the total length in meters of the reach, and then multiplied by 100 to get a residual depth of the thalweg (Kaufmann et al. 1999). See Kaufmann et al. (1999) for a detailed description of how these two metrics are calculated.

### *Topographic Surveys*

Beginning in 2012, the previous contractor selected new and old projects to collect topographic data using methodology adopted from the Columbia Habitat Monitoring Program (CHaMP) and available at monitoringmethods.org (e.g., Scientific Protocol for Salmonid Habitat Surveys within the Columbia Habitat Monitoring Program) (CHaMP 2013; Table 26). The River Bathymetry Toolkit console was also integrated into data processing to produce SRFB EMAP metrics that are compatible with the SRFB Program protocol and metrics for consistent use in data analysis (McKean et al. 2009; Tetra Tech 2013). Discrepancies were found between the provided summary tables, Access Database, and the CHaMP database in years where data was collected by the previous contractor; metric values provided in the summary tables were used in these instances.

**Table 26.** Project sites and topographic survey monitoring status.

| Site ID | Site name | Topo implemented | Monitoring year implemented |
|---|---|---|---|
| 02-1561CC | Edgewater Park | No | n/a |
| 02-1625 | SF Skagit Levee Setback | No | n/a |
| 04-1461 | Dryden | No | n/a |
| 04-1563 | Germany Creek | 2013 | Year 5 |
| 04-1573 | Lower Washougal | No | n/a |
| 04-1596 | Lower Tolt River | 2013 | Year 5 |
| 05-1398 | Fenster Levee | 2013 | Year 5 |
| 05-1466 | Lower Boise Creek | 2013 | Year 3 |
| 05-1521 | Raging River | No | n/a |
| 05-1546 | Gagnon | No | n/a |
| 06-2190 | Riverview Park | 2013 | Year 1 |
| 06-2223 | Greenwater River | 2013 | Year 3 |
| 06-2239CC | Fender Mill | No | n/a |
| 06-2250 | Chinook Bend | 2013 | Year 5 |
| 06-2277 | Upper Klickitat | No | n/a |
| 07-1519 | Reecer Creek | 2013 | Year 3 |
| 07-1691 | Lockwood Creek | 2013 | Year 5 |
| 10-1765 | Eschbach Park | 2013 | Year 0 |
| 11-1354 | Lower Dosewallips | 2013 | Year 0 |
| 12-1307 | Billy's Pond | 2013 | Year 0 |
| 12-1438 | Lower Nason Creek | 2013 | Year 0 |
| 12-1657 | George Creek | 2013 | Year 0 |
| Tucannon PA-26 | Tucannon PA-26 | 2013 | Year 0 |

### *Fish Surveys*

Snorkel surveys were conducted to quantify the number of fish in each impact and control reach during summer low flow (Crawford 2011). Two divers entered the downstream end of a reach and slowly moved upstream through each transect, stopping to occasionally relay the number, sizes, fish species, and observed micro-habitat characteristics (e.g., slow or fast water, off-channel or side channel habitat, large woody debris or boulder association). Only one snorkeler conducted the fish survey in streams smaller than 6 m wetted width and up to four snorkelers in larger streams. Fish length was visually estimated to the nearest 10 mm. Prior to fish surveys, stream temperature was measured, and visibility was recorded (low, medium, high).

Fish species encountered during snorkel surveys included several species of Pacific salmon *Oncorhynchus* spp., sculpin *Cottus* spp., sucker *Catostomus* spp., and dace *Rhinichthys* spp., as well as threespine stickleback *Gasterosteus aculeatus* and mountain whitefish *Prosopium williamsoni*. The analysis focused on juvenile (<250 mm) Chinook salmon, coho salmon, and steelhead because these fish were the intended target species for the restoration projects (Crawford 2011).

## 4.3.3 Data Analysis Methods

All projects were evaluated together as a category to assess trends in indicator response from year to year and the change between pre-project (Year 0) and post-project (Year 1, 2, 3, 5, and 10) conditions. Because monitoring began in different years for projects, some do not have the full 10 years of monitoring completed. As previously mentioned, there was no additional data collected in 2018 for MC-5/6 sites. Thirteen sites were included in the data analysis and 10 sites were excluded (Table 27). Statistical analysis was not conducted on individual projects. Summary data for all projects and metrics can be found in Appendix E.

### *Physical Habitat and Fish Density*

We attempted to conduct two statistical analyses described by Crawford (2011), previous annual reports (Tetra Tech 2016), and required under our contract. The required analyses include a mean difference analysis and a trend analysis to test whether projects were effective each monitoring year and remained effective through Year 10 (Crawford 2011).

For the mean difference method, the Year 0 values (impact minus control) were compared to each year of post-project (Years 1, 3, 5, and 10) (impact minus control) data using a paired one-sided *t*-test with $\alpha = 0.10$. If the data was not normally distributed, a paired one-sided nonparametric *t*-test (Wilcoxon) with $\alpha = 0.10$ was used. For each response variable, our unit of analysis was the paired difference between the impact reach compared to the control reach for each sample year. The null hypothesis is that the mean of the impact metrics across sites is equal to 0. This analysis was conducted on six habitat response variables (vertical pool profile area, mean residual profile depth, bank canopy cover, riparian vegetation structure, channel capacity, and floodprone width) and three fish response variables (juvenile Chinook salmon, coho salmon, and steelhead densities). Year 0*, Year 0**, and Year 2 were not included in this first analysis because they were not described in Crawford (2011).

The protocol for floodplain enhancement projects also calls for a trend analysis where the slopes of linear trend lines through time (Year 0 to Year 10) (impact minus control for each year), for each indicator at each project site, were estimated. Then, using these slopes, a *t*-test or nonparametric equivalent (Wilcoxon) test with α = 0.10 was to be used to test if the average of the slopes differed from 0 for each metric (Crawford 2011; Tetra Tech 2016; O'Neal et al. 2016). However, because many sites had only three years of data, we did not feel there was enough years of data to fit trend lines and complete this analysis.

**Table 27.** Floodplain projects and sampling years included in data analysis.

| Site ID | Site name | Year 0 sampling | Original protocol | Years included in analysis | Reason for full removal |
|---|---|---|---|---|---|
| 02-1561CC | Edgewater Park | 2004 | MC-6 | None | Reach locations changed since Year 0 |
| 02-1625 | SF Skagit Levee Setback | 2004 | MC-5 | 0, 1, 3, 5, 10 | |
| 04-1461 | Dryden | 2005 | MC-6 | 0, 1, 2, 5, 10 | |
| 04-1563 | Germany Creek | 2008 | MC-6 | None | Reach locations changed since Year 0 |
| 04-1573 | Lower Washougal | 2005 | MC-6 | 0, 1, 2, 5, 10 | |
| 04-1596 | Lower Tolt River | 2006 | MC-5 | 0, 1, 3, 5 | |
| 05-1398 | Fenster Levee | 2006 | MC-5 | 0, 1, 3, 5 | |
| 05-1466 | Lower Boise Creek | 2006 | MC-5 | 0, 1, 3, 5 | |
| 05-1521 | Raging River | 2006 | MC-5 | 0, 1, 3, 5, 10 | |
| 05-1546 | Gagnon | 2006 | MC-6 | 0, 1, 2, 5, 10 | |
| 06-2190 | Riverview Park | 2008 | MC-6 | None | Side channel vs. main channel comparison |
| 06-2223 | Greenwater River | 2007 | MC-5 | 0, 1, 3, 5 | |
| 06-2239CC | Fender Mill | 2007 | MC-6 | None | Dropped by previous contractor due to implementation issues |
| 06-2250 | Chinook Bend | 2007 | MC-5 | 0, 1, 3, 5 | |
| 06-2277 | Upper Klickitat | 2007 | MC-6 | None | Impact and control reach problems |
| 07-1519 | Reecer Creek | 2008 | MC-5 | None | Impact and control reach problems |
| 07-1691 | Lockwood Creek | 2008 | MC-6 | 0, 1, 2, 5 | |
| 10-1765 | Eschbach Park | 2013 | MC-5/6 | None | Impact reach changed since Year 0 |
| 11-1354 | Lower Dosewallips | 2013, 2015, 2017 | MC-5/6 | None | No post-project data; not implemented |
| 12-1307 | Billy's Pond | 2013 | MC-5/6 | None | Impact and control reach problems |
| 12-1438 | Lower Nason | 2014 | MC-5/6 | None | Impact and control reach problems |
| 12-1657 | George Creek | 2013 | MC-5/6 | 0, 1, 3 | |
| Tucannon PA-26 | Tucannon PA-26 | 2013 | MC-5/6 | 0, 1, 3 | |

### Decision Criteria

An additional approach set by managers was used to examine project effectiveness based on minimum standards (Crawford 2011). The management decision criteria were set for each metric and include an evaluation of the percent change in the mean differences between impact and control reaches for each analyzed metric (Table 28). The following equation was used to determine if a 20% change from baseline occurred for each project:

$$\% \, diff_{site:i,year:j} = \frac{Difference_{i,0} - Difference_{i,j}}{Difference_{i,0}}$$

Percent difference was determined for each site for a given year. Then the average percent difference for a given year was computed by taking the mean of all percent differences (all sites) for a given year:

$$\% \, AvDiff_{year:j} = mean(\% \, diff_{i,j})$$

**Table 28.** Decision criteria for habitat and fish metrics collected for floodplain enhancement projects.

| Metric | Decision criteria |
|---|---|
| *Physical habitat metrics* | |
| Vertical pool profile area ($m^2$) | Paired *t*-test for pre-project mean vs. each year of post-monitoring, $\alpha = 0.10$ for one-sided test. Detect a ≥ 20% change between impact and control by Year 10. |
| Mean residual profile depth (cm) | Paired *t*-test for pre-project mean vs. each year of post-monitoring, $\alpha = 0.10$ for one-sided test. Detect a ≥ 20% change between impact and control by Year 10. |
| Bank canopy cover (0-17) | Paired *t*-test for pre-project mean vs. each year of post-monitoring, $\alpha = 0.10$ for one-sided test. Detect a ≥ 20% change between impact and control by Year 10. |
| Riparian vegetation structure (%) | Paired *t*-test for pre-project mean vs. each year of post-monitoring, $\alpha = 0.10$ for one-sided test. Detect a ≥ 20% change between impact and control by Year 10. |
| Average channel capacity ($m^2$) | Paired *t*-test for pre-project mean vs. each year of post-monitoring, $\alpha = 0.10$ for one-sided test. Detect a ≥ 20% decrease between Year 0 and Year 10. |
| Floodprone width (m) | Paired *t*-test for pre-project mean vs. each year of post-monitoring, $\alpha = 0.10$ for one-sided test. Detect a ≥ 20% increase between Year 0 and Year 10. |
| *Juvenile fish abundance metrics* | |
| Chinook density (fish/$m^2$)<br>Coho density (fish/$m^2$)<br>Steelhead density (fish/$m^2$) | Paired *t*-test for pre-project mean vs. each year of post-monitoring, $\alpha = 0.10$ for one-sided test. Detect a ≥ 20% increase between Year 0 and Year 10. |

## 4.4 Results

### 4.4.1 Physical Habitat

There was a large amount of variability in the physical habitat metrics across all years of sampling and among projects and not all metrics were sampled in all years for all projects (see Appendix E). Analysis was only conducted if sample size (number of projects with suitable data) was five sites or higher. Sample size across metrics and across years varied dramatically and these differences influence statistical significance. Relative to the control reach, vertical pool profile area increased significantly in Years 1 and 10 ($P = 0.05$), but not other years ($P > 0.29$), while mean residual profile depth increased in all years except Year 3 ($P = 0.82$) (Figure 18; Table 29). Bank canopy cover and riparian vegetation structure did not increase following treatment in any of the post-project years ($P > 0.5$) (Figure 18, Figure 19; Table

29), though this could not be analyzed in Years 3 and 10 due to small sample sizes or no data collected in those years. Overall average channel capacity remained relatively stable following project implementation (Figure 19). Only Year 3 was significantly lower following project implementation when compared to Year 0 ($P$ = 0.08) (Table 29). Average channel capacity could not be analyzed in Year 10 because the sample size was not large enough to run an analysis ($n$ = 2). Failure to reduce the average channel capacity would indicate that the project is not effectively functioning at increasing floodplain connection (Crawford 2011). While floodprone width decreases in Year 1 compared to Year 0, no statistical analysis was conducted because sample sizes with suitable data was less than five sites for all years (Figure 19; Table 29).

Floodplain enhancement projects were successful at meeting Crawford (2011) management decision success criteria for vertical pool profile area and mean residual profile depth for the latest sampling year with a large enough sample size (Year 10). However, projects have not yet met management targets for canopy cover, riparian vegetation structure, or average channel capacity by the latest sampling year with a large enough sample size (Table 30). Floodprone width was not assessed because samples sizes were too small or were zero for all sampling years.

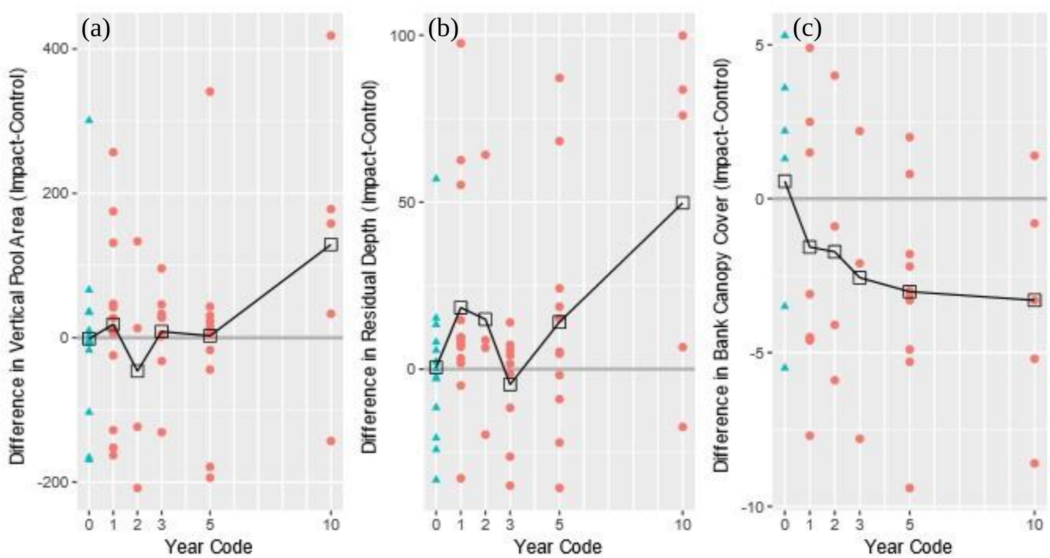


**Figure 18.** Mean difference (line and open squares) for vertical pool profile area (a), mean residual profile depth (b), and bank canopy cover (c) between the control and impact reaches for floodplain enhancement projects. The blue triangles and red circles represent before and (Year 0) after monitoring data (Year > 0), respectively.

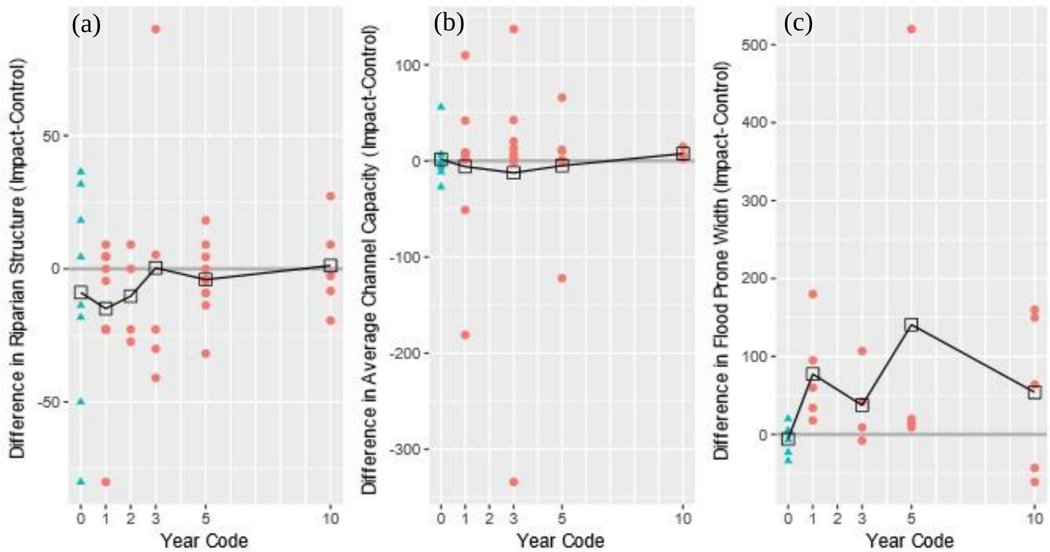


**Figure 19.** Mean difference (line and open squares) for riparian vegetation structure (a), average channel capacity (b), and floodprone width (c) between the control and impact reaches for floodplain enhancement projects. The blue triangles and red circles represent before and (Year 0) after monitoring data (Year > 0), respectively.

**Table 29.** Summary results for paired one-tailed test of the difference between the impact and control reaches for six physical habitat metrics within floodplain enhancement projects. Bolded *P*-values indicate statistical significance (α = 0.10). Projects that had data collected in Year 2 were not included in this analysis (Crawford 2011). Statistical analysis was only performed if sample size (projects with suitable data) was 5 or higher (n/a). The mean difference represents the average difference in response between Year 0 (impact minus control) and Year 1, 3, 5, or 10 (impact minus control) for each metric and year combination.

| Metric | Years compared | Sample size (sites) | Test | *P*-value | Mean difference |
|---|---|---|---|---|---|
| Vertical pool profile area ($m^2$) | 0↔1 | 13 | Paired Wilcoxon | **0.05** | 20.0 |
| | 0↔3 | 9 | Paired Wilcoxon | 0.75 | -24.5 |
| | 0↔5 | 11 | Paired Wilcoxon | 0.29 | 3.4 |
| | 0↔10 | 5 | Paired *t*-test | **0.05** | 128.0 |
| Mean residual profile depth (cm) | 0↔1 | 13 | Paired Wilcoxon | **0.01** | 17.9 |
| | 0↔3 | 9 | Paired Wilcoxon | 0.82 | -11.3 |
| | 0↔5 | 11 | Paired *t*-test | **0.09** | 13.5 |
| | 0↔10 | 5 | Paired *t*-test | **0.06** | 46.8 |
| Bank canopy cover (0-17) | 0↔1 | 5 | Paired *t*-test | 0.70 | -2 |
| | 0↔3 | 0 | n/a | n/a | n/a |
| | 0↔5 | 5 | Paired *t*-test | 0.85 | -4 |
| | 0↔10 | 4 | n/a | n/a | n/a |
| Riparian vegetation structure (%) | 0↔1 | 7 | Paired Wilcoxon | 0.50 | -2 |
| | 0↔3 | 2 | n/a | n/a | n/a |
| | 0↔5 | 5 | Paired *t*-test | 0.77 | -9 |
| | 0↔10 | 4 | n/a | n/a | n/a |
| Average channel capacity ($m^2$) | 0↔1 | 9 | Paired Wilcoxon | 0.21 | -7.5 |
| | 0↔3 | 9 | Paired Wilcoxon | **0.08** | -14 |
| | 0↔5 | 7 | Paired Wilcoxon | 0.15 | -7.1 |
| | 0↔10 | 2 | n/a | n/a | n/a |
| Floodprone width (m) | 0↔1 | 4 | n/a | n/a | n/a |
| | 0↔3 | 4 | n/a | n/a | n/a |
| | 0↔5 | 3 | n/a | n/a | n/a |
| | 0↔10 | 2 | n/a | n/a | n/a |

**Table 30.** Summary of floodplain enhancement project physical success based on management decision criteria outlined in Crawford (2011). Criteria were not assessed (n/a) if sample sizes were too small.

| Metric | Year | *t*-test or Wilcoxon test met | % change from baseline | Sample size (sites, *n*) | $n \geq 20\%$ |
|---|---|---|---|---|---|
| Vertical pool profile area ($m^2$) | Year 1 | Yes | 349 | 13 | 9 |
| | Year 3 | No | 240 | 9 | 6 |
| | Year 5 | No | -90 | 11 | 5 |
| | Year 10 | Yes | 315 | 5 | 4 |
| Mean residual profile depth (cm) | Year 1 | Yes | 1,423 | 13 | 11 |
| | Year 3 | No | 1,053 | 9 | 4 |
| | Year 5 | Yes | -1,263 | 11 | 6 |
| | Year 10 | Yes | 2,355 | 5 | 5 |
| Bank canopy cover (0-17) | Year 1 | No | -50 | 5 | 2 |
| | Year 3 | n/a | n/a | 0 | n/a |
| | Year 5 | No | -83 | 5 | 2 |
| | Year 10 | n/a | n/a | 4 | n/a |
| Riparian vegetation structure (%) | Year 1 | No | -1 | 7 | 3 |
| | Year 3 | n/a | n/a | 2 | n/a |
| | Year 5 | No | -11 | 5 | 2 |
| | Year 10 | n/a | n/a | 4 | n/a |
| Average channel capacity ($m^2$) | Year 1 | No | 746 | 9 | 7 |
| | Year 3 | Yes | 176 | 9 | 7 |
| | Year 5 | No | 83 | 7 | 5 |
| | Year 10 | n/a | n/a | 2 | n/a |
| Floodprone width (m) | Year 1 | n/a | n/a | 4 | n/a |
| | Year 3 | n/a | n/a | 4 | n/a |
| | Year 5 | n/a | n/a | 3 | n/a |
| | Year 10 | n/a | n/a | 2 | n/a |

### 4.4.2 Fish Densities

There was a large amount of variability in fish densities between control and impact reaches across all years and sites, with several sites having low densities of all three fish species or no fish present at all (see Appendix E). Many sites had one or more fish species not present in all years of project monitoring and fish surveys were not conducted in all years of post-project monitoring completed to date, making sample sizes too small for analysis in Years 3 and 10. Chinook densities were lower in each year following project implementation and no significant response to restoration was detected in any post-project year of monitoring ($P > 0.57$) (Figure 20; Table 31). In contrast, coho salmon densities were higher in each year following project implementation and significant response to restoration was detected in Years 1 and 5 when compared to Year 0 ($P < 0.06$) (Figure 20; Table 31). Steelhead densities were higher in all post-project monitoring years except Year 1, though no significant response to restoration was detected (Figure 20; Table 31). Based on the management decision criteria for project success presented in Crawford (2011), by the latest sampling year with a large enough sample size, floodplain projects were effective in increasing coho salmon, though were not effective in increasing Chinook salmon and steelhead densities (Table 32). While SRFB protocols call for examining fish per unit area (fish/$m^2$), this could overlook a total increase in fish numbers if the total wetted area in the impact reach increased. Therefore, we also examined densities in fish per linear meter (fish/m) and found similar results with no significant increases for Chinook or steelhead ($P > 0.10$), and a significant increase for coho in Year 1 and Year 5 ($P < 0.06$).

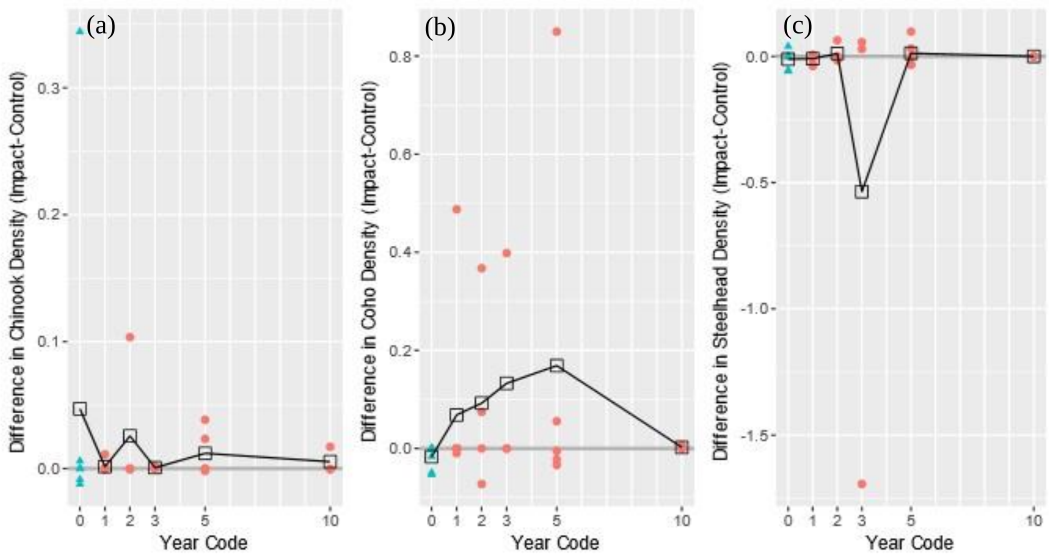


**Figure 20.** Mean difference (line and open squares) for densities of Chinook salmon (a), coho salmon (b), and steelhead (c) between the control and impact reaches for floodplain enhancement projects. The blue triangles represent pre-treatment monitoring data (Year 0) while the red circles represent post-treatment monitoring data (Year > 0).

**Table 31.** Summary results for paired one-tailed test of the difference between the impact and control reaches for juvenile fish densities within floodplain projects. Bolded *P*-values indicate statistical significance ($\alpha = 0.10$). Projects that had data collected in Year 2 were not included in this analysis (Crawford 2011). Statistical analysis was only performed if sample size (projects with suitable data) was 5 or higher (n/a). The mean difference represents the average difference in response between Year 0 (impact minus control) and Year 1, 3, 5, or 10 (impact minus control) for each metric and year combination.

| Metric | Years compared | Sample size (sites) | Test | *P*-value | Mean difference |
|---|---|---|---|---|---|
| Chinook density (fish/m$^2$) | 0↔1 | 7 | Paired Wilcoxon | 0.61 | -0.0455 |
| | 0↔3 | 3 | n/a | n/a | n/a |
| | 0↔5 | 5 | Paired Wilcoxon | 0.57 | -0.0527 |
| | 0↔10 | 3 | n/a | n/a | n/a |
| Coho density (fish/m$^2$) | 0↔1 | 7 | Paired Wilcoxon | **0.05** | 0.0853 |
| | 0↔3 | 3 | n/a | n/a | n/a |
| | 0↔5 | 5 | Paired Wilcoxon | **0.06** | 0.1926 |
| | 0↔10 | 3 | n/a | n/a | n/a |
| Steelhead density (fish/m$^2$) | 0↔1 | 7 | Paired Wilcoxon | 0.19 | 0.0020 |
| | 0↔3 | 3 | n/a | n/a | n/a |
| | 0↔5 | 5 | Paired Wilcoxon | 0.22 | 0.0244 |
| | 0↔10 | 3 | n/a | n/a | n/a |

**Table 32.** Summary results of the mean differences analysis and change detection results of fish densities based on decision criteria in Crawford (2011).

| Metric | Year | *t*-test or Wilcoxon test met | % change from baseline | Sample size (sites, *n*) | $n \geq 20\%$ |
|---|---|---|---|---|---|
| Chinook density (fish/m$^2$) | Year 1 | No | 31 | 7 | 3 |
| | Year 3 | n/a | n/a | 3 | n/a |
| | Year 5 | No | 93 | 5 | 3 |
| | Year 10 | n/a | n/a | 3 | n/a |
| Coho density (fish/m$^2$) | Year 1 | Yes | 47 | 7 | 4 |
| | Year 3 | n/a | n/a | 3 | n/a |
| | Year 5 | Yes | 1,781 | 5 | 4 |
| | Year 10 | n/a | n/a | 3 | n/a |
| Steelhead density (fish/m$^2$) | Year 1 | No | 116 | 7 | 5 |
| | Year 3 | n/a | n/a | 3 | n/a |
| | Year 5 | No | 3,199 | 5 | 3 |
| | Year 10 | n/a | n/a | 3 | n/a |

## 4.5 Discussion

A total of 23 floodplain enhancement projects were sampled by the PE monitoring program, which began in 2004; 13 projects were included in our analysis of floodplain enhancement projects, though several metrics had a smaller sample size due to two different protocols (MC-5 and MC-6) being combined into one in 2010. Results suggest floodplain projects are successfully increasing vertical pool profile area and mean residual profile depth by Year 10 ($n = 5$). Increases in vertical pool profile area and mean residual profile depth were expected and consistent with previous studies on floodplain enhancement (e.g., Morley et al. 2005; Weber et al. 2009; ISEMP 2013). Several projects also included the addition of large woody debris (LWD) within the project reach, which can be effective at increasing habitat heterogeneity and pool depth (Roni et al. 2008; Jones et al. 2014; Roni et al. 2015). Wood is an important component of channel structure and can have dramatic effects on channel pattern (Collins and Montgomery 2002); however, LWD was not monitored in floodplain enhancement project category (Crawford 2011).

Bank canopy cover decreased over time since project implementation, with six out of nine projects with post-project data having a measured decrease in canopy cover in the most recent year of sampling when compared to Year 0. The results for riparian vegetation structure and bank canopy cover may have not shown a significant increase due to the numerous project types (levee setback, floodplain reconnection, creation of floodplain, etc.) within the floodplain enhancement category and the many degrees to which construction may impact the riparian habitat. Some projects clear vegetation prior to a large levee removal or creation of a new channel, while other projects may experience little impact if the project involved reconnection of the main channel to an existing off-channel habitat. Additionally, several floodplain enhancement projects were paired with riparian plantings while others were not, which may lead to a more rapid response in some projects and not others. There are only four floodplain projects with Year 10 data and five with Year 5 data included in the analysis, which may contribute to the lack of a significant response. In addition, the current SRFB metrics require all three layers of riparian vegetation (canopy, understory, and ground cover) to be present in order to be counted as riparian structure (Crawford 2011), and thus may not be very sensitive to small changes in riparian cover and structure. More than ten years post implementation may be needed for some riparian plant species to reach the 5-m canopy height threshold required in the riparian vegetation structure metric of the protocol as well as to increase overall sample size. Therefore, it may not be surprising that significant differences in riparian structure have not yet been observed. Other metrics frequently used to monitor change in riparian vegetation due to floodplain restoration include ground cover, taxa richness and diversity, canopy heights, and overall riparian area (Pess et al. 2005). These metrics should be considered for monitoring changes in riparian conditions at future SRFB floodplain enhancement projects to capture more rapid change.

While there was some indication that floodprone width increased in Year 1 following project implementation, data were available for only three or four suitable projects in any given year, making analysis and interpretation of results difficult. An increase in floodprone width would indicate projects are increasing connectivity of the main channel to the floodplain and therefore increasing the amount of area engaged during high flow events. Because floodprone width was initially only measured in MC-5 projects, there were several projects without Year 0 data. As the connection with the floodplain increases, the average channel capacity is also expected to decrease (Crawford 2011), yet we did not see significant results for decreasing channel capacity. Average channel capacity should decrease once the constraining feature is removed, indicating that over bank flows will occur more frequently, and floodplain connection should be improved. As more time passes after implementation and more high flow events continue to engage and change the floodplain, it is possible that more projects will see a decrease in channel capacity.

Floodplain enhancement projects did not show any evidence of significant changes in Chinook salmon or steelhead densities (fish/$m^2$ or fish/m), while there were positive results for coho salmon by Year 5. Levee removal/setback, new channel creation, channel reconnection, and channel remeandering projects have been shown to increase Chinook salmon, coho salmon, and in some cases steelhead numbers, while improving the health and productivity of river ecosystems (Nickelson et al. 1992; Richards et al. 1992; Morley et al. 2005; Klein et al. 2007; Levell and Chang 2008; Hillman et al. 2016). Salmonids and other fishes rapidly colonize newly accessible habitats following floodplain habitat reconnection of critical rearing habitat (Sommer et al. 2001; Roni et al. 2008). Thus, the SRFB results in Year 5 for coho salmon are consistent with previous studies. The varying fish results detected at SRFB projects, particularly for Chinook salmon, are likely due to low sample size (fish were not enumerated at all sites or years) and season sampled. They may also be reflective of high inter-annual variability in juvenile salmonid numbers, inconsistencies in season sampled, interproject variability, differences in species targeted for restoration, and control and impact reach inconsistencies.

There was high variability in fish use (densities) among sites and sampling years, which may be partly attributed to high variability in habitat conditions. While juvenile salmonid densities are driven in part by adult escapement and densities of salmonids varied among years and streams, the MBACI design in part accounts for this by examining the difference between paired treatment and controls in each site (stream). The purpose of the paired control is to help account for interannual variability in escapement and other environmental factors. However, the timing and consistency of fish sampling may have also added to the variability and reduced the likelihood of detecting differences. While the SRFB protocol calls for monitoring at summer low flow or winter high flows, most projects were sampled between April and September, though the month and sometimes the season varied within and among projects. Consistent seasonal sampling and sampling for multiple life stages may help to increase detection of targeted species and other fish species. Many floodplain enhancement projects were constructed to increase and enhance winter spawning and rearing habitat for salmonids and would benefit from consistent sampling during winter months presumably during winter low flow as sampling at winter high flows is generally not possible. The timing of the seasonal monitoring also needs to be confined to a smaller sample window, as fish surveys at several projects varied from May until December, with many projects not sampled in similar seasons consistently across years for comparison.

Based on the SRFB management targets (Crawford 2011), floodplain enhancement projects are not meeting minimum targets for success for many metrics. The mixed outcome for many of the floodplain enhancement project metrics suggests the need for more robust or nuanced statistical analyses. However, data for all physical habitat (vertical pool profile area, mean residual profile depth, bank canopy cover, riparian vegetation structure, average channel capacity, floodprone width) and fish metrics (Chinook and coho salmon, steelhead) were highly skewed and no transformation was adequate to meet assumptions of normality required to run a mixed-effects BACI analysis. Several projects had to be dropped completely from analysis due to monitored reach locations shifting across years. Other projects had to be dropped from certain metric analysis due to inconsistencies in data values leading to large outliers (i.e., 06-2277 Upper Klickitat control reach – average channel capacity in Year 2 is 14,629 $m^2$ and in Year 5 is 4 $m^2$; 07-1519 Reecer Creek control reach – floodprone width in Year 0 is 2,500 m and in Year 5 is 11.5 m) and the merging of the MC-5 and MC-6 protocols leading to a lack of Year 0 values in certain metrics.

Some of the lack of response of both fish and physical habitat to SRFB floodplain enhancement projects monitored is likely due to inconsistencies in data collection and changes in protocols. Four of the six physical habitat metrics and the three fish density metrics were not initially collected in both floodplain protocols (MC-5 constrained channel and MC-6 channel connectivity) when the monitoring program began in 2004. Therefore, once the two protocols were combined in 2010 and projects were to be analyzed together, many projects were missing Year 0 metrics to compare to all post-project years (Table 33). The post-project sampling schedule was also different for both protocols where MC-5 was monitored in Years 1, 3, 5, and 10 and MC-6 in Years 1, 2, 5, and 10. Similar issues of data collection and consistency arose with the addition of topographic surveys under the combined MC-5/6 floodplain enhancement protocol. The topographic survey, which is an improvement over the original PE habitat survey protocol, provides a complete topographic map and allows calculation of changes in habitat conditions such as pool area and depth, channel capacity, volume of newly created habitat, and floodplain connectivity. However, the topographic survey was implemented after Year 0 on many projects, leaving few projects available to assess changes in newly created off-channel habitat or other floodplain topography metrics before and after restoration (see Table 26). Thus, the full benefit of the costlier and more detailed topographic surveys cannot be fully realized. Additionally, many of the projects that began monitoring after the two protocols were combined into MC-5/6, and would therefore have topographic data and many other metrics collected in Year 0, had to be excluded from the analysis due inconsistencies in impact and control reaches or other issues (see Table 27).

While the added topographic surveys attempt to capture the multitude of changes taking place throughout the floodplain, some surveys still did not capture the full extent of the floodplain and fish response in the entire reach (mainstem and side-channels). Floodplain enhancement projects should extend identification of channel physical habitat metrics and fish measurements beyond the main channel and should include the floodplain and all of its channels (Pess et al. 2005). Neither the adapted EMAP or CHaMP topographic survey methods used for PE, were designed to survey outside the active stream channel. Moreover, several projects only monitored the created or enhanced side channel and not the main channel or other existing habitat (i.e., 04-1461 Dryden, 04-1563 Germany Creek, 05-1466 Lower Boise Creek, 05-1546 Gagnon, 06-2190 Riverview Park, 07-1519 Reecer Creek, 11-1354 Lower Dosewallips). We recommend monitoring an entire floodplain reach (main channel and side-channels) both before and after the restoration action to better capture changes in physical habitat and fish use.

Using a BACI monitoring approach helps to account for environmental variability and temporal trends found in both impact and control reaches to better discern floodplain enhancement effects from natural variability (Underwood 1992; Roni et al. 2005). However, selection of appropriate controls is critical to increase the probability of detecting restoration response if one exists (Roni et al. 2013). A control reach should be selected to be as similar as possible in all respects to the impact reach and considered beyond the influence of the treatment (Downes et al. 2002). The underlying assumption is that the impact reach would have behaved approximately the same as the control reach in the absence of the floodplain enhancement (Underwood 1992). There were several sites in this study that had issues regarding the control reach selection and Year 0 monitoring, which could have ultimately masked significant results. Several projects included the creation of a new channel in an area where no channel was previously located. These constructed floodplain habitats would also have immediate results following project implementation if Year 0 was sampled where the channel would be constructed because all values would be zero (02-1561 Edgewater Park, 04-1461 Dryden, 06-2190 Riverview Park). In contrast, other projects that included the construction of a new channel used an existing channel in Year 0 and post-project data was collected in the newly constructed channel, but not the old channel that was still active and connected to the stream (05-1466 Lower Boise Creek, 07-1519 Reecer Creek, 10-1765 Eschbach Park). Many other projects had poor impact and control reach comparisons, either by comparing a side channel to the mainstem or comparing a backwater alcove to a mainstem flow-through side-channel.

Stratifying sites by geographic or climatic region, channel size, target fish species, or other factors may help account for differences among floodplain enhancement sites. The geographic extent of sites in this monitoring program extended throughout Washington State and east and west of the Cascade Mountains where mean rainfall varied from 56 to 257 cm/yr. Vegetation type, growing season characteristics, fish species distribution and use, and regional weather patterns varied across this extent and could influence site specific results. Similarly, type of floodplain enhancement at the sites varied considerably. For example, 06-2250 Chinook Bend was a levee removal project on the mainstem Snoqualmie River intended to connect the river to the floodplain at lower flows than pre-project conditions, targeting fall Chinook salmon. The 05-1546 Gagnon project reconnected an isolated off-channel pond habitat, targeting spring Chinook salmon, coho salmon, and steelhead. Stratifying by ecoregion or targeted fish species could help alleviate some of the influences these factors may have on the results and our understanding of the effectiveness of floodplain enhancement.

Previous studies have clearly demonstrated that it is possible to monitor and detect fish response to floodplain, instream, and other restoration techniques (e.g., Swales and Levings 1989; Morley et al. 2005; Roni et al. 2008). However, the inconsistencies in data collection across years in this study, including lack of fish and riparian data, sampling in different seasons, poorly matched impact and control reaches in some cases, and limitations of current protocols, likely prevented us from detecting a significant response to restoration. It could also be that some projects were not successful at improving habitat or fish numbers, but it is more likely that the monitoring was not adequate to detect a response to floodplain restoration rather than the restoration was not effective. Future monitoring of floodplain enhancement projects should consider stratifying projects by ecoregion, seasonal fish sampling (summer, winter), more rigorous selection of treatment and controls, improved habitat survey methods, consistent seasonal sampling periods among sites and years, monitoring an entire floodplain reach rather than just the project location (e.g., constructed side-channel), and using a post-treatment design that does not require extensive pre-project or lengthy post-project data collection.

**Table 33.** Availability of Year 0 data for each floodplain enhancement project. Projects below the dark bar and shaded in grey have been dropped from the analysis (see Table 27). Y = Metric has Year 0 data for that project. D = Metric has Year 0 data for that project, but project was dropped from analysis.

| Site ID | Site name | Original protocol | Pool profile area | Residual profile depth | Canopy cover | Riparian structure | Channel capacity | Floodprone width | Chinook density | Coho density | Steelhead density | CHaMP topo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 02-1625 | SF Skagit Levee Setback | MC-5 | Y | Y | Y | Y | Y | Y | --- | --- | --- | --- |
| 04-1461 | Dryden | MC-6 | Y | Y | Y | Y | --- | --- | Y | Y | Y | --- |
| 04-1573 | Lower Washougal | MC-6 | Y | Y | Y | Y | --- | --- | Y | Y | Y | --- |
| 04-1596 | Lower Tolt River | MC-5 | Y | Y | Y | Y | Y | --- | --- | --- | --- | --- |
| 05-1398 | Fenster Levee | MC-5 | Y | Y | --- | --- | Y | Y | --- | --- | --- | --- |
| 05-1466 | Lower Boise Creek | MC-5 | Y | Y | --- | --- | Y | Y | Y | Y | Y | --- |
| 05-1521 | Raging River | MC-5 | Y | Y | --- | --- | Y | Y | --- | --- | --- | --- |
| 05-1546 | Gagnon | MC-6 | Y | Y | Y | Y | --- | --- | Y | Y | Y | --- |
| 06-2223 | Greenwater River | MC-5 | Y | Y | --- | --- | Y | Y | --- | --- | --- | --- |
| 06-2250 | Chinook Bend | MC-5 | Y | Y | --- | --- | Y | Y | --- | --- | --- | --- |
| 07-1691 | Lockwood Creek | MC-6 | Y | Y | Y | Y | --- | --- | Y | Y | Y | --- |
| 12-1657 | George Creek | MC-5/6 | Y | Y | --- | Y | Y | --- | Y | Y | Y | Y |
| Tucannon PA-26 | Tucannon PA-26 | MC-5/6 | Y | Y | --- | Y | Y | --- | Y | Y | Y | Y |
| 02-1561CC | Edgewater Park | MC-6 | D | D | D | D | --- | --- | D | D | D | --- |
| 04-1563 | Germany Creek | MC-6 | D | D | D | D | --- | --- | D | D | D | --- |
| 06-2190 | Riverview Park | MC-6 | D | D | D | D | --- | --- | D | D | D | --- |
| 06-2239CC | Fender Mill | MC-6 | D | D | D | D | --- | --- | D | D | D | --- |
| 06-2277 | Upper Klickitat | MC-6 | D | D | D | D | --- | --- | D | D | D | --- |
| 07-1519 | Reecer Creek | MC-5 | D | D | --- | --- | D | D | --- | --- | --- | --- |
| 10-1765 | Eschbach Park | MC-5/6 | D | D | D | D | --- | --- | D | D | D | D |
| 11-1354 | Lower Dosewallips | MC-5/6 | D | D | D | D | D | D | D | D | D | D |
| 12-1307 | Billy's Pond | MC-5/6 | D | D | D | D | D | D | D | D | D | D |
| 12-1438 | Lower Nason | MC-5/6 | D | D | D | D | D | D | D | D | D | D |

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# CHAPTER 5. SUMMARY AND RECOMMENDATIONS

The original goals of the PE Program as defined by the GSRO and SRFB were to answer three management questions including:

1. Are restoration treatments having the intended effects regarding local habitats and their use by salmon;
2. Are some treatments types more effective than others at achieving specific results; and
3. Can project monitoring results be used to improve the design of future projects?

An additional question, posed by the SRFB Monitoring Panel and RCO is:

4. What has been learned to date from the PE Program that can assist in redesigning the next phase of PE?

In this chapter, we summarize the results to date for each of the major categories of projects evaluated by PE, compare those to results from other studies, and attempt to answer these questions for each project type. We then summarize the overall response to the above questions 1 through 3, and then address question 4 by discussing the answer in the sections 5.3 Strengths and Weaknesses of PE 2004 to 2018 and 5.4 Recommendations for the Future below. While it was originally intended that ten categories of restoration action would be evaluated, two were combined (MC-5 and MC-6), one was never implemented (MC-9 Estuary), and MC-7 (Spawning Gravel) was dropped early on because of lack of projects to monitor. Therefore, seven categories of restoration types were included in the PE Program including (Figure 21):

- MC-1: Fish Passage
- MC-2: Instream Habitat
- MC-3: Riparian Planting
- MC-4: Livestock Exclusion
- MC-5/6: Floodplain Enhancement
- MC-8: Diversion Screening
- MC-10: Habitat Protection

CFS took over the PE Program in the fall of 2016 and we conducted the final data collection and analysis for MC-2 Instream Habitat, MC-4 Livestock Exclusion, and MC-5/6 Floodplain Enhancement. The methods, results, discussion, and recommendations for each of these categories was described in detail in Chapters 2, 3, and 4 of this report. Data collection for MC-1 Fish Passage, MC-3 Riparian Planting, MC-8 Diversion Screening, and MC-10 Habitat Protection was completed prior to 2016 (see Table 34). While we have summary data and most raw data for these previously monitored projects, we did not do the original analysis and here we only provide a summary of results for these four completed project types, based on data and results from previously completed annual reports. The site selection, data collection, and data analysis did not receive the same level of scrutiny as that for MC-2, MC-4, and MC-5/6 project categories.

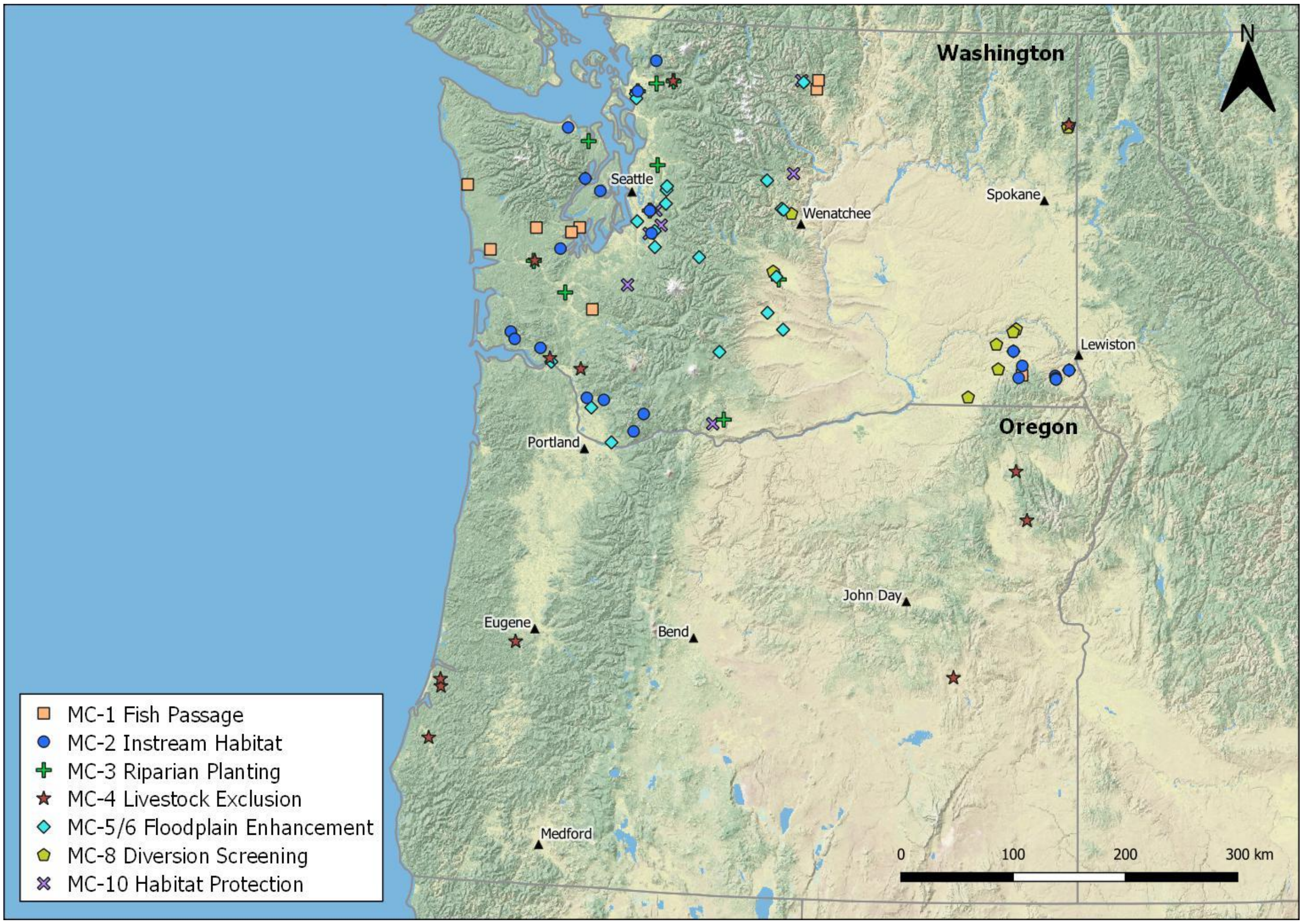


**Figure 21.** Location of different action types monitored under the Project Effectiveness (PE) Monitoring Program 2004 to 2018. Monitoring and analysis for instream habitat, livestock exclusion, and floodplain enhancement was completed in 2018.

**Table 34.** Summary of sampling scheduled, number of sites sampled, years data collected, report or where results are reported, metrics examined, and summary results for each project type monitored under the SRFB Project Effectiveness Monitoring Program. The monitoring schedule reflect what was originally planned, not all projects received monitoring through Year 5 or 10.

| Category | Name | # of sites | Monitoring schedule | Years collected | Year of final report | Report reference | Metrics | Key findings |
|---|---|---|---|---|---|---|---|---|
| MC-1 | Fish Passage | 9 | 0, 1, 2, 5 | 2004-2009 | 2009 | Tetra Tech 2010 | Juvenile salmon densities, spawner and redd counts | • Significant increase in juvenile coho densities<br>• No significant differences for juvenile Chinook and steelhead densities or adult spawners and redds<br>• All sites met engineering criteria for fish passage<br>• Results for coho densities consistent with literature on barrier removal |
| MC-2 | Instream Habitat | 23 | 0, 1, 3, 5, 10 | 2004-2018 | 2018 | Chapter 2 this document | Vertical pool profile area, mean residual profile depth, LWD, juvenile salmon densities | • Significant increase in LWD by Year 10<br>• Significant increase in residual profile depth by Year 5, but no longer in Year 10<br>• No significant differences for vertical pool profile area and fish densities by Year 5 or 10<br>• Results for physical response not consistent with literature, which typically show positive response. Fish response inconsistent with recent studies in PNW on salmonid response |
| MC-3 | Riparian Planting | 9 | 0, 1, 3, 5, 10 | 2004-2015 | 2015 | Tetra Tech 2016 | Percent survival, woody coverage, canopy cover, riparian vegetation, bank erosion | • Significant increase in percent woody cover over time<br>• No significance differences for bank erosion, canopy cover, and vegetation structure<br>• Planting survival was not significantly different among years<br>• Results partially consistent with literature, but limited published work is available |
| MC-4 | Livestock Exclusion | 12 | 0, 1, 3, 5, 10 | 2004-2017 | 2018 | Chapter 3 this document | Bank erosion, riparian vegetation, canopy cover, pool tail fines | • Significantly decrease in bank erosion and increase riparian structure by Year 10<br>• No significant effects of livestock exclusion on bank canopy cover or pool tail fines<br>• Results for bank erosion and riparian structure consistent with literature, though most literature also shows an increase in canopy cover |
| MC-5/6* | Floodplain Enhancement | 23 | 0, 1, 3, 5, 10 | 2004-2017 | 2018 | Chapter 4 this document | Vertical pool profile area, mean residual profile depth, canopy cover, riparian vegetation, channel capacity, floodprone width, juvenile salmon densities | • Results were highly variable by metric and year<br>• Not consistent with most literature on floodplain restoration as most other studies have reported positive physical and biological responses |
| MC-8 | Diversion Screening | 10 | 1, 2 | 2005-2008 | 2009 | Tetra Tech 2010 | Compliance | • All projects were in compliance with 80% of parameters measured and considered effective<br>• Little published literature to compare results |
| MC-10 | Habitat Protection | 10 | 0, 3, 8 | 2004-2014 | 2014 | Tetra Tech 2015 | Vertical pool profile area, mean residual profile depth, LWD, percent fines, substrate embeddedness, bank erosion, canopy cover, riparian vegetation, basal area and density, non-native cover, juvenile salmon densities | • Most metrics show little change from 2004-2014<br>• Significant decrease in the basal area of deciduous vegetation and increase in conifer basal area<br>• Significant decrease in invasive plant species<br>• Significant decrease in indices of biotic integrity for fish and macroinvertebrates<br>• Little published literature to compare results |

*MC-5 and MC-6 were combined into one category in 2010. The original sample schedule for MC-5 was Year 0, 1, 3, 5, and 10 and for MC-6 was Year 0, 1, 2, 5, and 10.

## 5.1 Results to Date (2004 to 2018)

### 5.1.1 MC-1 Fish Passage

Data collection for fish passage occurred from 2004 through 2009 and final results for this project category were provided in the 2009 Annual Report (Tetra Tech 2010). A total of nine projects were monitored across eastern and western Washington (Figure 21; Table 35). Metrics collected included juvenile salmonid abundance and redd and spawner counts. We found inconsistencies in the numbers reported in the SRFB Access database, summary tables provided by the previous contractor, and the data reported in the 2009 Annual Report. For example, most spawner data were reported as 0 in the summary table, while there were spawner counts greater than zero in the database and 2009 Annual Report. Therefore, we assumed that the numbers in the 2009 Annual Report were correct and report those in Appendix A. Because this category was completed prior to CFS taking over the PE Program in 2016, we did not reanalyze the data. In the 2009 Annual Report, a significant increase was reported in juvenile coho salmon densities in Year 5, but no significant differences were detected for steelhead parr, juvenile Chinook, adult coho or coho redds, or Chinook spawners (Tetra Tech 2010). The lack of response of adult Chinook and coho spawners and coho redds is not surprising given that data were available for only five sites and the longer time frame needed to detect an adult salmon response to restoration or habitat change (Bisson et al. 1997; Korman and Higgins 1997; Ham and Pearsons 2000). Not all juvenile species were present at all sites, suggesting that sample sizes were small for juvenile steelhead and Chinook as well. The results for juvenile coho are consistent with previous studies that indicated if a fish passage barrier is removed, rapid recolonization can occur (Pess et al. 2005; Roni et al. 2008; Anderson et al. 2014; Pess et al. 2014; Erkinaro et al. 2017). The densities of fish below the fish passage barrier and the quality of the habitat upstream of the barrier play a key role in whether and how quickly fish recolonize an area upstream of a barrier (Pess et al. 2012; Anderson et al. 2014). As noted, in the 2009 Annual Report (Tetra Tech 2010), the densities of fish were low downstream of some barrier removal projects that were monitored, which may have influenced results. No habitat data was collected so it is not known what the quality of the habitat was upstream and downstream of the barriers or whether treatments and controls had similar habitat quality. Additionally, detecting fish response to removal of partial fish passage barriers can be more difficult than detecting response to removal of complete fish passage barriers. We did not have information on whether sites were complete or partial fish passage barriers, but five of the nine sites had juvenile coho or steelhead present in the impact (upstream) reach before the project was implemented suggesting they were partial barriers prior to replacement. The 2009 Annual Report indicated that all sites met engineering criteria for fish passage detailed in Bates et al. (2003) and specifications from the Family Forest Fish Passage Program under the Washington DNR. This is encouraging given that Price et al. (2010) demonstrated that more than 30% of new or recently replaced culverts in Washington State are still barriers to fish passage.

While the positive response was limited to juvenile coho salmon, it is encouraging given the limited sample size, the low juvenile fish densities or absence of some fish species seen at many projects (Tetra Tech 2010), the large geographic area covered, and that many of the nine projects sampled appear to be have been only partial barriers to fish passage. In addition to issues outlined above, we noted a number of issues with data collection that may have added additional noise. This included treatments and controls for a site being on different streams (projects 02-1530; based on the coordinate locations provided in the summary tables), treatments and controls being located long distances upstream or downstream from the barrier (projects 04-1485, 04-1489), changes in length monitored from one year to a next at some sites (project 02-1530), a control for one site being used as a treatment for another (projects 04-1485, 04-1489), and inconsistencies in season data were collected across years at some sites (i.e., a site being sampled in spring one year and summer or winter the next). The lack of any information on the stream characteristics or instream habitat data in the treatment (above culvert) and control (below culvert) reach limit the applicability of the results to other similar projects. Collecting instream habitat data would also have helped explain differences in fish numbers above and below barriers before and after treatment and among sites. Finally, the inconsistencies in the database, summary data, and the final report for this category creates concerns about overall data quality for this category.

**Table 35.** Description of fish passage projects evaluated between 2004 and 2009. Information from 2009 Annual Report (Tetra Tech 2010).

| Site ID | Site name | Stream | Description |
|---|---|---|---|
| 02-1530 | Salmon River Tributary | Salmon River | Replace 72" culvert with a 1.37 m outfall drop to an adequately sized culvert, provide unimpeded access to 0.8 mi of spawning and rearing habitat |
| 02-1574 | Melaney Creek Fish Passage Project | Malaney Creek | Replace culvert barrier on Melaney Creek to a 22' x 100' bottomless box culvert; provide better access to 2.5 mi of functional and intact habitat |
| 04-1470 | Hiawatha Fish Passage | Hiawatha Creek | Replace undersized culvert to a 20' wide bottomless arched culvert; provide better habitat connectivity, complexity, and spawning and rearing opportunities |
| 04-1485 | Fulton Dam Barrier Removal | Chewuch River | Create new diversion structure, roughened channel, and head gate control to replace old rock dam on the Chewuch River, Okanogan County |
| 04-1489 | Chewuch Dam Barrier Removal | Chewuch River | Replace concrete dam, remove Denil fish passage ladder, and roughen streambed on the Chewuch River at river mile 8; increase upstream fish access |
| 04-1668 | Beeville Road at MP 2.09 | Peterson Creek | Replace two culverts (gradient and perch conditions), to a single 18' wide oval culvert; open 6,102 m of habitat |
| 04-1689 | Lucas Creek Barrier Correction | Lucas Creek | Replace of 82" x 65" x 48' culvert with a 1' drop, to an adequate bottomless culvert; install gravel, grade controls, and LWD; restore 2.8 mi of fish passage |
| 04-1695 | Dekay Road Fish Barrier | Polson Creek | Replace 3 culverts with 2 bottomless box culverts and 1 concrete bridge; allow better access to rearing and spawning habitat in tributary of WF Hoquiam River |
| 05-1498 | Curl Lake Intake Barrier Removal | Tucannon River | Construct sloped channel and pool above the existing weir while simultaneously lowering the weir by 1' on the Tucannon River to increase fish passage |

Despite limitations with data collection and results, barrier removal projects are known to be highly successful. We do not recommend that barrier removal projects continue to be monitored unless there are some specific case studies needed to answer questions about specific or unique barrier removal projects. Should additional monitoring on this category be considered, we would recommend more careful selection of treatments and controls, collection of habitat data alongside fish data, stratification of sites by eastern and western Washington and possibly species, and improved data management. The MBACI design with one year of pre-project data may be appropriate if examining projects collectively but does not allow one to say much about individual projects. If the goal is to be able to report on effectiveness of individual projects, a minimum of two or three years of pre-project fish data is recommended.

### 5.1.2 MC-2 Instream Habitat

A total of 23 sites instream habitat sites were monitored between 2004 and 2018, though six sites were excluded from the final analyses because of problems with treatments and controls, previous data collection, or the treatment simply not being implemented. The methods, results, and recommendations for MC-2 are described in detail in Chapter 2 and we provide a summary below but refer readers to Chapter 2 for more detail.

Significant increases in LWD volume in Year 5 and Year 10 and mean residual profile depth in Year 5 were detected. However, no significant differences in vertical pool profile area, or juvenile salmonid abundance (coho and Chinook salmon, steelhead) were detected. The positive response for LWD volume is expected given that the treatment consisted of placing LWD into the impact reaches. The lack of a stronger physical response, and the lack of fish response are somewhat surprising given that LWD volume increased. Many studies on LWD placement have reported increases in juvenile salmonids, particularly coho salmon (e.g., Cederholm et al. 1997; Roni and Quinn 2001; see Roni et al. 2015a for detailed review). The lack of a significant increase in juvenile fish response for the SRFB instream habitat projects may be due to the low number of projects that have been monitored for ten years post-treatment. However, most studies have shown that channel and fish respond relatively quickly to placement of LWD and instream structures (Roni et al. 2015a). It should be noted that the actual changes in physical habitat detected for this project category were modest, which may explain the lack of fish response. The lack of fish response could lead one to assume that the projects monitored were not effective. However, issues with implementation and monitoring protocols likely increased variability and limited the ability to measure and detect physical and biological responses to the instream habitat projects monitored. These issues include sampling only during summer low flow conditions, the species and fish sizes sampled, possible issues with selection of control and impact reaches, inconsistent sample timing from year-to-year (e.g., June for one year and October for another), and the lack of stratification by geographic region. The SRFB monitoring protocols do not directly measure pool area and residual pool depth, two metrics that have been consistently shown to respond to instream habitat restoration techniques. The CHaMP topographic surveys implemented at some sites in 2012 and 2013 provide more detailed habitat information, but this methodology was not consistently implemented on all projects.

Many of the issues that limited the ability of PE to detect a stronger response could be overcome by stratifying projects by ecoregion, consistent seasonal fish sampling (summer and winter), more rigorous selection of treatment and controls, improved habitat survey methods, and the use of a post-treatment design that does not require extensive pre-project data collection. Given that instream habitat, and wood placement in particular, has been relatively well evaluated (Roni et al. 2015a; Clark and Roni 2018), we do not recommend continued evaluation of MC-2 instream habitat projects. However, a focused well-controlled study examining different levels of wood placement may be warranted to assist with specific project design questions.

### 5.1.3 MC-3 Riparian Plantings

Data collection for riparian planting occurred between 2004 to 2015 and final results for this project category were provided in the 2015 Annual Report (Tetra Tech 2016). A total of 10 projects were sampled, though 1 project never received plantings so only 9 projects were included (Figure 21; Table 36). Metrics monitored included bank erosion, shade, vegetation structure, percent woody cover, and planting survival. Summary metrics are reported in Appendix C. No significant differences in bank erosion, shade, and vegetation structure were detected, though small improvements were observed for all three metrics (Tetra Tech 2016). Percent woody cover was examined only at impact (treatment) sites and showed a significant increase over time (Tetra Tech 2016). It was not clear why percent woody cover was only examined at impact sites and only post-treatment. Planting survival was not significantly different among years, indicating that planting survival was high, though in some cases planting survival exceeded 100% (Tetra Tech 2016). For planting survival, we found inconsistencies in the numbers reported in the SRFB Access database, summary tables provided by the previous contractor, and the data reported in the 2008 Annual Report, which was one of the last years that the report included raw data value tables (Tetra Tech 2009). For example, several sites (projects 02-1623, 04-1655, 04-1676, 04-1711) had survival reported in Year 3 as less than 100% in the 2008 Annual Report (Tetra Tech 2009), though the provided summary tables had survival values that were greater than 100%. We reported the values provided in the summary tables in Appendix C since they reflected results reported in the most recent Tetra Tech annual report (Tetra Tech 2016). The Monitoring Panel recommended discontinuing monitoring of this category and no data was collected beyond 2015 (Tetra Tech 2016).

**Table 36.** Description of riparian planting projects monitored between 2004 and 2015. Information from 2015 Annual Report (Tetra Tech 2016).

| Site ID | Site name | Stream | Description |
|---|---|---|---|
| 02-1446 | Centralia Riparian | Chehalis River | Plant east bank of mainstem Chehalis River |
| 02-1561R | Edgewater Park | Skagit River | Create side channel followed by planting project on lower Skagit River |
| 02-1623 | Snohomish River Confluence | Snohomish River | Plant north bank of Snohomish River 1 mi below confluence of Skykomish and Snoqualmie rivers |
| 04-1649 | Salmon Snow Creek | Snow Creek | Plant lower 1 mi reach of small stream (< 7 m wide) near Discovery Bay |
| 04-1655R | Hoy Riparian | Skagit River | Fence and plant south bank of Skagit River near Hamilton, WA |
| 04-1660R | Cedar Rapids | Cedar River | Remove levee, place LWD, and re-plant on Cedar River |
| 04-1676 | YTAHP Wilson Creek | Wilson Creek | Plant both banks of a small (< 7 m wide) creek in Ellensburg, WA |
| 04-1698R | Vance Creek | Vance Creek | Plant small (< 7 m wide) creek near Elma, WA |
| 04-1711 | Lower Klickitat | Klickitat River | Plant mainstem Klickitat River near Klickitat, WA |

Previous studies have indicated that many factors can influence the success of riparian planting projects including depth of planting, browse protection, exposure, aspect, soil augmentation, irrigation, and periodic maintenance (Opperman and Merenlender 2000; Roni et al. 2002, 2008; Sweeney et al. 2002; Hall et al. 2015). Unpublished studies in the Columbia River Basin have reported riparian planting survival rates of 60% or more (Hillman et al. 2016). The high survival rates (100%) reported for the monitored SRFB projects are as high as one could expect from a project. For example, plant survival on CREP projects in eastern Washington was 80% (Smith 2013). Other studies on riparian planting have reported improvements in riparian cover, shade, and other measures of riparian conditions (Connin 1991; Lennox et al. 2011; Hillman et al. 2016). While SRFB riparian monitoring sites showed improving trends in bank erosion, shade, and vegetation structure, the differences were not significant. This appears to differ from other studies which have found significant improvements in these metrics. Given plant survival rates were high (100%), the lack of response for SRFB riparian monitoring it is likely reflective of limitations of the monitoring protocols used or their implementation, or duration of the monitoring (10 years). Indeed, most monitoring of riparian projects is less than 10 years and longer-term studies have shown a positive relationship between recovery of plant cover and density that peaks somewhere between 20 and 25 years after riparian restoration (Lennox et al. 2011). Thus, it is possible that longer-term monitoring may show improvements in riparian cover, shade, and other factors. Projects occurred across the state, on a variety of stream types, and in many cases in conjunction with other restoration actions in many cases (e.g., channel construction). This may have contributed to additional variability that made detecting significant differences difficult with a sample size of only nine projects.

The limitations of the riparian monitoring protocol and monitored metrics, which are similar to livestock exclusion projects and were discussed in detail in Chapter 3, likely contributed to the inability to detect a response. Moreover, having survival in excess of 100% between years at four sites suggests either additional planting occurred or problems with data collection and management. The 2015 Annual Report states that it was difficult to accurately detect which plants were from the original plantings and which were a result of volunteer growth (Tetra Tech 2016), while actual values for survival changed from the 2008 Annual Report (Tetra Tech 2009). There were also irregularities in when monitoring occurred with some sites being sampled in spring one year and summer or fall the next, and one site where sampling occurred in November and even January in one year (project 02-1561). At two sites, the total reach length sampled varied by more than 100 m (projects 02-1561, 04-1660). Again, these could be errors in data entry, though collectively they raise concerns about the quality of monitoring data and data management.

Riparian planting is a widespread common approach, that has not been well evaluated in Washington State or elsewhere and requires long-term monitoring (>15 years). Given the limited number of sites, limitations of the protocol, and potential irregularities in data collection and management, the limited response reported by Tetra Tech (2016) for this project type is not surprising. Because of this and the variety of factors effecting the success of riparian restoration (e.g., treatments, site conditions, browse protection, ecoregion, water table, invasive species), additional monitoring and evaluation of this project category is needed and warranted. A multi-BACI design or even multiple before-after design, is likely still appropriate, but more rigorous riparian monitoring protocols are needed and potential use of remote sensing to map riparian features would be needed. Sample size would need to be greatly increased to 30 or more sites and sites stratified by eastern and western Washington and treatment type. Fortunately, sampling of riparian vegetation at restoration projects even with field-based approaches can typically be done rapidly. For example, treatment and control reaches can often be mapped on the same day by a two-person team using the latest approaches (CFS unpublished data). Sampling of riparian projects would also need to be longer term as canopy cover, shade, and other riparian and bank or instream metrics may take 20 years or more to become fully realized and few long-term studies exist (Roni et al. 2008; Lennox et al. 2011). Therefore, monitoring riparian sites at 0, 1, 5, 10, 15, 20 and 25 years is likely needed.

### 5.1.4 MC-4 Livestock Exclusion

A total of 12 livestock exclusion sites were monitored between 2004 and 2017, with completion of monitoring in 2018. The methods, results, and recommendations for livestock exclusion are described in detail in Chapter 3 and we provide a brief summary below but refer readers to Chapter 3 for more detail and Appendix D for project summary metrics. Results indicate that livestock exclusion projects significantly reduced bank erosion and improved riparian structure by Year 10, but we found no significant effects of livestock exclusion on bank canopy cover or pool tail fines. The reduction in bank erosion is consistent with previous studies on livestock exclusions (Platts 1991; Sarr 2002; Kauffman et al. 1997; Medina et al. 2005; Roni et al. 2008; Archibald 2015), which have generally shown decreases in bank erosion and increases in riparian vegetation structure and shade.

It is possible that canopy cover may continue to improve in impact reaches with continued livestock exclusion. As discussed in detail in Chapter 3, the lack of change in canopy cover and fine sediment are likely the results of several factors including: evidence of livestock grazing in many impact reaches, livestock exclusion in control reaches, limitations of the riparian sampling protocols, and additional noise due to some control reaches that were not well matched with impact reaches. First, many projects had intact fencing, but there were several instances where gates were left open, the fence was in the lay down position, or cattle were accessing the reach from upstream or downstream of the project location. Second, there were instances of control and impact (treatment) reaches that were poorly matched, including sites on different streams, differing land use, or other restoration treatments occurring on the impact but not the control. In other cases, livestock were also excluded from the control or the control was a reach that had never been subject to livestock grazing. These issues added additional noise or variability making detecting differences due to the treatment more difficult. Similarly, both the SRFB protocol and the implementation of the protocol likely further limited the ability to detect changes. Riparian structure used in OWEB-SRFB monitoring differed from other studies monitoring the response of riparian vegetation to cattle exclusion. Other studies focused on densities of all plant species, plant height, leaf litter accumulation, amounts of bare substrate, and compositional changes (Sarr 2002). Thus, more rigorous protocols would help detect changes. The timing of the monitoring varied with some sites being consistently sampled in the same month across years, and others being monitored in late spring one year, and summer or fall the next. Given that the analysis is on differences between treatment and controls, as long as treatment and controls in a site are sampled in the same season, this should correct for differences in seasonal sampling. However, that assumes grazing impacts do not vary across seasons, which is uncommon, and thus may have added additional variability to the data. Finally, the projects cover a broad geographic region spanning several ecoregions and at a minimum we would recommend stratifying sites by eastern and western Washington (or Oregon if OWEB sites continue to be included).

The lack of stronger response for all metrics examined should not be taken to mean that livestock exclusion projects are not successful or that the overall MBACI design was not appropriate for evaluating livestock exclusion projects. Despite the many issues we describe above, there was still some positive response detected which is strong evidence that if livestock are excluded, bank stability and riparian conditions will recover. Because the success of livestock exclusion is largely tied to maintaining fences and assuring livestock are excluded, we recommend focusing on implementation (compliance) monitoring rather than effectiveness monitoring for this project category. Should effectiveness monitoring of livestock exclusions projects be continued or included for future projects, we recommend the following: 1) more rigorous selection of impact and control reaches, 2) improved methods for monitoring riparian vegetation and shade, 3) stratification of sites by ecoregion, 4) assuring the contractor implements monitoring correctly and consistently across years, and 5) monitoring additional instream morphological and biological metrics.

### 5.1.5 MC-5/6 Floodplain Enhancement

A total of 23 sites floodplain enhancement sites were monitored between 2004 and 2017, though 10 sites could not be used in the final analysis because of problems with data collection, impact (treatment) and control pairing, or the treatment was never implemented (one site). The methods, results, and recommendations for floodplain projects are described in detail in Chapter 4 and we provide a summary below but refer readers to Chapter 4 for more detail and Appendix E for project summary metrics.

Results were highly variable by metric and year with significant changes in vertical pool profile area in Year 1 and 10, mean residual profile depth in Year 1, 5, and 10, average channel capacity in Year 3, and juvenile coho salmon density in Year 1 and Year 5. No significant changes were found for bank canopy cover, riparian vegetation structure, or Chinook salmon and steelhead densities. The positive changes in vertical pool profile area, mean residual profile depth, and coho salmon density are consistent with previous studies on floodplain restoration (e.g., Morley et al. 2005; Roni et al. 2008; Weber et al. 2009; Hillman et al. 2016), though results from SRFB projects have been relatively modest. The lack of a stronger response of other salmonids is somewhat surprising given positive responses reported particularly for coho and Chinook salmon in other studies (Nickelson et al. 1992; Richards et al. 1992; Morley et al. 2005; Hillman et al. 2016). The lack of results may be due to low densities across most sites, with several sites having no fish of a particular species found across several years of sampling. Moreover, the monitoring of fish, channel capacity, and floodprone width was not done consistently within and among projects across years, making detection of differences due to restoration more difficult.

Mixed results across all metrics and the inability to assess data using more rigorous statistical methods (mixed-effects models) may be due to a variety of other factors including: sample timing, variability in restoration treatments, need for geographic stratification, and added variability from controls that were not well matched with impact reaches. Rather than an indication that the SRFB funded floodplain enhancement projects monitored were not successful, it highlights long-term challenges in implementing a MBACI design, limitations of the protocols used, and problems with implementation of the actual monitoring. It is inevitable that a few sites may have to be excluded because the restoration was not implemented in the required time. However, the combination of the MC-5 and MC-6 categories in 2010, which had different protocols and sample schedules, and issues with selecting similar treatment and controls, added additional variability and resulted in data from 10 of the 23 sites not being useable. Moreover, neither the SRFB protocol or the CHaMP protocols are well suited for monitoring floodplain projects as they focus on the active channel. Because floodplain enhancement projects are typically designed to reconnect side channels and the floodplain with the main channel, it is critical that a protocol that captures both the floodplain and in-channel topography is used. Given the advances in remote sensing, an efficient approach using a combination of remote sensing and field-based methods should be used.

While the original protocol called for fish surveys during summer low flow and winter high flow, the timing of fish and habitat surveys did not consistently occur during summer and winter months. This again added additional variability and emphasizes the need for consistent timed fish surveys during summer and winter. The 23 sites monitored covered a broad range of ecoregions in eastern and western Washington. In the future, stratifying sites by geographic or climatic region, channel size, or target fish species should help account for differences among floodplain enhancement sites.

Floodplain restoration projects are critical for Chinook salmon recovery and are some of the largest and most popular techniques. Therefore, they are a priority for monitoring and evaluation and should be part of future PE monitoring. The optimal study design will depend in part on the number and size of floodplain restoration projects completed and proposed. If most floodplain projects are on the order of one to two kilometers in length, a post-treatment design would be a more efficient and proven method of evaluating the effectiveness of this project category (e.g., Hering et al. 2015; Schmutz et al. 2016; see Roni et al. 2018). In summary, future monitoring of floodplain enhancement projects should consider stratifying projects by ecoregion, seasonal fish sampling (summer, winter), more rigorous selection of treatment and controls, improved survey methods that cover the entire floodplain, and using a post-treatment design that does not require extensive pre-project or lengthy post-project data collection.

### 5.1.6 MC-8 Diversion Screening

Data collection for diversion screening occurred between 2004 to 2008 and final results for this project category were provided in the 2009 Annual Report (Tetra Tech 2010). A total of nine diversion screening projects were monitored (Figure 21; Table 37). Monitoring of this category was simple compliance monitoring to determine whether diversion screens met Washington Department of Fish and Wildlife and National Oceanic and Atmospheric Administration (NOAA) Fisheries Guidance (Crawford 2011a). In both years monitored (Years 1 and 2 post-treatment), all projects were in compliance with 80% of parameters measured and considered effective. In part because this was largely compliance monitoring and success depends on maintenance and cleaning of screens, monitoring of diversion screens was discontinued in 2009 (Tetra Tech 2010). Data for this category were not available in the SRFB PE Access database or summary tables, but we were able to pull data out of the 2008 Final Report and provided it in Appendix F (Tetra Tech 2009). There were eleven categorical metrics for determining whether a diversion screen is meeting management criteria (parallel flow, approach velocity, uniform flow, sweeping velocity vs approach velocity, sweeping velocity decrease, screen mesh size, corrosion resistant, gaps, maximum water withdrawal, debris accumulation, and clearance) (see Crawford 2011a for a description). Because this category is compliance monitoring, we do not think it should be part of project effectiveness monitoring and we did not examine the sites, protocols, or design in detail. It does appear that there are a range of types of diversion screens and not all metrics may be appropriate for each type of diversion screen.

**Table 37.** Description of diversion screening projects evaluated between 2004 and 2009. Multiple sites were monitored at project number 04-1373 and 04-1568 resulting in a total of nine diversions screens evaluated. Information from 2008 Annual Report (Tetra Tech 2009).

| Site ID | Site name | Stream | Description |
|---|---|---|---|
| 02-1540 | Touchet River Screens | Touchet River | Install pump intake screen to reduce fish take from pond surface withdrawal |
| 02-1543 | Walla Walla Fish Screening | Garrison Creek | Install fish screens and flow meters on 100 small urban irrigation pump diversions of fish bearing streams and ditches in Walla Walla County |
| 02-1544 | Tucannon River Screens | Tucannon River | Install fish screens upstream and downstream of Territorial Road on the Tucannon River to reduce fish take and streambed disturbance |
| 02-1656 | Dry/Cabin Creek Fish Screening | Dry Creek | Install fish screen, fish passage structure, mini-pivot irrigation systems, and riparian tree and shrub plantings to a tributary of the Yakima River |
| 04-1373a | Indian Creek - McDaniels 1 | Indian Creek | Install diversion screens and fish bypass system on private property of Indian Creek |
| 04-1373b | Indian Creek - McDaniels 2 | Indian Creek | Install diversion screens and fish bypass system on private property of Indian Creek |
| 04-1373c | Indian Creek - Roy | Indian Creek | Install diversion screens and fish bypass system on private property of Indian Creek |
| 04-1508 | Jones-Shotwell Screen & Diversion | Unnamed Creek | Replace existing fish screens on the lower Wenatchee River |
| 04-1568a | Garfield County Screening - Deadman | Deadman Creek | Install 30 fish screens throughout Garfield County on multiple streams |
| 04-1568b | Garfield County Screening - Meadow | Meadow Creek | Install 30 fish screens throughout Garfield County on multiple streams |

## 5.1.7 MC-10 Habitat Protection

Data collection for habitat protection projects occurred between 2004 to 2014 and final results for this project category were provided in the 2015 Annual Report (Tetra Tech 2016). Data for this category are provided in Appendix G. Rather than effectiveness monitoring and monitoring of control and impact sites, habitat protection projects were status and trend monitoring of impact (habitat protection) project area (Tetra Tech 2016; Table 38). Monitoring at these sites included a combination of protocols for upland, riparian, and instream protocols and 23 different metrics were identified for monitoring in the original study plan (Crawford 2011b). Metrics monitoring included but were not limited to wood volume, residual pool profile area, percent fines, canopy cover, riparian vegetation structure, non-native shrub and vascular plant cover, conifer density and basal area, fish species assemblage index, macroinvertebrates indices of integrity, as well as intertidal measures for estuarine projects. Because of this, questions being asked were different than other project types and included:

1. Does the habitat quality at this parcel rate highly as compared to standard indices of ecological health?
2. Is the habitat quality at this parcel maintaining or improving through time?

**Table 38.** Description of habitat projection projects evaluated between 2004 and 2009. Information from 2008 Annual Report (Tetra Tech 2009).

| Site ID | Site name | Stream | Description |
|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | Entiat River | Approximately 3 mi on the Entiat River mainstem to protect spawning and rearing habitat |
| 00-1788 | Rock Creek/Ravensdale-Retreat | Rock Creek | Approximately 204 acres along Rock Creek, a tributary to the Cedar River, including areas previously harvested for timber |
| 00-1841 | Metzler Park Side Channel Acquisition | Green River | Over 900 acres on a side channel of the Green River, northwest of Enumclaw; 75 acres are hydraulically connected and provide rearing habitat |
| 01-1353 | Logging Camp Canyon Acquisition | Logging Camp Creek | 293 acres previously used for timber harvest and cattle grazing in the Klickitat River watershed to protect spawning and rearing habitat |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | Chimacum Creek | 15.3 acres of forested riparian habitat to protect the shoreline, estuary, and forested stream |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | Mashel River | 65 acres of old-growth timber; protects 1 mi of Mashel River shoreline |
| 02-1592 | Curley Creek Estuary Acquisition | Curley Creek | Approximately 20 acres of Curley Creek, which includes the entire shoreline, surrounding slopes, and upland forest parcels |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | Issaquah Creek | 152 acres of mature forests, wetlands, and riparian habitat, along 1.5 mi of Issaquah Creek; protects excellent rearing and spawning habitat |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | Methow River | Protect 1,000 acres and 6.8 mi of river between Winthrop and Mazama; property consists of riparian, side channels, LWD, and spawning areas |
| 04-1335 | Piner Point on Maury Island | Puget Sound | Approximately 6 acres on the southeast tip of Maury Island, to conserve 400 m of shoreline and nearshore functions |

Based on summary information in the 2014 Annual Report, most metrics had shown little change from 2004 through 2014 (Tetra Tech 2015), which suggests sites are remaining stable. A significant decrease in the basal area of deciduous vegetation and increase in conifer basal area was reported. Invasive plant species were also reported to have decreased based on measures of both the relative and absolute cover of herbaceous species (Tetra Tech 2015). In contrast, indices of biotic integrity for fish and macroinvertebrates were reported to have decreased significantly. Monitoring of this category was discontinued in 2016 based on the recommendations of the Monitoring Panel (Tetra Tech 2017). First, it should be noted that the SRFB effort to evaluate this category represents one of the few programs to collect data on acquisition and protection projects (Roni et al. 2014). Given that this category of project is really status and trend monitoring, the rapid advances in remote sensing, and the mix of upland, estuarine, and in-channel habitat as well as sites in both eastern and western Washington, it was wise to discontinue this project category. As noted by Tetra Tech (2017), if monitoring of this category was to be continued in the future, projects should be stratified by estuarine and riverine as they use very different protocols. In addition, it would be wise to stratify by eastern and western Washington, site condition (degraded or high quality), and other factors. For example, some lands are acquired to protect high quality habitat, while others are degraded, but assumed that protection would allow passive recovery of the sites. Thus, these two very different scenarios would have different trends over time and should not be combined into one analysis. There have been many advances in remote sensing since the SRFB protocols for MC-10 were developed back in 2003 and 2004 and revised in 2011, and much of the information on vegetation cover could be captured by remote sensing with some field work for ground truthing. This would also allow the entire sites to be covered rather than a small portion as described in the protocol. That being said, it is probably wise that monitoring of acquisition and habitat protection sites be part of a status and trend monitoring program, rather than an effectiveness monitoring program.

## 5.2 Response to Original PE Questions

The original three PE questions largely focus on examining and comparing all restoration project types evaluated. While we attempted to answer these in the summaries by action type above, we provide more direct response to the original three PE questions for restoration project types below.

1. Are restoration treatments having the intended effects regarding local habitats and their use by salmon?

   For most restoration treatments, based on PE it appears that the treatments are having limited effects on local habitat and their use by salmon. However, this appears to be in large part due to how PE monitoring was implemented (e.g., control selection, data collection) and limitations of the protocols rather than a lack of restoration success. We describe these limitations and recommendations for improving PE in the following sections of this chapter.

2. Are some treatments types more effective than others at achieving specific results?

   Similarly, because results were inconclusive for many project types, this question cannot be adequately answered at this time.

3. Can project monitoring results be used to improve the design of future projects?

   For livestock exclusion, results from PE in combination with other published studies emphasize that future projects should assure livestock are excluded. For other restoration project types evaluated under PE, the results to date provide limited information to improve future project design. This is in part due to how PE was implemented and limitations of some monitoring protocols.

## 5.3 Strengths and Weaknesses of PE 2004 to 2018

Based on findings and progress on the seven categories of PE summarized above, we summarize what we believe are the strengths and weaknesses of the original PE Program and make recommendations for future PE monitoring. First, PE is one of the few large PE monitoring programs implemented anywhere to date and the only one that has been completed in the Pacific Northwest (Roni et al. 2018). Most published project effectiveness monitoring has focused on effectiveness of one or a few techniques and a small number of study sites (Ernst et al. 2010; Louhi et al. 2016), relied on a meta-analysis of a series of case studies (e.g., Avery 2004; Binns 2004), or conducted post-treatment study designs (Roni and Quinn 2001; Louhi et al. 2011). The SRFB PE Program also represents the largest effectiveness monitoring program implemented by a state receiving Pacific Coastal Salmon Recovery funds.

While some of the results of PE have been promising, many project types have shown small or no increases in key metrics. Programmatic effectiveness monitoring programs like PE are not without challenges which include: selecting appropriate treatments and controls, selecting appropriate protocols and metrics, consistent data collection across years and crews, controlling restoration timing and location, data management, and others (Roni et al. 2005, 2015b, 2018). The SRFB PE Program has run into some of the challenges seen in other large monitoring programs including inconsistent protocols, poor pairing of treatments and controls, assuring control reaches are not treated, data management problems, and inconsistent or changing sampling protocols (Reid 2001; Bennett et al. 2016; Roni et al. 2018). Many of these are implementation or procedural rather than design issues (Reid 2001), which have limited the usefulness of data and made detecting significant differences due to restoration difficult. This has resulted in questions about whether the actual restoration actions implemented are ineffective or if aspects of the design, monitoring protocols, implementation, or analysis and reporting have limited the ability of the PE Program to detect a response. The lack of response seen in the SRFB PE Program to date should not be seen as evidence that fish or habitat responses to floodplain or instream habitat restoration measures cannot be measured, as other studies in other regions have detected response for many of the action types examined under PE (see Roni et al. 2008, 2014, and Hillman et al. 2016 for reviews). Rather, the results emphasize the importance of proper design and implementation of large programmatic effectiveness monitoring programs.

With the exception of MC-8 diversion screening and MC-10 habitat protection, all other action types were implemented with a MBACI design, with samples sizes of 9 to more than 20 projects depending upon the action type. The MBACI design has long been considered an optimal design for monitoring habitat change or evaluating restoration effectiveness (Underwood 1991; Downes et al. 2002; Roni et al. 2005; Bennett et al. 2016), though it has rarely been implemented at a broad scale due to the cost, need for diligent project coordination and management, and the lengthy time frame needed to produce results. However, it appears to only be successful when implemented on a handful of projects as collecting before and after data on many treatments and controls has proven difficult (see Roni et al. 2018 for a review). The PE Program presents a good example of this where many sites had to be excluded from analysis or dropped because a control site was restored or access at some sites was denied in post-treatment years by landowners.

Another design issue is the temporal replication. PE was originally designed, to collect one year of pre-project data and multiple years of post-project data. There was a relatively straightforward comparison of pre-project data (impact minus control) to one year of post-project data using a paired *t*-test and each year analyzed separately (Crawford 2011c). This is actually a fairly robust design assuming one uses just one year before and one year after in a paired-design analysis with the goal to detect differences in the effectiveness of a project category. If one tries to apply a trend analysis to this, or a more robust BACI type analysis with a linear mixed-effects model, one year of pre-project data makes the design unbalanced and becomes highly dependent on the single pre-project data point. The result is often a call for more pre-project data and a power and sample size analysis that suggests much more pre-project data is needed to detect a difference (Lierman and Roni 2008; O'Neal et al. 2016). However, as has been demonstrated by PE, collecting even one year of pre-project data is often difficult as project sponsors may change both the design and location of restoration a few months before a project is implemented. In some cases, crews tried to collect pre-project immediately before implementation, and then a few months later in the same summer[2]. Similarly, collecting multiple years of pre-project data at many sites can be very difficult as has

[2] This is also an example of less than ideal implementation when pre-project data and post-project data were collected in the same year rather than 1 year before and 1 year after.

been observed in the Bonneville Power Administration's (BPA) Action Effectiveness Monitoring program, which has been collecting two rather than one year of pre-project data.

PE was designed with the understanding that a simple *t*-test would be used to compare data one year before and one year after project implementation, with the analysis being repeated with each additional year of data collection. At some point an additional analysis was added to the PE Program—including a trend analysis using a *t*-test on the slopes of individual sites (Tetra Tech 2016). We examined these two approaches as well as a mixed-effects BACI model (Chapter 2 and 3). We examined the first two because they were a requirement of our contract, and the third, because it is what is typically used for a BACI design (Underwood 1992; Downes et al. 2002; Schwarz 2015). These three analyses produced similar results, but given the monitoring design used by the SRFB, we have the most confidence in the paired *t*-test analysis. The *t*-test is a simple analysis, easily understood by managers, and is robust to minor violations of assumptions of normality. Moreover, we feel *t*-tests are the most appropriate analysis given that there is only one year of pre-project data. If one is interested in looking at trends in project effectiveness, one can look at the trends in differences before and after Year 1 (Year 1 minus Year 0), Year 3 (Year 3 minus Year 0), and Year 5 (Year 5 minus Year 0) (Figure 22). This is basically the data used for the paired *t*-test for each before (Year 0) and after (Year 1, 3, 5, etc.) and the trend should be apparent graphically. Finally, the protocols for PE call for using a one-sided *t*-test with a 0.10 level of significance. One would hope that we would only see increases due to restoration, though that is not always the case, which is why we would typically conduct a two-sided test and look at the direction of any significant changes. A 0.10 level of significance with a one-sided *t*-test is equivalent to a 0.20 level of significance with a two-sided t-test and a more liberal level of significance (i.e., more likely to detect a change that is not real) than we have seen used in other studies or that we would recommend using in the future. The level of statistical significance is in part a policy decision and some managers may be more comfortable with a more liberal confidence interval and greater room for error than seen in most studies.

### 5.3.1 Protocols

Most of the protocols used for PE were based on protocols developed for the EPA EMAP Program (Kaufmann et al. 1999; Larsen et al. 2001, 2004). This nationwide status and trend monitoring program had a long history, and the metrics had been widely tested. When PE was developed in the early 2000s, there was push for standardized protocols and a push to use EPA protocols. These protocols were selected for both PE and the Intensively Monitored Watersheds (IMWs). While EMAP protocols and metrics were suitable for the goals of EPA's EMAP program, and would appear suitable for monitoring instream habitat characteristics, they are not well suited to measure response to many restoration techniques. This is largely because they do not measure metrics that often directly respond to wood placement or floodplain restoration such as percent pool habitat, area of different types of habitat, residual pool depth, or areas outside the active channel. For example, the EMAP protocols calculate vertical pool profile area and mean residual profile depth, which are surrogates for but not actual measurements of pool area or residual pool depth. An attempt was made in 2013 to implement a topographic survey based on CHaMP. This again would seem logical given that BPA had implemented a large program using this very intensive topographic survey method across the Columbia River Basin and

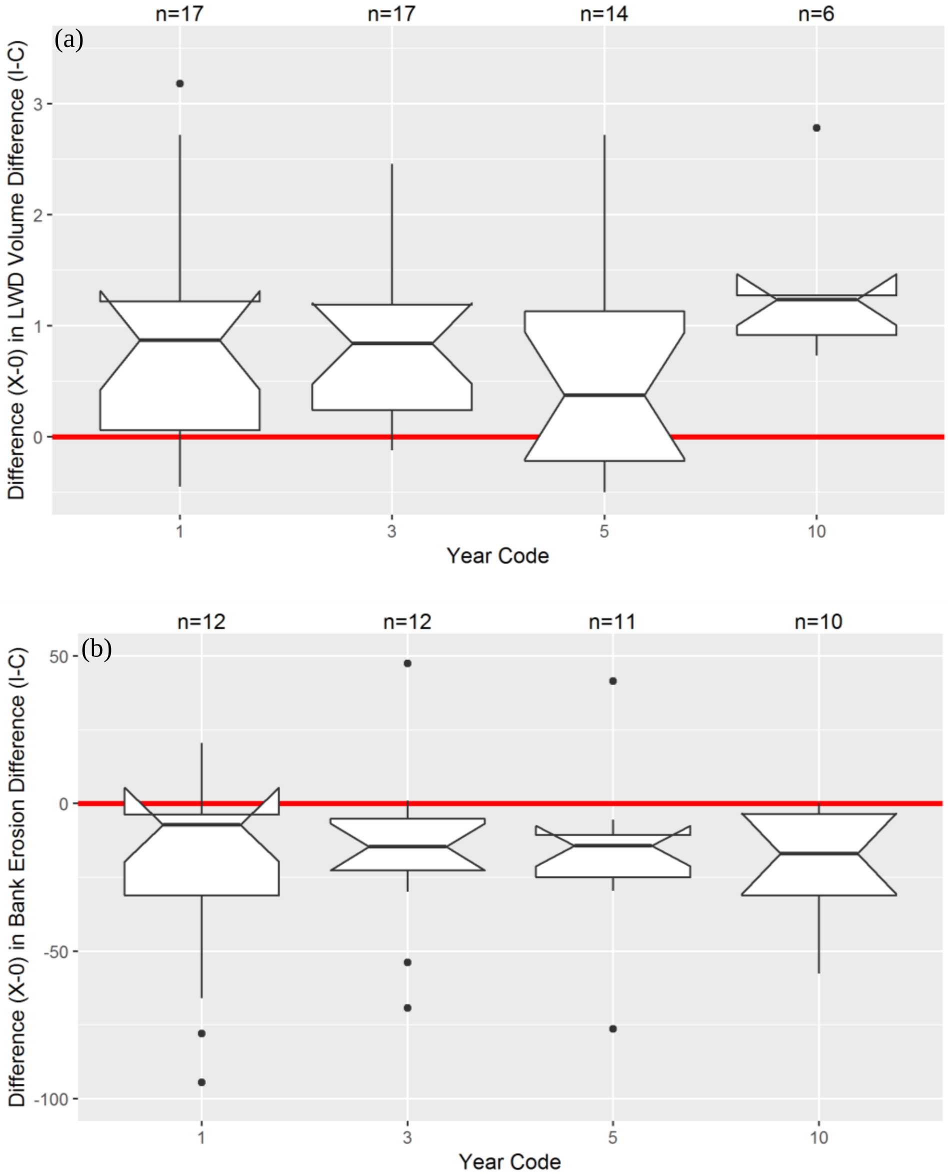


**Figure 22.** Example of box plots showing the difference in the impact (I) minus control (C) of Year 0 minus the impact minus control for each subsequent year (Year 1, 3, 5, 10) for large wood volume (MC-2) and bank erosion (MC-4). The top graph (a) for large wood volume, highlights that some metrics will initially increase but show no trend, while the bottom graph (b) shows that a slight trend may occur over time.

required many of its contractors to use this approach. The CHaMP protocol is also very labor intensive, requiring a three-person crew 2 to 4 days in many cases to conduct just the topographic survey, which also increased the cost of monitoring. Unfortunately, adopting the CHaMP topographic survey and protocols led to changes in the protocol for some sites midway through the PE Program for floodplain and to a lesser extent instream habitat project categories. Only two floodplain sites had pre-project CHaMP topographic surveys, while the rest of the floodplain sites did not. Thus, for floodplain projects, pre-project data collected using the SRFB protocol was typically being compared to post-project data collected using CHaMP topographic surveys. Thus, the benefits of this more intensive and costly habitat survey approach were not realized and the PE metrics were simply extracted from the CHaMP topographic surveys. Wood surveys were also not consistent among CHaMP and PE, with the CHaMP protocol for wood and other metrics changing several times since it was implemented and was not necessarily the same bin classes as the basic SRFB protocol (CHaMP 2011; Crawford 2011d; CHaMP 2013). This is consistent with findings by Rosgen et al. (2018), who conducted a detailed review of CHaMP for BPA and reported widespread inconsistencies in data collection, survey length and extent, and high variability in many metrics that should not have changed from one survey to the next. Because of widespread issues with the CHaMP protocol, BPA is phasing out the CHaMP program and it is unclear how data for PE sites housed in the CHaMP database will be managed or available in the future, though, as noted previously, much of the data is not useful for PE. Neither CHaMP or PE SRFB protocols were designed to monitor outside the active channel. This is major shortcoming for floodplain enhancement projects (MC-5/6) as much of the expected changes would be additional side channels and off-channel habitats outside the bankfull channel.

The protocol for examining riparian vegetation structure for livestock exclusion and riparian planting projects could also have been more robust. Percent fines was only collected post-treatment at livestock exclusion sites, and no habitat data was collected for fish passage barrier projects. There have been many advances in methods for monitoring riparian vegetation and floodplain restoration both for ground-based surveys as well as remote sensing (Merritt et al. 2017; Roni et al. *In review*) and any monitoring of future riparian planting and floodplain projects should use a combination of remote sensing and field surveys.

### 5.3.2 Implementation

A critical part of any monitoring program is implementation. The design, replication, field methods, and protocols can be rigorous, but many large effectiveness monitoring programs fail due to issues with implementation (Reid 2001; Roni et al. 2015b, 2018). The SRFB PE Program is a large program, and the SRFB and Tetra Tech should be commended for implementing a large effectiveness monitoring program with so many different project types. As noted previously, given the size of the program, it is not unexpected that maintaining all treatments and controls as treatments and controls over the long-term would not be possible and some sites would have to be dropped because of unforeseen changes in ownership or additional restoration. In taking over the project in 2016, we have the advantage of hindsight and have unfortunately found fairly consistent problems with implementation of PE that have added additional variability, resulting in many sites needing to be dropped. These issues seemed to cut across all project types and include issues of selection of poorly matched treatment and controls, timing and season of data collection, and extent and location of treatments and controls from one year to the next. There are several sources that provide guidance on selecting treatments and controls and the differences between treatments, controls, and references (e.g. Downs et al. 2002; Roni et al. 2005, 2013). Again, with a large program like this, one might expect that a few projects might have these issues. However, the issues with implementation are so consistent and widespread that field crews that implemented the SRFB PE Program likely did not understand the importance of attention to these details or the ramifications of them to the monitoring program and ultimately the analysis and reporting.

### 5.3.3 Data Management

The management of the data for a large program like PE is a critical component, and failure to adequately manage data can render even the best monitoring data useless. Most of the raw data for PE are housed in a SRFB PE Access database, though some of the topographic survey data is housed on the CHaMP database. In addition, Tetra Tech provided summary data with all metrics and years in excel spreadsheets for six of the seven categories as part of the completion of their contract. We relied on these data for our analysis, but when we re-ran some summary statistics for projects in the database, we found some inconsistencies in the summary datasheets, data in the SRFB PE database, the CHaMP database, and those reported in annual reports. For example, spawner and redd count data for barrier removal projects are listed as mostly 0 in the summary spreadsheets though have values greater than zero in the PE database and annual reports; riparian planting survival rates differed between the summary sheet and the PE database and previous annual reports; fish counts for floodplain sites were reported as 0 in summary tables when in fact they were never snorkeled; and wood counts for instream projects differed between annual reports, CHaMP database, PE database, and summary database. We were not able to locate any documentation that described why these data were missing, inconsistent, or what changes were made to data to be used in analysis and annual reports. Again, this suggests that there was not adequate documentation of the data collected and used in the analysis. It unfortunately undermines our confidence in the quality of the data collected and in the database. The previous contractor had recommended that the PE data be moved to a more user-friendly platform (K. Dublanica, RCO, pers. communication). Indeed, the PE Access database is cumbersome, and databases have advanced greatly since the inception of PE. However, moving the database to a model platform is probably not a good use of funds at this time given other issues with data collection, implementation, and data management.

## 5.4 Recommendations for the Future

Based on our analyses and results discussed above, existing literature, recent reviews on programmatic project effectiveness monitoring programs (Roni et al. 2018; Weber et al. 2018), and our experience with different types of habitat restoration projects over the last 25 years, we provide recommendations for future project effectiveness monitoring. Specifically, we discuss what categories the SRFB should continue to monitor, the most appropriate monitoring designs and protocols, and key considerations for both implementation and data management.

First, of the seven project categories originally implemented under PE, only a few warrant additional monitoring and at least two simply need better compliance monitoring (Table 39). Barrier removal projects are considered one of the most successful salmon habitat restoration projects assuming the barrier is completely removed, or the stream crossing or fish passage structure remains passable (Pess et al. 2005; Clark et al. *In review*). Thus, this project type is best monitored with simple compliance monitoring to assure the structure continues to meet fish passage criteria established by WDFW and others. While results for instream habitat projects monitored under PE showed an increase in some physical habitat metrics as expected, they did not show significant increases in fish numbers. However, this is likely the result of numerous factors not necessarily related the effectiveness of projects. Moreover, instream habitat projects have been widely evaluated most recently under BPA's Action Effectiveness Monitoring (AEM) Program, which looked at nearly 30 projects in the Columbia River Basin (Clark and Roni 2018). They are also one of the most common techniques being evaluated under the IMW program (Bennett et al. 2016). These and other studies have shown that most salmonids respond positively to placement of instream wood, and that the amount and location of wood placement are key factors determining physical and biological response (Roni et al. 2015a). Therefore, additional broad-scale monitoring of instream projects is not recommended, though a focused well-controlled study examining different levels of wood placement may be warranted to assist with specific project design questions.

**Table 39.** Different categories of project types and whether they should be included in a future phase of the Project Effectiveness Monitoring Program (PE) and why or why not.

| Category | Name | Additional PE monitoring | Reason |
|---|---|---|---|
| MC-1 | Fish Passage | No | Well studied |
| MC-2 | Instream Habitat | No | Well studied with exception of winter data and specific design considerations |
| MC-3 | Riparian Planting | Yes | Common technique with limited monitoring and variable success |
| MC-4 | Livestock Exclusion | No | Well studied; success dependent on maintaining fencing; conduct compliance monitoring |
| MC-5/6* | Floodplain Enhancement | Yes | Increasingly common approach, previous PE monitoring inconclusive due to implementation issues |
| MC-8 | Diversion Screening | No | Compliance monitoring |
| MC-10 | Habitat Protection | No | This should be part of a status and trend monitoring program. |
| NA | Nearshore | Yes | Increasing common technique that has not been evaluated and could be easily done |
| NA | Estuarine | No | It would be difficult to evaluate as part of PE, but case studies evaluating this category should be initiated as part of comprehensive monitoring program (IMW or other) |

Monitoring of riparian planting projects produced inconclusive results. This is, however, a widespread technique that has received relatively little effectiveness monitoring. Moreover, most projects occur at a site or reach scale which is well suited for a PE Program (Roni et al. 2005, 2013, 2018). A common component of riparian planning projects is invasive plant species removal and this sub-category of riparian restoration has also not been well evaluated. As noted previously, the original BACI design is likely appropriate for riparian projects including invasive plant removal, but a larger sample size, including stratification by ecoregion and monitoring using more rigorous field and remote sensing protocols is needed. For livestock exclusion projects, despite some limitations in the protocols and implementation, the results are consistent with previous studies and highlight the need for compliance (implementation) monitoring rather than effectiveness monitoring (see Chapter 3). There is limited information on fish response to livestock exclusion projects, and most studies have shown inconclusive results for fish. However, additional information on fish response would best be obtained as a case study or research project than as part of PE. Similarly, diversion screening projects, are effective assuming they are maintained and require simple continuous compliance monitoring and do not need to be included as part of PE monitoring. PE does represent one of the few programs that have attempted to monitor acquisition and habitat protection projects, but this is really status and trend monitoring without any control or real treatment. This category is likely best monitored as part of status and trends monitoring program that uses a combination of remote sensing and field-based sampling.

Monitoring of floodplain enhancement projects under PE was discontinued in 2018, because of inconsistencies in data collection across years, including lack of fish and riparian data, sampling in different seasons, poorly matched impact and control reaches in some cases, and limitations of current protocols. Floodplain enhancement is, however, one of the most common restoration methods and is critical for recovering Chinook salmon. It is a project category in need of additional monitoring and evaluation and should be a priority for the PE Program moving forward. There have been considerable improvements in methods for monitoring floodplain projects since the inception of PE in 2004, and both new protocols and a different monitoring design are needed to effectively and efficiently evaluate floodplain projects. The original SRFB PE monitoring was designed back in the early 2000s when many projects were relatively small (100 to 1,000 m in length) and often included one or two techniques. These types of projects and their size lend themselves to the monitoring approach historically utilized by the SRFB. Floodplain projects have become increasingly complex, often involving multiple restoration action types (e.g., riparian planting, wood placement, side channel creation, levee removal). Moreover, while there are still many floodplain projects that cover a kilometer or two, some projects cover many kilometers. For example, for the middle Entiat Project, eight kilometers of riverine and floodplain habitat are proposed to be restored in 2019 and 2020 using a combination of wood placement, levee removal, and reconnection or creation of side channels. To properly inform monitoring of floodplain enhancement projects, we queried the PRISM data base to get details on project size in recent years (Figure 23). While we are aware of several large projects in recent years, the data in the PRISM database suggest that floodplain projects have not been increasing in number and size and the average annual projects size appears to be on the order of 0.5 miles (0.8 kilometers).

This suggests that effectiveness monitoring of floodplain projects should be focused at the reach scale (1 to 2 kilometers). This also helps inform the design and protocols that one might use to evaluate projects of this size. As noted previously, the MBACI design has long been considered an optimal design for monitoring habitat change or evaluating restoration effectiveness (Downes et al. 2002; Roni et al. 2005; Bennett et al. 2016), though it has rarely been implemented at a broad scale due to the cost, need for diligent project coordination and management, and the lengthy time frame needed to produce results. It is also difficult to change the protocols once it is initiated. Our recent review of PE monitoring approaches also indicated that MBACI monitoring is only tractable with a handful of projects. Moreover, the extensive post-treatment (EPT) design has been widely used particularly in Europe in recent years to evaluate floodplain restoration projects (e.g., Hering et al. 2015; Schmutz et al. 2016; see Roni et al. 2018 for review). It has also been used to monitor effectiveness of reconnected side channels as well as instream structures in the Pacific Northwest (Morley et al. 2005; Clark and Roni 2018). This design, which includes sampling multiple (>10) paired treatments and controls at some point after treatment, can be completed in a relatively short period of time (two to three years) assuming a large enough population of projects are available with suitable treatments and controls. Because pre-project data is not collected, it does not typically allow one to determine effectiveness of a specific project, but similar to the original PE Program, it does provide information on the average response of a project category. Moreover, the extensive replication at a number of sites, typically 15 to 30 projects are monitored, allows one to examine why some projects are more successful than others. Given the number of completed floodplain projects in the database (>200), it appears there is an adequate sample size to use this design to evaluate completed floodplain projects. Treatments and controls 500 m to 2 km in length could be selected for monitoring with protocols that use a combination of remote sensing and field surveys. Rather than separate out

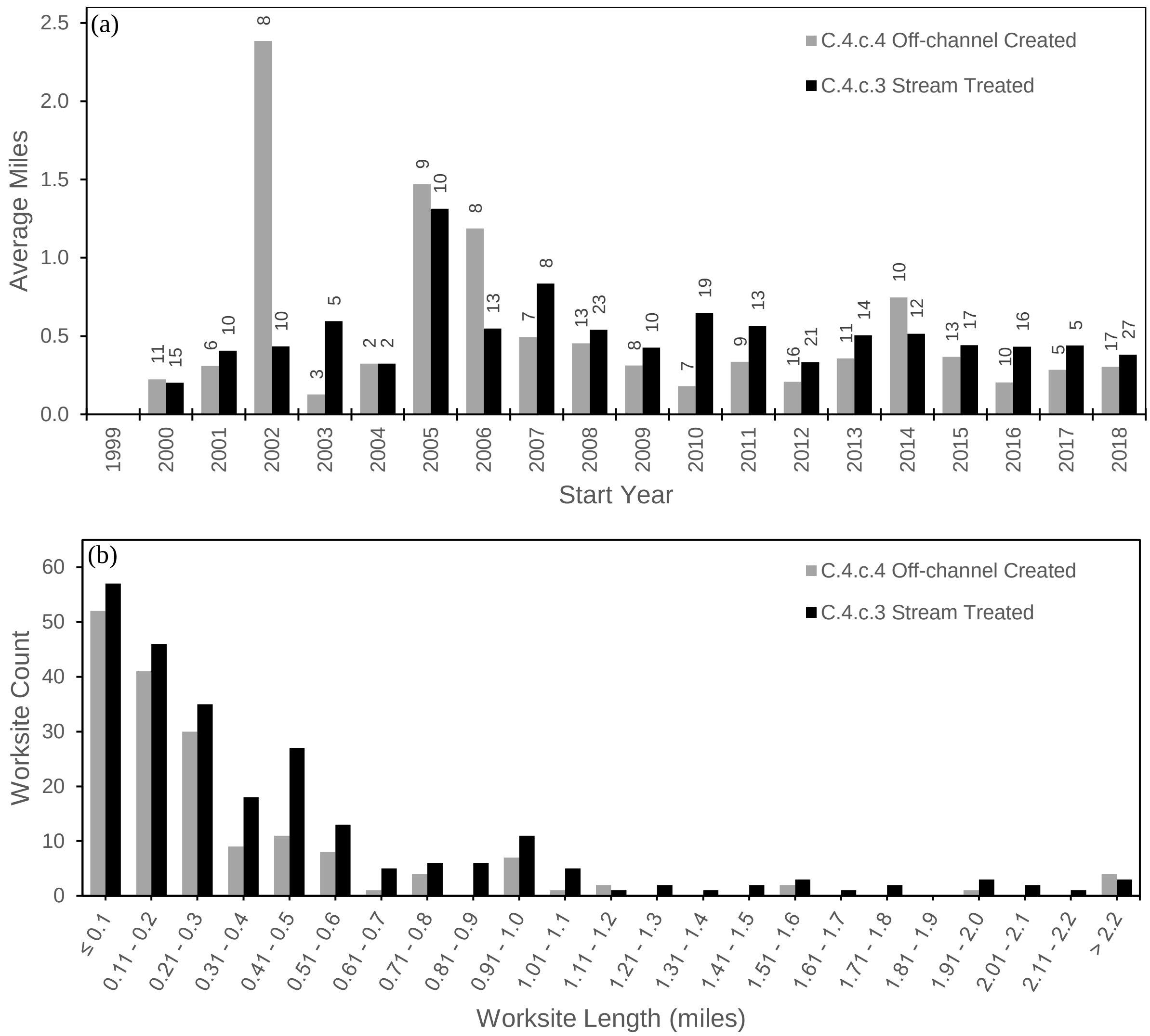


**Figure 23.** Average length in miles of channel structure placed, off-channel created, and stream treated per project worksite from 1999 to 2018 reported in the PRISM databased (a). The numbers above each bar indicate the number of worksites (restoration sites). We used project work site, because several multi-year projects include worksites on multiple streams. Histogram showing the frequency of different sizes of floodplain projects in terms of off-channel miles created and stream length treated (b).

reconnected side channels, wood placement, riparian planting, and other specific techniques that would be implemented at a particular work site, the entire channel and floodplain would be monitored to incorporate the response of all the treatments to the project area. Because this design focuses on completed projects, some of the previously monitored sites could be included assuming they have suitable treatments and controls. In addition, given that BPA is currently evaluating numerous floodplain projects across the interior Columbia River Basin above Bonneville Dam as part of their AEM Program, it would be wise for PE to focus on western Washington. This would eliminate some of the need for stratification of sites in eastern and western Washington and assure that a similar group of fish species are present at most sites and will be adequately enumerated with consistent timing of sampling (summer or winter low flow). For example, one challenge with eastern and western Washington sites was the presence of juvenile spring Chinook at eastern Washington sites during summer, while fall Chinook present at most western Washington sites had already emigrated to sea and were not observed.

A key part of continuing to monitor floodplain enhancement projects, would be completely revising protocols to use the latest methodologies. We recently reviewed historic, current, and new methods for evaluating the physical and biological effectiveness of floodplain restoration projects, including both field and remote sensing-based approaches (Roni et al. *In review*). Having a topographic survey of treatment and control sites will be important and the use of a real time kinematic (RTK), a Lidar equipped drone, or other methods rather than a total station would allow relatively rapid topographic mapping of sites (i.e., a treatment and control pair could be mapped in 1 to 2 days). Surveys for juvenile salmonids could be conducted with snorkel surveys and repeated consistently in both summer low flow and winter low flow to quantify fish response. The winter sampling in western Washington is more difficult and would have to be conducted at night, but it can be done (Roni and Quinn 2001; Morley et al. 2005). However, it is possible that environmental DNA (eDNA) could be used to sample sites in winter if simple presence and absence in side channels is desired.

The design and approach described in the previous paragraph, would not work well to evaluate very large floodplain restoration projects that cover several kilometers. These large projects, which are far less common, could be evaluated as part of PE using a simple before and after restoration design and modern remote sensing techniques (e.g., Lidar, drone-based aerial photography), combined with efficient sampling protocols (e.g., long-profiles, habitat surveys using RTK units, snorkel surveys, eDNA). This is also possible because often the very large floodplain restoration projects take several years to plan, allowing adequate time to get pre-project data. Moreover, the physical changes on a project that covers 5 kilometers, or more are typically so large that graphical analysis can clearly demonstrate the changes in pool habitat, side channels, and floodplain connection. We are currently testing this approach on the middle Entiat as part of BPA's AEM Program and will have results for that later this winter that would help inform the protocols evaluating additional large floodplain projects like this.

Two other project categories that have not been evaluated are nearshore and estuarine restoration. Given the high percentage of bank armoring in Puget Sound and other marine shorelines in Washington State and the importance of these habitats for juvenile salmon and forage fish, nearshore has become an increasingly common restoration strategy. It is also one restoration type we have relatively little information on its overall effectiveness, particularly for salmon. In looking at data reported in PRISM on nearshore projects, there appear to be 59 unique worksites with the average length of shoreline armoring removal ranging from a few hundreds of feet to nearly a mile (Figure 24). Based on these data, there are enough projects that have been implemented in Puget Sound in the last ten or more years, that a simple extensive post-treatment design examining paired treatment (removal of bank armoring) and control (armored banks) would be relatively easy to implement. A similar design has been used with success to compare natural and armored shorelines in Puget Sound for forage fish and invertebrates, and also bank armoring removal in the Duwamish River (e.g., Rice 2006; Tonnes 2008; Morley et al. 2012; Heerhartz et al. 2015; Dethier et al. 2016). Because the nearshore project category is in the marine environment and juvenile salmonids and other fish use of these habitats varies throughout the year, sampling is more complex than examining removal of bank armoring in the riverine environment. However, each group of paired sites could be topographically mapped including habitat characterized with an RTK unit or total station early in the year, and then fish and other biota quantified at key seasons throughout the year. Typically, a sample of 12 or more paired sites is adequate to detect significant differences, particularly if all the sites are in Puget Sound. A slightly larger sample might be needed if sites in other coastal areas are included.

While estuarine restoration was an original category under PE, it was never implemented. The monitoring of estuarine restoration projects is potentially the most complicated in part because of the diversity of estuaries in terms of size, morphology, and other factors. For example, there are 16 delta estuaries in Puget Sound, plus many other barrier or coastal inlet embayments (often called pocket estuaries) (Cereghino et al. 2012). Restoration of these areas is a high priority for salmon recovery. There are a variety of restoration measures implemented, though monitoring and evaluation of these actions to date has largely been through individual case studies (e.g., Skagit River IMW, Qwuloolt/Snohomish River Estuary Monitoring). Estuarine restoration projects include removal of tide gates and culverts, fill, dikes, and other infrastructure as well as creation of new estuarine habitat and channel modification. Moreover, analysis of project and work site data for estuary restoration projects indicates that projects are split between large major Puget Sound estuaries and small or pocket estuaries, with 66 of 96 project work sites implemented between 2000 and 2018 occurring in one of 16 large Puget Sound estuaries.

Given differences in size and variety of project types and estuaries, a coordinated programmatic approach for PE monitoring with multiple paired treatments and controls is likely not feasible, particularly for the 16 large delta estuaries in Puget Sound. However, estuarine effectiveness could include a landscape scale component using remote sensing to map broad-scale changes in coverage, vegetation/habitat types, and connectivity as well as local or site scale evaluation of certain project types (dike removal, tide-gate replacement, channel restructuring). It could also include a handful of BACI case studies for both large delta and small estuaries. This would most likely require stratifying by drainage area or estuary type (delta vs. embayment). While most of the estuarine projects are in Puget Sound, there are projects along the Strait of Juan de Fuca, the Washington Coast, and in the Columbia River Estuary and the scope of the monitoring would need to be clearly defined. Another approach would be to use remote sensing to evaluate physical changes similar to status and trends monitoring currently underway (Beechie et al. 2017), to classify different types of marine habitats, and then conduct fish and other biological monitoring at a random subsample of these different habitats. The fish capacity data and presumably other biological data could be applied to other sites to provide estimates of increases in fish abundance due to different estuarine restoration measures.

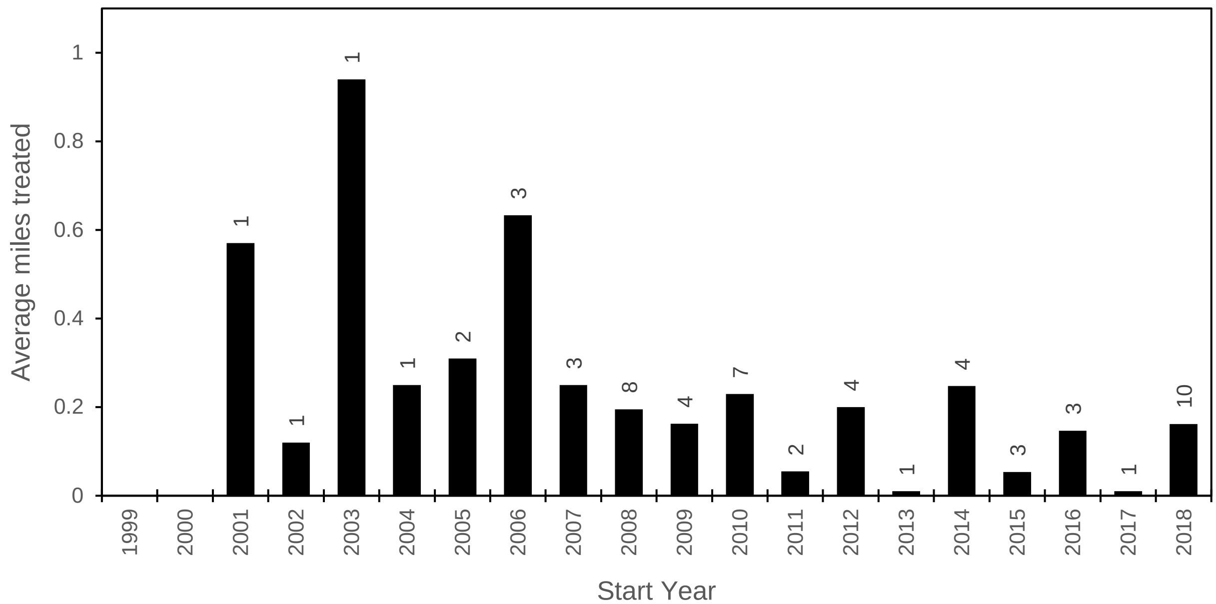


**Figure 24.** Average length of shoreline armoring removed for nearshore restoration projects per worksite from 1999 to 2018 reported in the PRISM databased. This represents a total of 59 worksites. The numbers above each bar indicate the number of worksites (restoration sites). We used project work site, because several multi-year projects include worksites on multiple streams or unique locations.

Finally, any future PE monitoring needs to address the implementation, data management, and reporting issues that have limited the ability of PE to detect changes for the seven project types evaluated to date. First, it is critical that those selecting sites and collecting data understand the ramifications to the study design, results, and analysis of making changes to protocols, treatments and controls, or timing of sampling. Much of this can be overcome by diligent coordination and assuring that those who designed the program remain involved in data collection, analysis, and reporting. Second, a clear program for data management that includes an accessible database, quality control and assurance, and a process for documentation of any modifications to data collected. Third, is to assure that annual reports are in a standard scientific format of questions, methods, results, and discussion and recommendations and include a summary of all data collected in appendices. This reporting format assures that funders and partners can see the data and identify any potential problems early in the program and facilitates comprehensive technical review by an independent science panel. Finally, initial results of the first phase of PE were published in O’Neal et al. (2016), but, given the issues with sites and data we have identified as well as additional data collected since 2015, it will be important to publish a follow-up paper with more recent findings that highlights lessons learned. This would be easiest for livestock exclusion and instream habitat projects, because there is new data, but with some additional analysis could, be done for all project categories.

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# APPENDIX A: MC-1 FISH PASSAGE PROJECT DATA

**Table A-1.** Juvenile Chinook salmon densities (fish/m$^2$) in the impact and control reach for all sampling years for barrier projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 |
|---|---|---|---|---|---|---|---|---|
| 02-1530 | Salmon River Tributary | Impact | 0 | --- | 0 | 0 | --- | 0 |
| | | Control | 0 | --- | 0 | 0 | --- | 0 |
| 02-1574 | Melaney Creek Fish Passage Project | Impact | 0 | 0 | 0 | 0 | --- | --- |
| | | Control | 0 | 0 | 0 | 0.0038 | --- | --- |
| 04-1470 | Hiawatha Fish Passage | Impact | 0 | 0 | 0 | 0 | --- | --- |
| | | Control | 0 | 0 | 0 | 0 | --- | --- |
| 04-1485 | Fulton Dam Barrier Removal | Impact | 0.0005 | 0.0085 | 0 | 0.0001 | --- | --- |
| | | Control | 0 | 0.0006 | 0.0014 | 0 | --- | --- |
| 04-1489 | Chewuch Dam Barrier Removal | Impact | 0 | --- | 0.0246 | 0.0006 | 0.0003 | --- |
| | | Control | 0.0005 | --- | 0.0085 | 0 | 0.0001 | --- |
| 04-1668 | Beeville Road at MP 2.09 | Impact | 0 | --- | 0.0067 | 0.0105 | --- | --- |
| | | Control | 0.0012 | --- | 0 | 0.0014 | --- | --- |
| 04-1689 | Lucas Creek Barrier Correction | Impact | 0 | --- | 0 | 0 | --- | --- |
| | | Control | 0 | --- | 0 | 0 | --- | --- |
| 04-1695 | Dekay Road Fish Barrier | Impact | 0 | --- | 0 | 0.0050 | --- | --- |
| | | Control | 0 | --- | 0 | 0.0025 | --- | --- |
| 05-1498 | Curl Lake Intake Barrier Removal | Impact | 0.0244 | --- | 0.0510 | 0.0120 | --- | --- |
| | | Control | 0.0514 | --- | 0.0349 | 0.0231 | --- | --- |

**Table A-2.** Juvenile Coho salmon densities (fish/m$^2$) in the impact and control reach for all sampling years for barrier projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 |
|---|---|---|---|---|---|---|---|---|
| 02-1530 | Salmon River Tributary | Impact | 0 | --- | 0.0364 | 0.1827 | --- | 0.2034 |
| | | Control | 0.0499 | --- | 0.0231 | 0.3512 | --- | 0.1844 |
| 02-1574 | Melaney Creek Fish Passage Project | Impact | 0 | 0 | 0 | 0.0128 | --- | --- |
| | | Control | 0.0102 | 0.0260 | 0.0026 | 0.0340 | --- | --- |
| 04-1470 | Hiawatha Fish Passage | Impact | 0 | 0.0088 | 0 | 0.1591 | --- | --- |
| | | Control | 0.0082 | 0.0272 | 0 | 0.2148 | --- | --- |
| 04-1485 | Fulton Dam Barrier Removal | Impact | 0 | 0 | 0 | 0 | --- | --- |
| | | Control | 0 | 0 | 0 | 0 | --- | --- |
| 04-1489 | Chewuch Dam Barrier Removal | Impact | 0 | --- | 0 | 0 | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | 0 | --- |
| 04-1668 | Beeville Road at MP 2.09 | Impact | 0.0202 | --- | 0.1481 | 0.1063 | --- | --- |
| | | Control | 0.0617 | --- | 0.0292 | 0.1025 | --- | --- |
| 04-1689 | Lucas Creek Barrier Correction | Impact | 0.0217 | --- | 0.0334 | 0.3084 | --- | --- |
| | | Control | 0 | --- | 0 | 0.1620 | --- | --- |
| 04-1695 | Dekay Road Fish Barrier | Impact | 0.0112 | --- | 0.0236 | 0.0318 | --- | --- |
| | | Control | 0.0100 | --- | 0.0533 | 0.0050 | --- | --- |
| 05-1498 | Curl Lake Intake Barrier Removal | Impact | 0 | --- | 0 | 0 | --- | --- |
| | | Control | 0 | --- | 0 | 0 | --- | --- |

**Table A-3.** Juvenile steelhead densities (fish/m$^2$) in the impact and control reach for all sampling years for barrier projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 |
|---|---|---|---|---|---|---|---|---|
| 02-1530 | Salmon River Tributary | Impact | 0.0189 | --- | 0.0211 | 0 | --- | 0.0452 |
| | | Control | 0.4853 | --- | 0.0099 | 0 | --- | 0.0007 |
| 02-1574 | Melaney Creek Fish Passage Project | Impact | 0.0072 | 0 | 0 | 0.0016 | --- | --- |
| | | Control | 0.0276 | 0.0014 | 0.0026 | 0.0101 | --- | --- |
| 04-1470 | Hiawatha Fish Passage | Impact | 0 | 0 | 0 | 0.0035 | --- | --- |
| | | Control | 0.0218 | 0.0049 | 0.0150 | 0.0027 | --- | --- |
| 04-1485 | Fulton Dam Barrier Removal | Impact | 0.0025 | 0.0011 | 0.0010 | 0.0033 | --- | --- |
| | | Control | 0.0036 | 0.0025 | 0.0007 | 0.0030 | --- | --- |
| 04-1489 | Chewuch Dam Barrier Removal | Impact | 0.0062 | --- | 0.0023 | 0.0009 | 0.0046 | --- |
| | | Control | 0.0025 | --- | 0.0011 | 0.0010 | 0.0033 | --- |
| 04-1668 | Beeville Road at MP 2.09 | Impact | 0 | --- | 0.0135 | 0.0174 | --- | --- |
| | | Control | 0.0024 | --- | 0.0029 | 0.0152 | --- | --- |
| 04-1689 | Lucas Creek Barrier Correction | Impact | 0.0449 | --- | 0.0509 | 0.0722 | --- | --- |
| | | Control | 0.0871 | --- | 0.2221 | 0.0222 | --- | --- |
| 04-1695 | Dekay Road Fish Barrier | Impact | 0 | --- | 0.0007 | 0.0030 | --- | --- |
| | | Control | 0 | --- | 0.0013 | 0.0025 | --- | --- |
| 05-1498 | Curl Lake Intake Barrier Removal | Impact | 0.0329 | --- | 0.0643 | 0.0496 | --- | --- |
| | | Control | 0.0408 | --- | 0.1004 | 0.0659 | --- | --- |

**Table A-4. S**pawner count (number/km) and redd count (number/km) in the impact and control reach for all sampling years for barrier projects. Missing values were not reported in that year for a particular site. Values reported in this table reflect values in the 2008 Annual Report (Tetra Tech 2009) due to several missing values in the provided summary tables.

| | | | Adult spawner count / redd count | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Site ID** | **Site name** | **Reach** | **Year 0** | **Year 0*** | **Year 1** | **Year 2** | **Year 3** | **Year 5** |
| 02-1530 | Salmon River Tributary | Impact | 0 / 0 | --- / --- | 173 / 7 | 7 / 7 | --- / --- | --- / --- |
| | | Control | 53 / 67 | --- / --- | 73 / 7 | 20 / 0 | --- / --- | --- / --- |
| 02-1574 | Melaney Creek Fish Passage Project | Impact | 5 / 0 | --- / --- | 105 / 5 | 5 / 0 | --- / --- | --- / --- |
| | | Control | 48 / 10 | --- / --- | 157 / 19 | 0 / 0 | --- / --- | --- / --- |
| 04-1470 | Hiawatha Fish Passage | Impact | 0 / 0 | 0 / 0 | 227 / 13 | --- / --- | --- / --- | --- / --- |
| | | Control | 0 / 0 | 2,720 / 253 | 127 / 20 | --- / --- | --- / --- | --- / --- |
| 04-1485 | Fulton Dam Barrier Removal | Impact | 16 / 4 | --- / --- | 8 / 0 | 2 / 0 | --- / --- | --- / --- |
| | | Control | 8 / 0 | --- / --- | 4 / 2 | 0 / 0 | --- / --- | --- / --- |
| 04-1489 | Chewuch Dam Barrier Removal | Impact | 256 / 64 | --- / --- | 92 / 80 | 12 / 2 | 2 / 2 | --- / --- |
| | | Control | 16 / 4 | --- / --- | 8 / 0 | 2 / 0 | 2 / 0 | --- / --- |
| 04-1668 | Beeville Road at MP 2.09 | Impact | 0 / 0 | --- / --- | 0 / 0 | 0 / 0 | --- / --- | --- / --- |
| | | Control | 0 / 0 | --- / --- | 0 / 0 | 0 / 0 | --- / --- | --- / --- |
| 04-1689 | Lucas Creek Barrier Correction | Impact | 0 / 0 | --- / --- | 2 / 0 | 0 / 0 | --- / --- | --- / --- |
| | | Control | 0 / 0 | --- / --- | 5 / 14 | 0 / 0 | --- / --- | --- / --- |
| 04-1695 | Dekay Road Fish Barrier | Impact | 0 / 0 | --- / --- | 0 / 0 | 5 / 0 | --- / --- | --- / --- |
| | | Control | 0 / 0 | --- / --- | 5 / 0 | 0 / 0 | --- / --- | --- / --- |
| 05-1498 | Curl Lake Intake Barrier Removal | Impact | 0 / 0 | --- / --- | 5 / 0 | 38 / 24 | --- / --- | --- / --- |
| | | Control | 2 / 17 | --- / --- | 10 / 5 | 62 / 14 | --- / --- | --- / --- |

# APPENDIX B: MC-2 INSTREAM HABITAT PROJECT DATA

**Table B-1.** Average vertical pool profile area (m$^2$) in the impact and control reach for all sampling years for instream projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1444 | Little Skookum Valley | Impact | 7.6 | --- | 12.2 | --- | 16.0 | 11.7 | 6.3 |
| | | Control | 19.5 | --- | 27.3 | --- | 20.6 | 9.1 | 7.3 |
| 02-1463 | Salmon Creek | Impact | 17.3 | --- | 17.9 | --- | 23.0 | 33.7 | 26.5 |
| | | Control | 12.4 | --- | 10.0 | --- | 11.7 | 15.5 | 8.1 |
| 02-1515* | Upper Trout Creek | Impact | --- | --- | 78.3 | --- | 86.5 | 79.0 | --- |
| | | Control | --- | 21.2 | 21.3 | --- | 23.4 | 29.6 | --- |
| 02-1561IS* | Edgewater Park | Impact | 0.0 | --- | 21.7 | --- | 25.9 | 65.7 | 11.3 |
| | | Control | 0.0 | --- | 0.0 | --- | 0.0 | 41.6 | 0.0 |
| 04-1209IS | Chico Creek | Impact | 16.7 | 22.0 | 19.6 | --- | 25.2 | 24.3 | 25.9 |
| | | Control | 24.5 | 35.8 | 22.9 | --- | 28.8 | 35.8 | 32.8 |
| 04-1338 | Lower Newaukum | Impact | 25.0 | --- | 24.9 | --- | 16.0 | 27.0 | 27.1 |
| | | Control | 7.3 | --- | 7.1 | --- | 16.7 | 23.7 | 12.7 |
| 04-1448 | PUB Bar Habitat | Impact | 85.2 | --- | 159.9 | --- | 231.5 | 172.2 | 215.1 |
| | | Control | 56.2 | --- | 64.9 | --- | 128.1 | 76.1 | 60.8 |
| 04-1575 | Upper Washougal | Impact | 81.5 | --- | 106.4 | --- | 97.6 | 115.5 | 110.7 |
| | | Control | 124.1 | --- | 112.5 | --- | 87.9 | 81.5 | 126.1 |
| 04-1589 | Dungeness River | Impact | 52.9 | 70.8 | 172.1 | --- | 46.7 | 79.6 | --- |
| | | Control | 65.2 | 87.3 | 84.0 | --- | 20.4 | 32.7 | --- |
| 04-1660IS | Cedar Rapids | Impact | 178.5 | 155.3 | 137.5 | --- | 232.5 | 117.2 | 73.3 |
| | | Control | 93.7 | 106.5 | 79.9 | --- | 72.0 | 70.8 | 105.3 |
| 05-1533* | Doty Edwards | Impact | 20.6 | --- | 43.9 | --- | 27.1 | 39.5 | 75.0 |
| | | Control | 27.0 | --- | 50.7 | --- | 23.3 | 42.9 | 88.8 |
| 07-1803 | Skookum Reach | Impact | 61.4 | --- | 52.8 | --- | 57.0 | 87.2 | --- |
| | | Control | 152.2 | --- | 125.8 | --- | 135.6 | 176.8 | --- |
| 11-1315* | Eagle Island | Impact | 36.8 | --- | 26.1 | --- | 37.4 | --- | --- |
| | | Control | 25.5 | --- | 32.0 | --- | 31.6 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 117.7 | 226.5 | --- | --- | --- | --- | --- |
| | | Control | 52.7 | 75.5 | --- | --- | --- | --- | --- |
| 12-1334* | Elochoman | Impact | 107.6 | --- | --- | --- | --- | --- | --- |
| | | Control | 115.5 | --- | --- | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 3.7 | --- | 19.0 | --- | 12.2 | 13.6 | --- |
| | | Control | 10.0 | --- | 9.3 | --- | 7.2 | 10.4 | --- |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | Impact | 18.2 | --- | 4.9 | --- | 13.4 | --- | --- |
| | | Control | 8.7 | --- | 14.4 | --- | 7.2 | --- | --- |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | Impact | 3.3 | --- | 7.2 | --- | 12.2 | --- | --- |
| | | Control | 8.7 | --- | 14.4 | --- | 7.2 | --- | --- |
| SF-F4 P1 | SF Asotin Creek Upper 1 | Impact | 5.5 | --- | 5.1 | --- | 8.4 | 7.7 | --- |
| | | Control | 10.4 | --- | 5.8 | --- | 7.7 | 10.6 | --- |
| SF-F4 P2 | SF Asotin Creek Upper 2 | Impact | 4.8 | --- | 4.4 | --- | 4.3 | 7.8 | --- |
| | | Control | 10.4 | --- | 5.8 | --- | 7.7 | 10.6 | --- |
| Tucannon PA-3 | Tucannon PA-3 | Impact | 27.4 | --- | 32.1 | 25.5 | 28.4 | 40.6 | --- |
| | | Control | 26.1 | --- | 22.0 | 22.1 | 19.2 | 29.7 | --- |
| Tucannon PA-14 | Tucannon PA-14 | Impact | 42.4 | --- | 45.6 | 57.1 | 39.6 | 49.4 | --- |
| | | Control | 40.5 | --- | 39.1 | 60.4 | 37.6 | 71.7 | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 49.5 | --- | 57.8 | --- | 70.5 | 31.1 | --- |
| | | Control | 53.0 | --- | 30.6 | --- | 24.3 | 58.4 | --- |

* denotes sites that all years of data were not included in analysis

**Table B-2.** Mean residual profile depth (cm) in the impact and control reach for all sampling years for instream projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1444 | Little Skookum Valley | Impact | 5.1 | --- | 8.1 | --- | 10.7 | 7.8 | 4.2 |
| | | Control | 13.0 | --- | 18.2 | --- | 13.7 | 10.1 | 7.0 |
| 02-1463 | Salmon Creek | Impact | 9.6 | --- | 10.0 | --- | 12.8 | 18.7 | 14.7 |
| | | Control | 7.2 | --- | 5.6 | --- | 6.5 | 8.6 | 4.5 |
| 02-1515* | Upper Trout Creek | Impact | --- | --- | 21.8 | --- | 24.0 | 21.9 | --- |
| | | Control | --- | 14.1 | 14.2 | --- | 15.6 | 19.8 | --- |
| 02-1561IS* | Edgewater Park | Impact | 0 | --- | 6.8 | --- | 8.2 | 20.5 | 3.5 |
| | | Control | 0 | --- | 0 | --- | 0 | 18.9 | 0 |
| 04-1209IS | Chico Creek | Impact | 6.7 | 8.8 | 7.9 | --- | 10.1 | 9.7 | 10.2 |
| | | Control | 9.8 | 14.3 | 9.2 | --- | 11.5 | 14.3 | 13.1 |
| 04-1338 | Lower Newaukum | Impact | 11.4 | --- | 11.3 | --- | 7.3 | 12.3 | 12.3 |
| | | Control | 3.3 | --- | 3.2 | --- | 7.6 | 10.8 | 5.8 |
| 04-1448 | PUB Bar Habitat | Impact | 26.6 | --- | 50.0 | --- | 72.3 | 53.8 | 67.2 |
| | | Control | 17.6 | --- | 20.3 | --- | 40.0 | 23.8 | 19.0 |
| 04-1575 | Upper Washougal | Impact | 16.3 | --- | 21.3 | --- | 19.5 | 23.1 | 22.1 |
| | | Control | 24.8 | --- | 22.5 | --- | 17.6 | 16.3 | 25.2 |
| 04-1589 | Dungeness River | Impact | 10.6 | 14.2 | 34.1 | --- | 9.3 | 15.9 | --- |
| | | Control | 13.0 | 17.5 | 18.7 | --- | 4.5 | 7.3 | --- |
| 04-1660IS | Cedar Rapids | Impact | 35.7 | 31.1 | 27.8 | --- | 46.5 | 29.3 | 18.3 |
| | | Control | 18.7 | 21.3 | 16.0 | --- | 14.4 | 14.2 | 21.1 |
| 05-1533* | Doty Edwards | Impact | 6.9 | --- | 14.6 | --- | 9.0 | 13.2 | 25.0 |
| | | Control | 15.0 | --- | 28.2 | --- | 7.8 | 26.8 | 29.6 |
| 07-1803 | Skookum Reach | Impact | 12.3 | --- | 10.6 | --- | 11.4 | 17.4 | --- |
| | | Control | 30.4 | --- | 25.2 | --- | 27.1 | 35.4 | --- |
| 11-1315* | Eagle Island | Impact | 22.5 | --- | 16.9 | --- | 23.4 | --- | --- |
| | | Control | 14.6 | --- | 19.4 | --- | 19.8 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 21.6 | 39.2 | --- | --- | --- | --- | --- |
| | | Control | 10.0 | 14.6 | --- | --- | --- | --- | --- |
| 12-1334* | Elochoman | Impact | 25.4 | --- | --- | --- | --- | --- | --- |
| | | Control | 26.5 | --- | --- | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 2.4 | --- | 11.9 | --- | 7.7 | 8.1 | --- |
| | | Control | 4.8 | --- | 4.5 | --- | 3.6 | 5.1 | --- |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | Impact | 9.6 | --- | 3.0 | --- | 8.5 | --- | --- |
| | | Control | 4.9 | --- | 8.1 | --- | 4.1 | --- | --- |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | Impact | 2.1 | --- | 4.2 | --- | 6.8 | --- | --- |
| | | Control | 4.9 | --- | 8.1 | --- | 4.1 | --- | --- |
| SF-F4 P1 | SF Asotin Creek Upper 1 | Impact | 3.6 | --- | 3.2 | --- | 5.3 | 4.6 | --- |
| | | Control | 6.6 | --- | 3.3 | --- | 4.4 | 5.8 | --- |
| SF-F4 P2 | SF Asotin Creek Upper 2 | Impact | 2.8 | --- | 2.9 | --- | 2.9 | 5.0 | --- |
| | | Control | 6.6 | --- | 3.3 | --- | 4.4 | 5.8 | --- |
| Tucannon PA-3 | Tucannon PA-3 | Impact | 9.8 | --- | 11.5 | 9.1 | 10.2 | 14.1 | --- |
| | | Control | 8.9 | --- | 7.7 | 7.7 | 6.7 | 10.2 | --- |
| Tucannon PA-14 | Tucannon PA-14 | Impact | 17.5 | --- | 18.8 | 23.3 | 16.2 | 19.7 | --- |
| | | Control | 15.0 | --- | 14.3 | 21.3 | 13.4 | 23.8 | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 14.6 | --- | 17.3 | --- | 20.1 | 9.4 | --- |
| | | Control | 12.4 | --- | 7.7 | --- | 6.1 | 13.5 | --- |

* denotes sites that all years of data were not included in analysis

**Table B-3.** Volume of LWD ($m^3$) in the impact and control reach for all sampling years for instream projects. Missing values were not measured in that year of sampling for a particular site. n/a = summary metric not provided in Tetra Tech summary tables, though data was collected.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1444 | Little Skookum Valley | Impact | 0 | --- | 0.24 | --- | 0.16 | -0.68 | -0.74 |
| | | Control | -1.38 | --- | -1.16 | --- | -1.38 | -1.16 | -1.86 |
| 02-1463 | Salmon Creek | Impact | 0.41 | --- | 1.40 | --- | 1.28 | 0.87 | 1.10 |
| | | Control | 1.13 | --- | 1.03 | --- | 1.16 | 1.62 | 0.60 |
| 02-1515* | Upper Trout Creek | Impact | --- | --- | 1.91 | --- | 1.39 | 1.93 | --- |
| | | Control | --- | 1.68 | 1.32 | --- | 1.27 | 1.44 | --- |
| 02-1561IS* | Edgewater Park | Impact | 0.74 | --- | 1.58 | --- | 1.13 | 1.32 | 1.17 |
| | | Control | 0.96 | --- | 0.79 | --- | 0.46 | 0.62 | 0.87 |
| 04-1209IS | Chico Creek | Impact | 0 | 0.16 | 1.05 | --- | 1.36 | 1.11 | 1.30 |
| | | Control | 0.55 | 0.50 | 0.38 | --- | 0.72 | 0.59 | 0.60 |
| 04-1338 | Lower Newaukum | Impact | 0.63 | --- | 1.75 | --- | 2.26 | 1.61 | 1.55 |
| | | Control | 0.99 | --- | 0.74 | --- | 0.16 | 0.82 | 0.63 |
| 04-1448 | PUB Bar Habitat | Impact | 0.98 | --- | 0.80 | --- | 1.25 | 1.41 | 1.26 |
| | | Control | 1.42 | --- | 1.14 | --- | 1.45 | 0.56 | 0.97 |
| 04-1575 | Upper Washougal | Impact | -0.16 | --- | 1.83 | --- | 1.85 | 1.76 | 1.82 |
| | | Control | 0.80 | --- | 0.07 | --- | 0.77 | 0 | 0 |
| 04-1589 | Dungeness River | Impact | 0.96 | 0.96 | 1.81 | --- | 1.24 | 1.54 | --- |
| | | Control | 1.14 | 1.45 | 1.07 | --- | 0.23 | 0.82 | --- |
| 04-1660IS | Cedar Rapids | Impact | 0.80 | 0.79 | 2.14 | --- | 1.23 | 1.05 | 1.53 |
| | | Control | 0.24 | -0.03 | -1.60 | --- | -0.47 | 0.34 | 0.16 |
| 05-1533* | Doty Edwards | Impact | 0.15 | --- | 0.90 | --- | 0.25 | 0.72 | 0.50 |
| | | Control | 1.08 | --- | 1.17 | --- | -0.33 | 1.00 | 0.95 |
| 07-1803 | Skookum Reach | Impact | 0.95 | --- | 0.53 | --- | 0.73 | 0.74 | --- |
| | | Control | 0.63 | --- | 0.15 | --- | 0.53 | 0.92 | --- |
| 11-1315* | Eagle Island | Impact | -0.74 | --- | 0.20 | --- | 1.17 | --- | --- |
| | | Control | 0.99 | --- | 1.46 | --- | 1.31 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 1.68 | 2.30 | --- | --- | --- | --- | --- |
| | | Control | 0.61 | 0.98 | --- | --- | --- | --- | --- |
| 12-1334* | Elochoman | Impact | 0.18 | --- | --- | --- | --- | --- | --- |
| | | Control | 1.05 | --- | --- | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | -0.50 | --- | 1.24 | --- | 1.27 | 0.97 | --- |
| | | Control | 0.05 | --- | -0.40 | --- | 0.89 | -0.09 | --- |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | Impact | 0 | --- | 0.08 | --- | 1.55 | --- | --- |
| | | Control | 0.65 | --- | -0.14 | --- | 0.45 | --- | --- |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | Impact | -0.75 | --- | -0.42 | --- | 1.07 | --- | --- |
| | | Control | 0.65 | --- | -0.14 | --- | 0.45 | --- | --- |
| SF-F4 P1 | SF Asotin Creek Upper 1 | Impact | 0 | --- | 0.18 | --- | 1.21 | -0.15 | --- |
| | | Control | -0.27 | --- | -0.13 | --- | 0.66 | -0.08 | --- |
| SF-F4 P2 | SF Asotin Creek Upper 2 | Impact | 0.18 | --- | 0.14 | --- | 1.14 | -0.06 | --- |
| | | Control | -0.27 | --- | -0.13 | --- | 0.66 | -0.08 | --- |
| Tucannon PA-3 | Tucannon PA-3 | Impact | 0.35 | --- | 1.37 | 1.25 | 1.23 | 1.29 | --- |
| | | Control | 0.40 | --- | 1.18 | 0.91 | 1.30 | 0.75 | --- |
| Tucannon PA-14 | Tucannon PA-14 | Impact | 1.08 | --- | 1.80 | 1.81 | 1.63 | 1.60 | --- |
| | | Control | 0.66 | --- | 0.87 | 1.35 | 0.69 | 1.30 | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 0.23 | --- | 0.98 | --- | 1.09 | 0.47 | --- |
| | | Control | -0.11 | --- | 1.09 | --- | n/a | 0.39 | --- |

* denotes sites that all years of data were not included in analysis

**Table B-4.** Juvenile Chinook salmon densities (fish/m$^2$) in the impact and control reach for all sampling years for instream projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | site Name | Reach | Year 0 | Year 0* | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|
| 02-1444 | Little Skookum Valley | Impact | 0 | --- | 0 | 0 | 0 | 0 |
| | | Control | 0 | --- | 0 | 0 | 0 | 0 |
| 02-1463 | Salmon Creek | Impact | 0.0095 | --- | 0 | 0 | 0.0011 | 0 |
| | | Control | 0 | --- | 0 | 0 | 0.0028 | 0 |
| 02-1515* | Upper Trout Creek | Impact | --- | --- | 0 | 0 | 0 | --- |
| | | Control | --- | 0 | 0 | 0 | 0 | --- |
| 02-1561IS* | Edgewater Park | Impact | 0 | --- | 0.0221 | 0 | 0 | 0 |
| | | Control | 0 | --- | 0 | 0 | 0 | 0 |
| 04-1209IS | Chico Creek | Impact | 0 | 0 | 0 | 0 | 0 | 0.0006 |
| | | Control | 0 | 0 | 0 | 0 | 0 | 0 |
| 04-1338 | Lower Newaukum | Impact | 0.0064 | --- | 0 | 0.0152 | --- | 0.0004 |
| | | Control | 0.0038 | --- | 0.0156 | 0.0516 | --- | 0.0007 |
| 04-1448 | PUB Bar Habitat | Impact | 0 | --- | 0 | 0 | 0.0005 | 0.0030 |
| | | Control | 0 | --- | 0.0003 | 0.0001 | 0.0005 | 0.0120 |
| 04-1575 | Upper Washougal | Impact | 0 | --- | 0 | 0 | 0 | 0 |
| | | Control | 0 | --- | 0 | 0 | 0 | 0 |
| 04-1589 | Dungeness River | Impact | 0.0187 | 0.0046 | 0.0029 | 0.0019 | 0.0130 | --- |
| | | Control | 0.0010 | 0.0059 | 0.0006 | 0.0012 | 0.0426 | --- |
| 04-1660IS | Cedar Rapids | Impact | 0 | 0.0005 | 0.0027 | 0 | 0 | 0.0013 |
| | | Control | 0.0101 | 0.0005 | 0 | 0 | 0 | 0 |
| 05-1533* | Doty Edwards | Impact | 0 | --- | 0 | 0.0005 | 0.0003 | 0.0002 |
| | | Control | 0 | --- | 0 | 0 | 0 | 0.0002 |
| 07-1803 | Skookum Reach | Impact | 0.0047 | --- | 0.0007 | 0.0002 | 0.0006 | --- |
| | | Control | 0.0017 | --- | 0.0017 | 0.0006 | 0.0008 | --- |
| 11-1315* | Eagle Island | Impact | 0.1291 | --- | 0.0094 | 0.0056 | --- | --- |
| | | Control | 0.0576 | --- | 0.0175 | 0.0334 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 0.0002 | 0.0150 | --- | --- | --- | --- |
| | | Control | 0 | 0 | --- | --- | --- | --- |
| 12-1334* | Elochoman | Impact | 0.0021 | --- | --- | --- | --- | --- |
| | | Control | 0.0077 | --- | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 0 | --- | 0 | 0 | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | 0 | --- |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | Impact | 0 | --- | 0 | 0 | --- | --- |
| | | Control | 0 | --- | 0 | 0 | --- | --- |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | Impact | 0 | --- | 0 | 0 | --- | --- |
| | | Control | 0 | --- | 0 | 0 | --- | --- |
| SF-F4 P1 | SF Asotin Creek Upper 1 | Impact | 0 | --- | 0 | 0 | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | 0 | --- |
| SF-F4 P2 | SF Asotin Creek Upper 2 | Impact | 0 | --- | 0 | 0 | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | 0 | --- |
| Tucannon PA-3 | Tucannon PA-3 | Impact | 0.1237 | --- | 0.0147 | 0.1123 | 0.0228 | --- |
| | | Control | 0.1275 | --- | 0.0436 | 0.0262 | 0.0106 | --- |
| Tucannon PA-14 | Tucannon PA-14 | Impact | 0.0968 | --- | 0.0289 | 0.1564 | 0.1366 | --- |
| | | Control | 0.1379 | --- | 0.0542 | 0.0427 | 0.0790 | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 0.0490 | --- | 0.0182 | 0.0219 | 0.0102 | --- |
| | | Control | 0.0430 | --- | 0.0069 | 0.0196 | 0.0085 | --- |

* denotes sites that all years of data were not included in analysis

**Table B-5.** Juvenile coho salmon densities (fish/m$^2$) in the impact and control reach for all sampling years for instream projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|
| 02-1444 | Little Skookum Valley | Impact | 0.0391 | --- | 0 | 0 | 0 | 0 |
| | | Control | 0.0485 | --- | 0 | 0.0268 | 0 | 0 |
| 02-1463 | Salmon Creek | Impact | 0.6241 | --- | 0.1086 | 0.3055 | 0.1987 | 0.1992 |
| | | Control | 0.1793 | --- | 0.0825 | 0.2738 | 0.0623 | 0.1228 |
| 02-1515* | Upper Trout Creek | Impact | --- | --- | 0 | 0 | 0 | --- |
| | | Control | --- | 0 | 0 | 0 | 0 | --- |
| 02-1561IS* | Edgewater Park | Impact | 0 | --- | 0.0004 | 0 | 0 | 0 |
| | | Control | 0 | --- | 0 | 0 | 0 | 0 |
| 04-1209IS | Chico Creek | Impact | 0.0717 | 0.0332 | 0.5001 | 0.0219 | 0.6927 | 0.5726 |
| | | Control | 0.1178 | 0.0943 | 0.7523 | 0.0399 | 0.2206 | 0.3460 |
| 04-1338 | Lower Newaukum | Impact | 0.0094 | --- | 0.1103 | 0.0842 | --- | 0.1449 |
| | | Control | 0.0028 | --- | 0.0109 | 0.0261 | --- | 0.0357 |
| 04-1448 | PUB Bar Habitat | Impact | 0 | --- | 0.0031 | 0.0001 | 0.0029 | 0 |
| | | Control | 0 | --- | 0.0073 | 0.0010 | 0.0162 | 0.0005 |
| 04-1575 | Upper Washougal | Impact | 0 | --- | 0 | 0 | 0 | 0 |
| | | Control | 0 | --- | 0 | 0 | 0 | 0 |
| 04-1589 | Dungeness River | Impact | 0.1952 | 0.0816 | 0.0253 | 0.0444 | 0.2290 | --- |
| | | Control | 0.1810 | 0.2606 | 0.0738 | 0.0110 | 0.2601 | --- |
| 04-1660IS | Cedar Rapids | Impact | 0 | 0.0089 | 0.0028 | 0 | 0.0082 | 0.0250 |
| | | Control | 0.0106 | 0.0141 | 0.0013 | 0.0017 | 0.0180 | 0.0135 |
| 05-1533* | Doty Edwards | Impact | 0.1309 | --- | 0.0573 | 0.0565 | 0.0931 | 0.0434 |
| | | Control | 0.0798 | --- | 0.0351 | 0.0179 | 0.0734 | 0.0594 |
| 07-1803 | Skookum Reach | Impact | 0 | --- | 0.0002 | 0.0001 | 0.0059 | --- |
| | | Control | 0.0001 | --- | 0.0001 | 0.0040 | 0.0058 | --- |
| 11-1315* | Eagle Island | Impact | 0.0158 | --- | 0.1678 | 0.5483 | --- | --- |
| | | Control | 0.0036 | --- | 0.0586 | 0.2314 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 0.2380 | 0.0011 | --- | --- | --- | --- |
| | | Control | 0.0944 | 0.0310 | --- | --- | --- | --- |
| 12-1334* | Elochoman | Impact | 0.0177 | --- | --- | --- | --- | --- |
| | | Control | 0.0328 | --- | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 0 | --- | 0 | 0 | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | 0 | --- |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | Impact | 0 | --- | 0 | 0 | --- | --- |
| | | Control | 0 | --- | 0 | 0 | --- | --- |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | Impact | 0 | --- | 0 | 0 | --- | --- |
| | | Control | 0 | --- | 0 | 0 | --- | --- |
| SF-F4 P1 | SF Asotin Creek Upper 1 | Impact | 0 | --- | 0 | 0 | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | 0 | --- |
| SF-F4 P2 | SF Asotin Creek Upper 2 | Impact | 0 | --- | 0 | 0 | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | 0 | --- |
| Tucannon PA-3 | Tucannon PA-3 | Impact | 0 | --- | 0 | 0 | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | 0 | --- |
| Tucannon PA-14 | Tucannon PA-14 | Impact | 0 | --- | 0 | 0 | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | 0 | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 0 | --- | 0 | 0 | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | 0 | --- |

* denotes sites that all years of data were not included in analysis

**Table B-6.** Juvenile steelhead densities (fish/m$^2$) in the impact and control reach for all sampling years for instream projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|
| 02-1444 | Little Skookum Valley | Impact | 0 | --- | 0 | 0 | 0 | 0.0130 |
| | | Control | 0 | --- | 0 | 0 | 0.0210 | 0.8753 |
| 02-1463 | Salmon Creek | Impact | 0.0677 | --- | 0.0577 | 0.0112 | 0.0117 | 0.1144 |
| | | Control | 0.0203 | --- | 0.0126 | 0.0074 | 0.0014 | 0.0230 |
| 02-1515* | Upper Trout Creek | Impact | --- | --- | 0.0426 | 0.0253 | 0.0586 | --- |
| | | Control | --- | 0.0065 | 0.0384 | 0.0407 | 0.1699 | --- |
| 02-1561IS* | Edgewater Park | Impact | 0 | --- | 0 | 0 | 0 | 0 |
| | | Control | 0 | --- | 0 | 0 | 0 | 0 |
| 04-1209IS | Chico Creek | Impact | 0.1542 | 0.0007 | 0.4239 | 0.1223 | 0.9853 | 0.2657 |
| | | Control | 0.3857 | 0 | 0.3971 | 0.3531 | 0.3867 | 0.1818 |
| 04-1338 | Lower Newaukum | Impact | 0.0307 | --- | 0.1610 | 0.0625 | --- | 0.1025 |
| | | Control | 0.0038 | --- | 0.0891 | 0.0625 | --- | 0.0298 |
| 04-1448 | PUB Bar Habitat | Impact | 0.0176 | --- | 0.0021 | 0.0236 | 0.0128 | 0.0516 |
| | | Control | 0.0126 | --- | 0.0913 | 0.0093 | 0.0022 | 0.0364 |
| 04-1575 | Upper Washougal | Impact | 0.0315 | --- | 0.0264 | 0.0148 | 0.1090 | 0.1734 |
| | | Control | 0.0216 | --- | 0.0169 | 0.0997 | 0.0685 | 0.3184 |
| 04-1589 | Dungeness River | Impact | 0.2461 | 0.0929 | 0.0479 | 0.1412 | 0.1016 | --- |
| | | Control | 0.4571 | 0.2265 | 0.1473 | 0.1058 | 0.2209 | --- |
| 04-1660IS | Cedar Rapids | Impact | 0.0012 | 0.0044 | 0.0016 | 0.0067 | 0.0083 | 0.0060 |
| | | Control | 0.0023 | 0.0089 | 0.0008 | 0.0038 | 0.0097 | 0.0015 |
| 05-1533* | Doty Edwards | Impact | 0.0050 | --- | 0.0002 | 0.0019 | 0.0075 | 0.0071 |
| | | Control | 0.0097 | --- | 0.0020 | 0.0028 | 0.0108 | 0.0059 |
| 07-1803 | Skookum Reach | Impact | 0.0022 | --- | 0.0174 | 0.0343 | 0.0453 | --- |
| | | Control | 0.0035 | --- | 0.0153 | 0.0709 | 0.0154 | --- |
| 11-1315* | Eagle Island | Impact | 0.0004 | --- | 0.0777 | 0.4309 | --- | --- |
| | | Control | 0.0003 | --- | 0.0156 | 0.1851 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 0.0175 | 0.0153 | --- | --- | --- | --- |
| | | Control | 0.0183 | 0.0171 | --- | --- | --- | --- |
| 12-1334* | Elochoman | Impact | 0.0017 | --- | --- | --- | --- | --- |
| | | Control | 0.0131 | --- | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 0.1478 | --- | 0.1590 | 0.0407 | 0.0197 | --- |
| | | Control | 0.2065 | --- | 0.1894 | 1.7344 | 0.0737 | --- |
| SF-F3 P2BR | SF Asotin Creek Lower 1 | Impact | 0.2268 | --- | 0.3878 | 0.2844 | --- | --- |
| | | Control | 0.2018 | --- | 0.2345 | 0.2395 | --- | --- |
| SF-F3 P3BR | SF Asotin Creek Lower 2 | Impact | 0.2268 | --- | 0.3878 | 0.2844 | --- | --- |
| | | Control | 0.2018 | --- | 0.2345 | 0.2395 | --- | --- |
| SF-F4 P1 | SF Asotin Creek Upper 1 | Impact | 0.3522 | --- | 0.4208 | 0.3879 | 0.2908 | --- |
| | | Control | 0.3474 | --- | 0.4971 | 0.5982 | 0.2875 | --- |
| SF-F4 P2 | SF Asotin Creek Upper 2 | Impact | 0.3522 | --- | 0.4208 | 0.3879 | 0.2908 | --- |
| | | Control | 0.3474 | --- | 0.4971 | 0.5982 | 0.2875 | --- |
| Tucannon PA-3 | Tucannon PA-3 | Impact | 0.2326 | --- | 0.0568 | 0.0887 | 0.0335 | --- |
| | | Control | 0.1521 | --- | 0.1761 | 0.0270 | 0.0257 | --- |
| Tucannon PA-14 | Tucannon PA-14 | Impact | 0.1640 | --- | 0.0964 | 0.2646 | 0.1445 | --- |
| | | Control | 0.2348 | --- | 0.2018 | 0.1495 | 0.1142 | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 0.1452 | --- | 0.1225 | 0.2931 | 0.0860 | --- |
| | | Control | 0.1055 | --- | 0.1612 | 0.2367 | 0.0916 | --- |

* denotes sites that all years of data were not included in analysis

# APPENDIX C: MC-3 RIPARIAN PLANTING PROJECT DATA

**Table C-1.** Riparian area (acres) planted and total number of plantings installed during project implementation of impact reaches for riparian planting projects (control reaches were not planted and therefore were not be monitored for this metric).

| Site ID | Site name | Area planted (acres) | Plantings (#) |
|---|---|---|---|
| 02-1446 | Centralia Riparian Restoration Project | 11.0 | 4,763 |
| 02-1561R | Edgewater Park Off-Channel Restoration | 34.0 | 53,052 |
| 02-1616R* | Vandersar Restoration Project | --- | --- |
| 02-1623 | Snohomish River Confluence Reach Restoration | 6.0 | 3,510 |
| 04-1649 | Salmon/Snow Lower Watershed Restoration | 29.0 | 17,597 |
| 04-1655R | Hoy Riparian Restoration Project | 38.0 | 10,705 |
| 04-1660R | Cedar Rapids Floodplain Restoration | 0.6 | 1,792 |
| 04-1676 | YTAHP Wilson Creek Riparian Restoration | 1.1 | 1,606 |
| 04-1698R | Vance Creek Riparian Planting | 0.3 | 150 |
| 04-1711 | Lower Klickitat Riparian Restoration | 5.2 | 4,733 |

* denotes site that was never planted and therefore monitoring was not continued

**Table C-2.** Percent survival (%) of riparian plantings in treatment reaches for riparian planting projects (control reaches were not planted and therefore were not be monitored for this metric). Survival was only measured in Year 1 and 3. Values reported in this table reflect values in the Tetra Tech summary tables, but do not match the 2008 Annual Report (Tetra Tech).

| Site ID | Site name | Year 1 | Year 3 |
|---|---|---|---|
| 02-1446 | Centralia Riparian Restoration Project | 100 | 95 |
| 02-1561R | Edgewater Park Off-Channel Restoration | 99 | 56 |
| 02-1616R* | Vandersar Restoration Project | --- | --- |
| 02-1623 | Snohomish River Confluence Reach Restoration | 100 | 135 |
| 04-1649 | Salmon/Snow Lower Watershed Restoration | 97 | 69 |
| 04-1655R | Hoy Riparian Restoration Project | 100 | 108 |
| 04-1660R | Cedar Rapids Floodplain Restoration | 94 | 16 |
| 04-1676 | YTAHP Wilson Creek Riparian Restoration | 62 | 184 |
| 04-1698R | Vance Creek Riparian Planting | 92 | 88 |
| 04-1711 | Lower Klickitat Riparian Restoration | 100 | 126 |

* denotes site that was never planted and therefore monitoring was not continued

**Table C-3.** Woody coverage (%) within the planted area of treatment reaches for planting projects (control reaches were not planted and therefore were not be monitored for this metric). Missing values were not measured in that year of sampling for a particular site. n/a = year prior to planting and therefore was not monitored.

| Site ID | Site name | Year 0 | Year 0* | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|
| 02-1446 | Centralia Riparian Restoration Project | n/a | --- | 2 | 1 | --- | 8 |
| 02-1561R | Edgewater Park Off-Channel Restoration | n/a | --- | 0 | 0 | 41 | 61 |
| 02-1616R* | Vandersar Restoration Project | n/a | n/a | --- | --- | --- | --- |
| 02-1623 | Snohomish River Confluence Reach Restoration | n/a | --- | 5 | 23 | 46 | 94 |
| 04-1649 | Salmon/Snow Lower Watershed Restoration | n/a | --- | 5 | 11 | 30 | 84 |
| 04-1655R | Hoy Riparian Restoration Project | n/a | --- | 3 | 2 | 12 | 41 |
| 04-1660R | Cedar Rapids Floodplain Restoration | n/a | n/a | 0 | 4 | 16 | --- |
| 04-1676 | YTAHP Wilson Creek Riparian Restoration | n/a | --- | 4 | 23 | 52 | 83 |
| 04-1698R | Vance Creek Riparian Planting | n/a | n/a | 1 | 2 | 6 | --- |
| 04-1711 | Lower Klickitat Riparian Restoration | n/a | --- | 12 | 29 | 35 | 50 |

* denotes site that was never planted and therefore monitoring was not continued

**Table C-4.** Bank canopy cover (0-17) in the impact and control reach for all sampling years for riparian planting projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|
| 02-1446 | Centralia Riparian Restoration Project | Impact | 5 | --- | 5 | 3 | 1 | 17 |
| | | Control | 12 | --- | 16 | 12 | 15 | 9 |
| 02-1561R | Edgewater Park Off-Channel Restoration | Impact | 17 | --- | 10 | 10 | 16 | 13 |
| | | Control | 17 | --- | 17 | 17 | 17 | 17 |
| 02-1616R* | Vandersar Restoration Project | Impact | 17 | 14 | --- | --- | --- | --- |
| | | Control | 14 | 11 | --- | --- | --- | --- |
| 02-1623 | Snohomish River Confluence Reach Restoration | Impact | 0 | --- | 9 | 12 | 13 | 16 |
| | | Control | 0 | --- | 0 | 17 | --- | 11 |
| 04-1649 | Salmon/Snow Lower Watershed Restoration | Impact | 13 | --- | 13 | 15 | 16 | 16 |
| | | Control | 17 | --- | 17 | 16 | 17 | 16 |
| 04-1655R | Hoy Riparian Restoration Project | Impact | 6 | --- | 3 | 5 | 12 | --- |
| | | Control | 17 | --- | 17 | 16 | 16 | --- |
| 04-1660R | Cedar Rapids Floodplain Restoration | Impact | 175 | 13 | 13 | 7 | 7 | --- |
| | | Control | 14 | 13 | 15 | 13 | 13 | --- |
| 04-1676 | YTAHP Wilson Creek Riparian Restoration | Impact | 4 | --- | 10 | 6 | 14 | 12 |
| | | Control | 4 | --- | 17 | 8 | 16 | 10 |
| 04-1698R | Vance Creek Riparian Planting | Impact | 14 | 16 | 14 | 17 | 15 | --- |
| | | Control | 15 | 17 | 16 | 17 | 13 | --- |
| 04-1711 | Lower Klickitat Riparian Restoration | Impact | 5 | --- | 5 | 8 | 10 | 11 |
| | | Control | 7 | --- | 4 | 6 | 9 | 9 |

* denotes site that was never planted and therefore monitoring was not continued

**Table C-5.** Center-of-channel canopy cover (0-17) in the impact and control reach for all sampling years for riparian planting projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|
| 02-1446 | Centralia Riparian Restoration Project | Impact | 0.0 | --- | --- | --- | --- | --- |
| | | Control | 1.3 | --- | --- | --- | --- | --- |
| 02-1561R | Edgewater Park Off-Channel Restoration | Impact | 16.6 | --- | 5.6 | 5.1 | 8.7 | 6.0 |
| | | Control | 16.5 | --- | 16.8 | 16.2 | 16.9 | 15.3 |
| 02-1616R* | Vandersar Restoration Project | Impact | 8.7 | 7.0 | --- | --- | --- | --- |
| | | Control | 7.3 | 6.7 | --- | --- | --- | --- |
| 02-1623 | Snohomish River Confluence Reach Restoration | Impact | 0.0 | --- | 5.0 | 6.7 | 10.3 | 12.4 |
| | | Control | 0.0 | --- | 0.0 | 17.0 | 14.6 | 12.6 |
| 04-1649 | Salmon/Snow Lower Watershed Restoration | Impact | 4.0 | --- | 8.3 | 10.3 | 11.8 | 11.7 |
| | | Control | 15.4 | --- | 15.6 | 15.7 | 15.7 | 15.0 |
| 04-1655R | Hoy Riparian Restoration Project | Impact | --- | --- | 0.0 | --- | 0.0 | --- |
| | | Control | --- | --- | 0.0 | --- | 0.0 | --- |
| 04-1660R | Cedar Rapids Floodplain Restoration | Impact | 5.5 | 3.7 | 3.5 | 4.6 | 2.0 | --- |
| | | Control | 4.3 | 6.3 | 5.9 | 4.4 | 3.6 | --- |
| 04-1676 | YTAHP Wilson Creek Riparian Restoration | Impact | 0.7 | --- | 0.5 | 0.6 | 1.5 | 1.8 |
| | | Control | 2.9 | --- | 4.0 | 3.0 | 5.6 | 3.2 |
| 04-1698R | Vance Creek Riparian Planting | Impact | 6.9 | 5.7 | 5.5 | --- | 7.5 | --- |
| | | Control | 9.4 | 9.1 | 9.8 | 10.8 | 9.9 | --- |
| 04-1711 | Lower Klickitat Riparian Restoration | Impact | 0.0 | --- | 0.4 | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | 0.5 |

* denotes site that was never planted and therefore monitoring was not continued

**Table C-6.** Riparian vegetation structure (%) in the impact and control reach for all sampling years for riparian planting projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|
| 02-1446 | Centralia Riparian Restoration Project | Impact | 9 | --- | 18 | 5 | 18 | 18 |
| | | Control | 100 | --- | 73 | 96 | 100 | 100 |
| 02-1561R | Edgewater Park Off-Channel Restoration | Impact | 100 | --- | 59 | 68 | 77 | 91 |
| | | Control | 100 | --- | 5 | 77 | 100 | 96 |
| 02-1616R* | Vandersar Restoration Project | Impact | 91 | 96 | --- | --- | --- | --- |
| | | Control | 41 | 86 | --- | --- | --- | --- |
| 02-1623 | Snohomish River Confluence Reach Restoration | Impact | 10 | --- | 0 | 18 | 9 | 77 |
| | | Control | 0 | --- | 0 | 9 | 0 | 0 |
| 04-1649 | Salmon/Snow Lower Watershed Restoration | Impact | 5 | --- | 9 | 46 | 91 | 55 |
| | | Control | 100 | --- | 82 | 91 | 100 | 77 |
| 04-1655R | Hoy Riparian Restoration Project | Impact | 18 | --- | 0 | 5 | 59 | 82 |
| | | Control | 59 | --- | 50 | 50 | 91 | 96 |
| 04-1660R | Cedar Rapids Floodplain Restoration | Impact | 86 | 77 | 5 | 59 | 27 | --- |
| | | Control | 96 | 80 | 82 | 50 | 32 | --- |
| 04-1676 | YTAHP Wilson Creek Riparian Restoration | Impact | 5 | --- | 0 | 5 | 9 | 9 |
| | | Control | 0 | --- | 5 | 14 | 23 | 27 |
| 04-1698R | Vance Creek Riparian Planting | Impact | 5 | 18 | 9 | 46 | 27 | --- |
| | | Control | 82 | 96 | 86 | 96 | 64 | --- |
| 04-1711 | Lower Klickitat Riparian Restoration | Impact | 9 | --- | 27 | 27 | 46 | 64 |
| | | Control | 18 | --- | 18 | 32 | 46 | 55 |

* denotes site that was never planted and therefore monitoring was not continued

**Table C-7.** Bank erosion (%) in the impact and control reach for all sampling years for riparian planting projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Station | Year 0 | Year 0* | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|
| 02-1446 | Centralia Riparian Restoration Project | Impact | 0 | --- | 50 | 50 | 15 | 3 |
| | | Control | 0 | --- | 12 | 18 | 2 | 0 |
| 02-1561R | Edgewater Park Off-Channel Restoration | Impact | 0 | --- | 0 | 11 | 0 | 21 |
| | | Control | 0 | --- | 0 | 0 | 1 | 0 |
| 02-1616R* | Vandersar Restoration Project | Impact | 100 | 73 | --- | --- | --- | --- |
| | | Control | 55 | 10 | --- | --- | --- | --- |
| 02-1623 | Snohomish River Confluence Reach Restoration | Impact | 0 | --- | 0 | 0 | 0 | 0 |
| | | Control | 0 | --- | 0 | 0 | 0 | 0 |
| 04-1649 | Salmon/Snow Lower Watershed Restoration | Impact | 0 | --- | 0 | 2 | 0 | 35 |
| | | Control | 20 | --- | 23 | 9 | 2 | 8 |
| 04-1655R | Hoy Riparian Restoration Project | Impact | 100 | --- | 100 | 96 | 4 | 0 |
| | | Control | 70 | --- | 90 | 83 | 0 | 0 |
| 04-1660R | Cedar Rapids Floodplain Restoration | Impact | 0 | 0 | 3 | 38 | 5 | --- |
| | | Control | 0 | 0 | 2 | 0 | 6 | --- |
| 04-1676 | YTAHP Wilson Creek Riparian Restoration | Impact | 72 | --- | 12 | 0 | 16 | 0 |
| | | Control | 66 | --- | 1 | 0 | 0 | 0 |
| 04-1698R | Vance Creek Riparian Planting | Impact | 0 | 70 | 0 | 0 | 0 | --- |
| | | Control | 0 | 40 | 0 | 0 | 11 | --- |
| 04-1711 | Lower Klickitat Riparian Restoration | Impact | 40 | --- | 31 | 40 | 2 | 16 |
| | | Control | 0 | --- | 0 | 0 | 0 | 0 |

* denotes site that was never planted and therefore monitoring was not continued

# APPENDIX D: MC-4 LIVESTOCK EXCLUSION PROJECT DATA

**Table D-1.** Bank erosion (%) in the impact and control reach for all sampling years for livestock exclusion projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|
| 02-1498 | SRFB: Abernathy | Impact | 2 | 3 | 4 | 7 | 0 |
| | | Control | 2 | 0 | 3 | 13 | 0 |
| 04-1655 | SRFB: Hoy Riparian | Impact | 100 | 100 | 96 | 4 | 0 |
| | | Control | 70 | 90 | 83 | 0 | 0 |
| 04-1698 | SRFB: Vance | Impact | 70 | 0 | 0 | 0 | 0 |
| | | Control | 40 | 0 | 0 | 11 | 0 |
| 05-1447 | SRFB: Indian Creek-Yates | Impact | 10 | 2 | 0 | 0 | 0 |
| | | Control | 0 | 0 | 0 | 0 | 0 |
| 05-1547 | SRFB: Rauth Coweeman | Impact | 33 | 21 | 7 | 30 | 19 |
| | | Control | 1 | 2 | 5 | 12 | 18 |
| 205-060a | OWEB: Bottle | Impact | 11 | 1 | 3 | 5 | 12 |
| | | Control | 7 | 2 | 12 | 15 | 31 |
| 205-060b | OWEB: NF Clark | Impact | 39 | 0 | 2 | 9 | 0 |
| | | Control | 37 | 5 | 8 | 32 | 0 |
| 206-072 | OWEB: Greys | Impact | 13 | 35 | 5 | 0 | --- |
| | | Control | 63 | 64 | 7 | 8 | --- |
| 206-095 | OWEB: Jordan | Impact | 95 | 0 | 6 | 12 | 12 |
| | | Control | 100 | 100 | 27 | 47 | 59 |
| 206-283a | OWEB: Johnson | Impact | 80 | 75 | 26 | 12 | 39 |
| | | Control | 4 | 77 | 4 | 12 | 20 |
| 206-283b | OWEB: Noble | Impact | 50 | 11 | 1 | --- | --- |
| | | Control | 0 | 28 | 21 | --- | --- |
| 206-357 | OWEB: NF Malheur | Impact | 71 | 42 | 37 | 7 | 29 |
| | | Control | 59 | 34 | 45 | 12 | 26 |

**Table D-2.** Riparian vegetation structure (%) in the impact and control reach for all sampling years for livestock exclusion projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|
| 02-1498 | SRFB: Abernathy | Impact | 100 | 100 | 100 | 100 | 100 |
| | | Control | 100 | 100 | 100 | 100 | 100 |
| 04-1655 | SRFB: Hoy Riparian | Impact | 18 | 0 | 5 | 59 | 82 |
| | | Control | 59 | 50 | 50 | 91 | 96 |
| 04-1698 | SRFB: Vance | Impact | 18 | 9 | 46 | 27 | 32 |
| | | Control | 96 | 86 | 96 | 64 | 91 |
| 05-1447 | SRFB: Indian Creek-Yates | Impact | 91 | 91 | 100 | 96 | 91 |
| | | Control | 100 | 100 | 100 | 86 | 100 |
| 05-1547 | SRFB: Rauth Coweeman | Impact | 91 | 73 | 82 | 77 | 82 |
| | | Control | 100 | 100 | 100 | 100 | 100 |
| 205-060a | OWEB: Bottle | Impact | 77 | 77 | 86 | 86 | 82 |
| | | Control | 100 | 100 | 96 | 100 | 91 |
| 205-060b | OWEB: NF Clark | Impact | 100 | 100 | 100 | 100 | 100 |
| | | Control | 100 | 100 | 100 | 100 | 100 |
| 206-072 | OWEB: Greys | Impact | 0 | 0 | 0 | 0 | --- |
| | | Control | 27 | 36 | 59 | 36 | --- |
| 206-095 | OWEB: Jordan | Impact | 5 | 9 | 23 | 14 | 41 |
| | | Control | 100 | 100 | 100 | 100 | 86 |
| 206-283a | OWEB: Johnson | Impact | 0 | 5 | 5 | 5 | 9 |
| | | Control | 0 | 5 | 14 | 5 | 0 |
| 206-283b | OWEB: Noble | Impact | 46 | 50 | 91 | --- | --- |
| | | Control | 5 | 0 | 9 | --- | --- |
| 206-357 | OWEB: NF Malheur | Impact | 0 | 0 | 14 | 0 | 0 |
| | | Control | 5 | 5 | 32 | 9 | 0 |

**Table D-3.** Bank canopy cover (0-17) in the impact and control reach for all sampling years for livestock exclusion projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 1 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|
| 02-1498 | SRFB: Abernathy | Impact | 16 | 15 | 14 | 16 | 14 |
| | | Control | 17 | 17 | 17 | 17 | 16 |
| 04-1655 | SRFB: Hoy Riparian | Impact | 6 | 3 | 5 | 12 | 0 |
| | | Control | 17 | 17 | 16 | 16 | 0 |
| 04-1698 | SRFB: Vance | Impact | 16 | 14 | 17 | 15 | 4 |
| | | Control | 17 | 16 | 17 | 13 | 16 |
| 05-1447 | SRFB: Indian Creek-Yates | Impact | 16 | 17 | 17 | 15 | 15 |
| | | Control | 12 | 16 | 16 | 12 | 13 |
| 05-1547 | SRFB: Rauth Coweeman | Impact | 15 | 14 | 14 | 16 | 14 |
| | | Control | 17 | 17 | 17 | 17 | 16 |
| 205-060a | OWEB: Bottle | Impact | 11 | 11 | 15 | 14 | 13 |
| | | Control | 15 | 15 | 16 | 15 | 13 |
| 205-060b | OWEB: NF Clark | Impact | 15 | 15 | 15 | 14 | 11 |
| | | Control | 14 | 13 | 14 | 12 | 10 |
| 206-072 | OWEB: Greys | Impact | 16 | 16 | 17 | 17 | --- |
| | | Control | 12 | 14 | 15 | 12 | --- |
| 206-095 | OWEB: Jordan | Impact | 2 | 2 | 16 | 17 | 12 |
| | | Control | 17 | 17 | 17 | 17 | 15 |
| 206-283a | OWEB: Johnson | Impact | 7 | 14 | 16 | 16 | 11 |
| | | Control | 16 | 15 | 17 | 16 | 13 |
| 206-283b | OWEB: Noble | Impact | 10 | 16 | 15 | --- | --- |
| | | Control | 12 | 15 | 15 | --- | --- |
| 206-357 | OWEB: NF Malheur | Impact | 4 | 3 | 5 | 5 | 4 |
| | | Control | 2 | 7 | 6 | 7 | 6 |

**Table D-4.** Pool tail fines (%) <2 mm and <6 mm in the impact and control reach for Year 10 sampling for livestock exclusion projects. Missing values were not measured by the previous contractor in Year 10 and n/a values did not have pools present to measure fines.

| Site ID | Site name | Reach | PTF <2mm (%) | PTF <6mm (%) |
|---|---|---|---|---|
| 02-1498 | SRFB: Abernathy | Impact | --- | --- |
| | | Control | --- | --- |
| 04-1655 | SRFB: Hoy Riparian | Impact | --- | --- |
| | | Control | --- | --- |
| 04-1698 | SRFB: Vance | Impact | n/a | n/a |
| | | Control | n/a | n/a |
| 05-1447 | SRFB: Indian Creek-Yates | Impact | n/a | n/a |
| | | Control | n/a | n/a |
| 05-1547 | SRFB: Rauth Coweeman | Impact | 0 | 6 |
| | | Control | 14 | 19 |
| 205-060a | OWEB: Bottle | Impact | 26 | 38 |
| | | Control | 76 | 93 |
| 205-060b | OWEB: NF Clark | Impact | 18 | 30 |
| | | Control | 100 | 100 |
| 206-072 | OWEB: Greys | Impact | --- | --- |
| | | Control | --- | --- |
| 206-095 | OWEB: Jordan | Impact | n/a | n/a |
| | | Control | 67 | 67 |
| 206-283a | OWEB: Johnson | Impact | 34 | 52 |
| | | Control | 57 | 70 |
| 206-283b | OWEB: Noble | Impact | --- | --- |
| | | Control | --- | --- |
| 206-357 | OWEB: NF Malheur | Impact | 3 | 5 |
| | | Control | 9 | 15 |

# APPENDIX E: MC-5/6 FLOODPLAIN ENHANCEMENT PROJECT DATA

**Table E-1.** Average vertical pool profile area ($m^2$) in the impact and control reach for all sampling years for floodplain enhancement projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC* | Edgewater Park | Impact | 0 | --- | 21.7 | 89.4 | --- | 65.7 | 11.3 |
| | | Control | 0 | --- | 0 | 0 | --- | 41.6 | 0 |
| 02-1625 | SF Skagit Levee Setback | Impact | 595.4 | --- | 644.9 | --- | 287.6 | 544.1 | 466.2 |
| | | Control | 294.0 | --- | 387.5 | --- | 418.5 | 203.3 | 47.4 |
| 04-1461 | Dryden | Impact | 0 | --- | 90.7 | 83.6 | --- | 7.5 | 192.2 |
| | | Control | 165.9 | --- | 242.5 | 207.1 | --- | 3.5 | 13.8 |
| 04-1563* | Germany Creek | Impact | 139.0 | --- | 120.1 | 7.7 | --- | 11.1 | --- |
| | | Control | 34.1 | --- | 188.8 | 44.4 | --- | 61.1 | --- |
| 04-1573 | Lower Washougal | Impact | 22.9 | --- | 76.0 | 51.8 | --- | 32.1 | 26.0 |
| | | Control | 192.2 | --- | 203.8 | 259.9 | --- | 210.7 | 168.6 |
| 04-1596 | Lower Tolt River | Impact | 41.8 | 29.7 | 65.5 | --- | 83.5 | 105.4 | --- |
| | | Control | 145.2 | 146.1 | 89.9 | --- | 53.8 | 122.3 | --- |
| 05-1398 | Fenster Levee | Impact | 184.1 | --- | 201.4 | --- | 81.8 | 116.8 | --- |
| | | Control | 173.6 | --- | 26.0 | --- | 113.7 | 73.9 | --- |
| 05-1466 | Lower Boise Creek | Impact | 9.6 | --- | 16.9 | --- | 12.9 | 15.6 | --- |
| | | Control | 14.2 | --- | 10.6 | --- | 10.9 | 9.0 | --- |
| 05-1521 | Raging River | Impact | 37.1 | --- | 74.3 | --- | 51.0 | 117.1 | 67.9 |
| | | Control | 34.0 | --- | 27.4 | --- | 23.2 | 161.1 | 34.6 |
| 05-1546 | Gagnon | Impact | 53.1 | --- | 149.7 | 147.7 | --- | 18.5 | 171.8 |
| | | Control | 16.9 | --- | 18.4 | 14.4 | --- | 3.5 | 13.8 |
| 06-2190* | Riverview Park | Impact | 0 | --- | 9.4 | 32.8 | --- | --- | --- |
| | | Control | 352.5 | --- | 193.9 | 217.1 | --- | --- | --- |
| 06-2223 | Greenwater River | Impact | 79.9 | --- | 189.7 | --- | 88.5 | 87.2 | --- |
| | | Control | 45.0 | --- | 148.1 | --- | 55.5 | 64.8 | --- |
| 06-2239CC* | Fender Mill | Impact | 0 | --- | 8.8 | 12.3 | --- | 16.1 | --- |
| | | Control | 19.9 | --- | 13.1 | 21.7 | --- | 15.1 | --- |
| 06-2250 | Chinook Bend | Impact | 215.0 | --- | 102.7 | --- | 220.1 | 136.4 | --- |
| | | Control | 148.6 | --- | 265.8 | --- | 124.3 | 330.4 | --- |
| 06-2277* | Upper Klickitat | Impact | 3.7 | --- | 30.0 | 28.1 | --- | 18.8 | --- |
| | | Control | 27.1 | --- | 24.0 | 23.1 | --- | 29.9 | --- |
| 07-1519* | Reecer Creek | Impact | 28.3 | --- | 25.8 | --- | 22.6 | 23.3 | --- |
| | | Control | 24.9 | --- | 34.0 | --- | 0 | 7.2 | --- |
| 07-1691 | Lockwood Creek | Impact | 2.9 | --- | 25.4 | 23.3 | --- | 40.4 | --- |
| | | Control | 20.1 | --- | 12.1 | 10.1 | --- | 10.1 | --- |
| 10-1765* | Eschbach Park | Impact | 0 | --- | 16.9 | --- | 24.6 | --- | --- |
| | | Control | 18.1 | --- | 20.8 | --- | 18.8 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 117.7 | 226.5 | --- | --- | --- | --- | --- |
| | | Control | 52.7 | 75.5 | --- | --- | --- | --- | --- |
| 12-1307* | Billy's Pond | Impact | 2.4 | --- | --- | --- | 9.8 | --- | --- |
| | | Control | 76.5 | --- | --- | --- | 54.6 | --- | --- |
| 12-1438* | Lower Nason | Impact | 12.1 | --- | 2.3 | --- | --- | --- | --- |
| | | Control | 10.3 | --- | 0 | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 3.7 | --- | 19.0 | --- | 12.2 | --- | --- |
| | | Control | 10.0 | --- | 9.3 | --- | 7.2 | --- | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 49.5 | --- | 57.8 | --- | 70.5 | --- | --- |
| | | Control | 53.0 | --- | 30.6 | --- | 24.3 | --- | --- |

* denotes sites that all years of data were not included in the analysis

**Table E-2.** Mean residual profile depth (cm) in the impact and control reach for all sampling years for floodplain enhancement projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC* | Edgewater Park | Impact | 0 | --- | 6.8 | 27.9 | --- | 20.5 | 3.5 |
| | | Control | 0 | --- | 0 | 0 | --- | 18.9 | 0 |
| 02-1625 | SF Skagit Levee Setback | Impact | 113.4 | --- | 129.0 | --- | 57.5 | 108.8 | 93.2 |
| | | Control | 56.0 | --- | 73.8 | --- | 83.7 | 40.7 | 9.5 |
| 04-1461 | Dryden | Impact | 0 | --- | 51.8 | 47.8 | --- | 41.9 | 108.7 |
| | | Control | 33.2 | --- | 48.5 | 41.4 | --- | 26.7 | 9.1 |
| 04-1563* | Germany Creek | Impact | 89.7 | --- | 24.0 | 4.8 | --- | 7.5 | --- |
| | | Control | 22.0 | --- | 37.8 | 27.7 | --- | 36.2 | --- |
| 04-1573 | Lower Washougal | Impact | 14.3 | --- | 47.5 | 32.4 | --- | 20.1 | 16.1 |
| | | Control | 38.4 | --- | 40.8 | 52.0 | --- | 42.1 | 33.4 |
| 04-1596 | Lower Tolt River | Impact | 8.4 | 5.9 | 13.1 | --- | 15.8 | 19.6 | --- |
| | | Control | 29.0 | 29.2 | 18.0 | --- | 50.7 | 21.4 | --- |
| 05-1398 | Fenster Levee | Impact | 102.3 | --- | 111.9 | --- | 54.5 | 68.0 | --- |
| | | Control | 96.4 | --- | 14.4 | --- | 66.1 | 43.8 | --- |
| 05-1466 | Lower Boise Creek | Impact | 6.4 | --- | 9.6 | --- | 8.7 | 10.5 | --- |
| | | Control | 9.3 | --- | 7.8 | --- | 7.1 | 5.9 | --- |
| 05-1521 | Raging River | Impact | 0.7 | --- | 14.9 | --- | 10.2 | 23.9 | 13.4 |
| | | Control | 0.7 | --- | 5.5 | --- | 4.6 | 32.9 | 6.8 |
| 05-1546 | Gagnon | Impact | 26.6 | --- | 74.8 | 73.8 | --- | 113.8 | 85.1 |
| | | Control | 11.3 | --- | 12.2 | 9.6 | --- | 26.8 | 9.1 |
| 06-2190* | Riverview Park | Impact | 0 | --- | 4.4 | 15.4 | --- | --- | --- |
| | | Control | 78.3 | --- | 54.9 | 63.8 | --- | --- | --- |
| 06-2223 | Greenwater River | Impact | 18.6 | --- | 49.6 | --- | 19.7 | 19.8 | --- |
| | | Control | 10.5 | --- | 34.9 | --- | 12.4 | 14.6 | --- |
| 06-2239CC* | Fender Mill | Impact | 0 | --- | 5.9 | 8.2 | --- | 10.8 | --- |
| | | Control | 13.3 | --- | 8.8 | 14.5 | --- | 10.1 | --- |
| 06-2250 | Chinook Bend | Impact | 43.0 | --- | 20.5 | --- | 44.0 | 26.5 | --- |
| | | Control | 29.7 | --- | 53.2 | --- | 45.3 | 62.1 | --- |
| 06-2277* | Upper Klickitat | Impact | 2.5 | --- | 20.0 | 17.9 | --- | 12.5 | --- |
| | | Control | 18.1 | --- | 16.0 | 16.2 | --- | 19.9 | --- |
| 07-1519* | Reecer Creek | Impact | 16.6 | --- | 16.1 | --- | 13.8 | 13.6 | --- |
| | | Control | 14.7 | --- | 22.8 | --- | 0.0 | 13.6 | --- |
| 07-1691 | Lockwood Creek | Impact | 1.9 | --- | 16.9 | 15.5 | --- | 25.5 | --- |
| | | Control | 13.4 | --- | 8.2 | 6.8 | --- | 6.8 | --- |
| 10-1765* | Eschbach Park | Impact | 0 | --- | 14.9 | --- | 22.3 | --- | --- |
| | | Control | 8.9 | --- | 10.4 | --- | 10.9 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 21.6 | 39.2 | --- | --- | --- | --- | --- |
| | | Control | 10 | 14.6 | --- | --- | --- | --- | --- |
| 12-1307* | Billy's Pond | Impact | 1.6 | --- | --- | --- | 7.0 | --- | --- |
| | | Control | 57.5 | --- | --- | --- | 44.0 | --- | --- |
| 12-1438* | Lower Nason | Impact | 11.2 | --- | 2.1 | --- | --- | --- | --- |
| | | Control | 10.0 | --- | 0 | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 2.4 | --- | 11.9 | --- | 7.7 | --- | --- |
| | | Control | 4.8 | --- | 4.5 | --- | 3.6 | --- | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 14.6 | --- | 17.3 | --- | 20.1 | --- | --- |
| | | Control | 12.4 | --- | 7.7 | --- | 6.1 | --- | --- |

* denotes sites that all years of data were not included in the analysis

**Table E-3.** Bank canopy cover (0-17) in the impact and control reach for all sampling years for floodplain enhancement projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC* | Edgewater Park | Impact | 17 | --- | 10 | 10 | --- | 11 | 13 |
| | | Control | 17 | --- | 17 | 17 | --- | 17 | 17 |
| 02-1625 | SF Skagit Levee Setback | Impact | 15 | --- | 14 | --- | 16 | --- | 10 |
| | | Control | 13 | --- | 12 | --- | --- | --- | 10 |
| 04-1461 | Dryden | Impact | 7 | --- | 2 | 3 | --- | 5 | 4 |
| | | Control | 2 | --- | 6 | 8 | --- | 14 | 12 |
| 04-1563* | Germany Creek | Impact | 16 | --- | 16 | 16 | --- | 16 | --- |
| | | Control | 15 | --- | 14 | 15 | --- | 15 | --- |
| 04-1573 | Lower Washougal | Impact | 2 | --- | 8 | 14 | --- | 6 | 6 |
| | | Control | 8 | --- | 6 | 10 | --- | 8 | 5 |
| 04-1596 | Lower Tolt River | Impact | 16 | 14 | --- | --- | --- | 14 | --- |
| | | Control | 13 | 14 | --- | --- | --- | 13 | --- |
| 05-1398 | Fenster Levee | Impact | --- | --- | --- | --- | 8 | 13 | --- |
| | | Control | --- | --- | --- | --- | 15 | 16 | --- |
| 05-1466 | Lower Boise Creek | Impact | --- | --- | 8 | --- | 14 | 14 | --- |
| | | Control | --- | --- | 16 | --- | 16 | 16 | --- |
| 05-1521 | Raging River | Impact | --- | --- | --- | --- | --- | 9 | 11 |
| | | Control | --- | --- | --- | --- | --- | 14 | 14 |
| 05-1546 | Gagnon | Impact | 14 | --- | 9 | 10 | --- | 11 | 7 |
| | | Control | 10 | --- | 13 | 11 | --- | 14 | 12 |
| 06-2190* | Riverview Park | Impact | 5 | --- | 3 | 7 | --- | --- | --- |
| | | Control | 14 | --- | 16 | 13 | --- | --- | --- |
| 06-2223 | Greenwater River | Impact | --- | --- | 17 | --- | 16 | 16 | --- |
| | | Control | --- | --- | 12 | --- | 13 | 14 | --- |
| 06-2239CC* | Fender Mill | Impact | 14 | --- | 11 | 11 | --- | 15 | --- |
| | | Control | 4 | --- | 8 | 13 | --- | 16 | --- |
| 06-2250 | Chinook Bend | Impact | --- | --- | --- | --- | --- | 9 | --- |
| | | Control | --- | --- | --- | --- | --- | 14 | --- |
| 06-2277* | Upper Klickitat | Impact | 12 | --- | 11 | 11 | --- | 10 | --- |
| | | Control | 10 | --- | 13 | 13 | --- | 14 | --- |
| 07-1519* | Reecer Creek | Impact | --- | --- | 0 | --- | 12 | 8 | --- |
| | | Control | --- | --- | 17 | --- | 17 | 16 | --- |
| 07-1691 | Lockwood Creek | Impact | 12 | --- | 13 | 12 | --- | 13 | --- |
| | | Control | 16 | --- | 16 | 16 | --- | 16 | --- |
| 10-1765* | Eschbach Park | Impact | 13 | --- | 8 | --- | --- | --- | --- |
| | | Control | 11 | --- | 7 | --- | --- | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 14 | --- | --- | --- | --- | --- | --- |
| | | Control | 17 | --- | --- | --- | --- | --- | --- |
| 12-1307* | Billy's Pond | Impact | 12 | --- | --- | --- | --- | --- | --- |
| | | Control | 15 | --- | --- | --- | --- | --- | --- |
| 12-1438* | Lower Nason | Impact | 17 | --- | --- | --- | --- | --- | --- |
| | | Control | 15 | --- | 0 | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |

* denotes sites that all years of data were not included in the analysis

**Table E-4.** Riparian vegetation structure (%) in the impact and control reach for all sampling years for floodplain enhancement projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC* | Edgewater Park | Impact | 100 | --- | 59 | 46 | --- | 68 | 91 |
| | | Control | 100 | --- | 5 | 91 | --- | 9 | 96 |
| 02-1625 | SF Skagit Levee Setback | Impact | 91 | --- | 68 | --- | 82 | --- | 100 |
| | | Control | 86 | --- | 59 | --- | --- | --- | 73 |
| 04-1461 | Dryden | Impact | 68 | --- | 36 | 36 | --- | 91 | 53 |
| | | Control | 50 | --- | 41 | 59 | --- | 86 | 73 |
| 04-1563* | Germany Creek | Impact | 96 | --- | 96 | 100 | --- | 86 | --- |
| | | Control | 91 | --- | 91 | 91 | --- | 91 | --- |
| 04-1573 | Lower Washougal | Impact | 32 | --- | 46 | 55 | --- | 36 | 59 |
| | | Control | 46 | --- | 41 | 55 | --- | 27 | 50 |
| 04-1596 | Lower Tolt River | Impact | 100 | 100 | --- | --- | --- | 96 | --- |
| | | Control | 68 | 91 | --- | --- | --- | 77 | --- |
| 05-1398 | Fenster Levee | Impact | --- | --- | --- | --- | 77 | 64 | --- |
| | | Control | --- | --- | --- | --- | 100 | 64 | --- |
| 05-1466 | Lower Boise Creek | Impact | --- | --- | 77 | --- | 59 | 86 | --- |
| | | Control | --- | --- | 100 | --- | 100 | 96 | --- |
| 05-1521 | Raging River | Impact | --- | --- | --- | --- | --- | 59 | 75 |
| | | Control | --- | --- | --- | --- | --- | 91 | 83 |
| 05-1546 | Gagnon | Impact | 91 | --- | 55 | 86 | --- | 77 | 70 |
| | | Control | 55 | --- | 77 | 77 | --- | 86 | 73 |
| 06-2190* | Riverview Park | Impact | 9 | --- | 0 | 18 | --- | --- | --- |
| | | Control | 55 | --- | 36 | 50 | --- | --- | --- |
| 06-2223 | Greenwater River | Impact | --- | --- | 96 | --- | 96 | 96 | --- |
| | | Control | --- | --- | 91 | --- | 91 | 100 | --- |
| 06-2239CC* | Fender Mill | Impact | 41 | --- | 77 | 77 | --- | 64 | --- |
| | | Control | 46 | --- | 59 | 81 | --- | 100 | --- |
| 06-2250 | Chinook Bend | Impact | --- | --- | --- | --- | --- | 91 | --- |
| | | Control | --- | --- | --- | --- | --- | 96 | --- |
| 06-2277* | Upper Klickitat | Impact | 68 | --- | 59 | 64 | --- | 73 | --- |
| | | Control | 50 | --- | 68 | 50 | --- | 55 | --- |
| 07-1519* | Reecer Creek | Impact | --- | --- | 0 | --- | 0 | 5 | --- |
| | | Control | --- | --- | 96 | --- | 100 | 100 | --- |
| 07-1691 | Lockwood Creek | Impact | 73 | --- | 68 | 68 | --- | 82 | --- |
| | | Control | 91 | --- | 91 | 96 | --- | 96 | --- |
| 10-1765* | Eschbach Park | Impact | 41 | --- | 32 | --- | 50 | --- | --- |
| | | Control | 73 | --- | 64 | --- | 60 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 86 | --- | --- | --- | --- | --- | --- |
| | | Control | 100 | --- | --- | --- | --- | --- | --- |
| 12-1307* | Billy's Pond | Impact | 68 | --- | --- | --- | 60 | --- | --- |
| | | Control | 59 | --- | --- | --- | 70 | --- | --- |
| 12-1438* | Lower Nason | Impact | 96 | --- | 68 | --- | --- | --- | --- |
| | | Control | 77 | --- | 0 | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 20 | --- | 20 | --- | 20 | --- | --- |
| | | Control | 100 | --- | 100 | --- | 50 | --- | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 50 | --- | 100 | --- | 90 | --- | --- |
| | | Control | 100 | --- | 100 | --- | 0 | --- | --- |

* denotes sites that all years of data were not included in the analysis

**Table E-5.** Average channel capacity (m$^2$) in the impact and control reach for all sampling years for floodplain enhancement projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC* | Edgewater Park | Impact | --- | --- | --- | --- | --- | --- | 13.2 |
| | | Control | --- | --- | --- | --- | --- | --- | 0 |
| 02-1625 | SF Skagit Levee Setback | Impact | 821.9 | --- | 647.5 | --- | 685.7 | 785.7 | 533.5 |
| | | Control | 766.0 | --- | 828.2 | --- | 1,020.2 | 907.8 | 518.6 |
| 04-1461 | Dryden | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 04-1563* | Germany Creek | Impact | --- | --- | --- | --- | --- | 0.7 | --- |
| | | Control | --- | --- | --- | --- | --- | 5.9 | --- |
| 04-1573 | Lower Washougal | Impact | --- | --- | --- | --- | --- | --- | 75.8 |
| | | Control | --- | --- | --- | --- | --- | --- | 73.5 |
| 04-1596 | Lower Tolt River | Impact | 47.7 | 72.6 | 45.1 | --- | 55.0 | 38.6 | --- |
| | | Control | 41.2 | 35.7 | 36.3 | --- | 12.4 | 28.2 | --- |
| 05-1398 | Fenster Levee | Impact | 89.7 | --- | 235.8 | --- | 112.9 | 78.5 | --- |
| | | Control | 101.5 | --- | 126.0 | --- | 92.6 | 66.8 | --- |
| 05-1466 | Lower Boise Creek | Impact | 9.3 | --- | 14.1 | --- | 7.5 | 5.0 | --- |
| | | Control | 10.0 | --- | 5.2 | --- | 5.2 | 4.3 | --- |
| 05-1521 | Raging River | Impact | 37.1 | --- | 76.0 | --- | 27.7 | 3.7 | 27.2 |
| | | Control | 38.7 | --- | 34.0 | --- | 14.7 | 5.3 | 21.5 |
| 05-1546 | Gagnon | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 06-2190* | Riverview Park | Impact | --- | --- | 4.9 | 6.1 | --- | --- | --- |
| | | Control | --- | --- | 55.2 | 66.6 | --- | --- | --- |
| 06-2223 | Greenwater River | Impact | 23.9 | --- | 16.1 | --- | 15.1 | 11.8 | --- |
| | | Control | 30.2 | --- | 10.1 | --- | 8.5 | 11.3 | --- |
| 06-2239CC* | Fender Mill | Impact | --- | --- | 4.7 | --- | --- | 4.1 | --- |
| | | Control | --- | --- | 6.2 | --- | --- | 4.6 | --- |
| 06-2250 | Chinook Bend | Impact | 194.2 | --- | 186.8 | --- | 179.7 | 235.6 | --- |
| | | Control | 221.5 | --- | 237.6 | --- | 42.8 | 170.2 | --- |
| 06-2277* | Upper Klickitat | Impact | --- | --- | --- | 22,653.1 | --- | 7.9 | --- |
| | | Control | --- | --- | --- | 14,629.1 | --- | 4.1 | --- |
| 07-1519* | Reecer Creek | Impact | 13.2 | --- | 0.9 | --- | 4.9 | 4.6 | --- |
| | | Control | 4.2 | --- | 3.7 | --- | --- | 1.1 | --- |
| 07-1691 | Lockwood Creek | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 10-1765* | Eschbach Park | Impact | --- | --- | 2.8 | --- | 4.5 | --- | --- |
| | | Control | 4.4 | --- | 4.3 | --- | 16.2 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 31.0 | 25.4 | --- | --- | --- | --- | --- |
| | | Control | 24.2 | 26.5 | --- | --- | --- | --- | --- |
| 12-1307* | Billy's Pond | Impact | 171.8 | --- | --- | --- | 78.2 | --- | --- |
| | | Control | 124.4 | --- | --- | --- | 109.5 | --- | --- |
| 12-1438* | Lower Nason | Impact | 1.6 | --- | 0.5 | --- | --- | --- | --- |
| | | Control | 1.9 | --- | --- | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 1.6 | --- | 3.7 | --- | 3.7 | --- | --- |
| | | Control | 2.5 | --- | 2.2 | --- | 1.9 | --- | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 6.6 | --- | 10.5 | --- | 8.0 | --- | --- |
| | | Control | 6.5 | --- | 8.7 | --- | 8.9 | --- | --- |

* denotes sites that all years of data were not included in the analysis

**Table E-6.** Floodprone width (m) in the impact and control reach for all sampling years for floodplain enhancement projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC* | Edgewater Park | Impact | --- | --- | --- | --- | --- | --- | 26.3 |
| | | Control | --- | --- | --- | --- | --- | --- | 15.9 |
| 02-1625 | SF Skagit Levee Setback | Impact | 162.3 | --- | 280.0 | --- | 291.7 | 716.7 | 373.3 |
| | | Control | 185.0 | --- | 185.0 | --- | 185.0 | 197.0 | 223.3 |
| 04-1461 | Dryden | Impact | --- | --- | --- | --- | --- | --- | 57.0 |
| | | Control | --- | --- | --- | --- | --- | --- | 99.7 |
| 04-1563* | Germany Creek | Impact | --- | --- | --- | --- | --- | 8.7 | --- |
| | | Control | --- | --- | --- | --- | --- | 20.8 | --- |
| 04-1573 | Lower Washougal | Impact | --- | --- | --- | --- | --- | --- | 216.0 |
| | | Control | --- | --- | --- | --- | --- | --- | 56.0 |
| 04-1596 | Lower Tolt River | Impact | --- | 57.7 | 93.0 | --- | 0 | 43.6 | --- |
| | | Control | 0 | 58.3 | 59.3 | --- | --- | 29.5 | --- |
| 05-1398 | Fenster Levee | Impact | 98.0 | --- | 285.3 | --- | --- | --- | --- |
| | | Control | 92.7 | --- | 105.0 | --- | --- | 37.0 | --- |
| 05-1466 | Lower Boise Creek | Impact | 39.0 | --- | --- | --- | 18.2 | --- | --- |
| | | Control | 19.3 | --- | --- | --- | 9.4 | --- | --- |
| 05-1521 | Raging River | Impact | 26.7 | --- | 85.3 | --- | 62.3 | --- | 86.0 |
| | | Control | 24.1 | --- | 24.9 | --- | 19.8 | --- | 21.9 |
| 05-1546 | Gagnon | Impact | --- | --- | --- | --- | --- | --- | 38.7 |
| | | Control | --- | --- | --- | --- | --- | --- | 99.7 |
| 06-2190* | Riverview Park | Impact | --- | --- | 17.5 | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 06-2223 | Greenwater River | Impact | 48.8 | --- | --- | --- | 20.6 | 77.8 | --- |
| | | Control | 82.7 | --- | --- | --- | 28.6 | 58.3 | --- |
| 06-2239CC* | Fender Mill | Impact | --- | --- | 91.1 | --- | --- | --- | --- |
| | | Control | --- | --- | 29.5 | --- | --- | --- | --- |
| 06-2250 | Chinook Bend | Impact | 82.8 | --- | 112.2 | --- | 0 | 98.7 | --- |
| | | Control | 89.8 | --- | 94.2 | --- | --- | 90.3 | --- |
| 06-2277* | Upper Klickitat | Impact | --- | --- | --- | 0 | --- | 999.0 | --- |
| | | Control | --- | --- | --- | --- | --- | 38.5 | --- |
| 07-1519* | Reecer Creek | Impact | 48.0 | --- | --- | --- | --- | 150.0 | --- |
| | | Control | 2,500.0 | --- | --- | --- | 12.2 | 11.5 | --- |
| 07-1691 | Lockwood Creek | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | 9.0 | --- |
| 10-1765* | Eschbach Park | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | 122.1 | --- | --- | --- | --- | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 49.4 | --- | --- | --- | --- | --- | --- |
| | | Control | 45.5 | --- | --- | --- | --- | --- | --- |
| 12-1307* | Billy's Pond | Impact | 91.7 | --- | --- | --- | --- | --- | --- |
| | | Control | 95.3 | --- | --- | --- | --- | --- | --- |
| 12-1438* | Lower Nason | Impact | 14.3 | --- | --- | --- | --- | --- | --- |
| | | Control | 8.0 | --- | --- | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |

* denotes sites that all years of data were not included in the analysis

**Table E-7.** Juvenile Chinook salmon densities (fish/m$^2$) in the impact and control reach for all sampling years for floodplain enhancement projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC* | Edgewater Park | Impact | 0 | --- | 0.0221 | 0.0066 | --- | 0 | 0 |
| | | Control | 0 | --- | 0 | 0 | --- | 0 | 0 |
| 02-1625 | SF Skagit Levee Setback | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 04-1461 | Dryden | Impact | 0 | --- | 0 | 0 | --- | 0.0388 | 0.0183 |
| | | Control | 0 | --- | 0.0002 | 0.0006 | --- | 0.0003 | 0.0011 |
| 04-1563* | Germany Creek | Impact | 0 | --- | 0 | 0 | --- | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | --- | 0 | --- |
| 04-1573 | Lower Washougal | Impact | 0.4841 | --- | 0.0001 | 0 | --- | 0.0007 | 0 |
| | | Control | 0.1398 | --- | 0.0003 | 0 | --- | 0.0025 | 0.0002 |
| 04-1596 | Lower Tolt River | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 05-1398 | Fenster Levee | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 05-1466 | Lower Boise Creek | Impact | 0.0009 | --- | 0 | --- | 0 | 0 | --- |
| | | Control | 0.0130 | --- | 0 | --- | 0 | 0 | --- |
| 05-1521 | Raging River | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 05-1546 | Gagnon | Impact | 0 | --- | 0 | 0.1054 | --- | 0.0238 | 0.0005 |
| | | Control | 0.0086 | --- | 0 | 0.0018 | --- | 0.0003 | 0.0011 |
| 06-2190* | Riverview Park | Impact | 0 | --- | 0 | 0 | --- | --- | --- |
| | | Control | 0 | --- | 0 | 0 | --- | --- | --- |
| 06-2223 | Greenwater River | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 06-2239CC* | Fender Mill | Impact | 0 | --- | 0 | 0 | --- | 0 | --- |
| | | Control | 0.0419 | --- | 0.0334 | 0.0272 | --- | 0 | --- |
| 06-2250 | Chinook Bend | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 06-2277* | Upper Klickitat | Impact | 0 | --- | 0 | 0 | --- | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | --- | 0 | --- |
| 07-1519* | Reecer Creek | Impact | --- | --- | --- | --- | --- | 0 | --- |
| | | Control | --- | --- | --- | --- | --- | 0 | --- |
| 07-1691 | Lockwood Creek | Impact | 0 | --- | 0 | 0 | --- | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | --- | 0 | --- |
| 10-1765* | Eschbach Park | Impact | 0.2521 | --- | 0 | --- | 0 | --- | --- |
| | | Control | 0.8638 | --- | 0 | --- | 0 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 0.0002 | 0.0150 | --- | --- | --- | --- | --- |
| | | Control | 0 | 0 | --- | --- | --- | --- | --- |
| 12-1307* | Billy's Pond | Impact | 0 | --- | --- | --- | 0 | --- | --- |
| | | Control | 0 | --- | --- | --- | 0 | --- | --- |
| 12-1438* | Lower Nason | Impact | 0.1068 | --- | 0 | --- | --- | --- | --- |
| | | Control | 0 | --- | 0 | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 0 | --- | 0 | --- | 0 | --- | --- |
| | | Control | 0 | --- | 0 | --- | 0 | --- | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 0.0490 | --- | 0.0182 | --- | 0.0219 | --- | --- |
| | | Control | 0.0430 | --- | 0.0069 | --- | 0.0196 | --- | --- |

* denotes sites that all years of data were not included in the analysis

**Table E-8.** Juvenile coho salmon densities (fish/m$^2$) in the impact and control reach for all sampling years for floodplain enhancement projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC* | Edgewater Park | Impact | 0 | --- | 0.0004 | 0 | --- | 0 | 0 |
| | | Control | 0 | --- | 0 | 0 | --- | 0 | 0 |
| 02-1625 | SF Skagit Levee Setback | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 04-1461 | Dryden | Impact | 0 | --- | 0.4878 | 0.3675 | --- | 0.0812 | 0.0068 |
| | | Control | 0 | --- | 0.0002 | 0 | --- | 0.0257 | 0 |
| 04-1563* | Germany Creek | Impact | 0 | --- | 0 | 1.9632 | --- | 1.1675 | --- |
| | | Control | 0.0402 | --- | 0.0008 | 0.1415 | --- | 0.0595 | --- |
| 04-1573 | Lower Washougal | Impact | 0 | --- | 0 | 0 | --- | 0.0005 | 0 |
| | | Control | 0 | --- | 0 | 0 | --- | 0.0054 | 0 |
| 04-1596 | Lower Tolt River | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 05-1398 | Fenster Levee | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 05-1466 | Lower Boise Creek | Impact | 0.0205 | --- | 0 | --- | 0.6572 | 1.0498 | --- |
| | | Control | 0.0370 | --- | 0 | --- | 0.2587 | 0.1998 | --- |
| 05-1521 | Raging River | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 05-1546 | Gagnon | Impact | 0 | --- | 0 | 0.0746 | --- | 0.0026 | 0 |
| | | Control | 0.0491 | --- | 0 | 0 | --- | 0.0250 | 0 |
| 06-2190* | Riverview Park | Impact | 0 | --- | 0 | 0 | --- | --- | --- |
| | | Control | 0 | --- | 0 | 0 | --- | --- | --- |
| 06-2223 | Greenwater River | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 06-2239CC* | Fender Mill | Impact | 0 | --- | 0 | 0 | --- | 0 | --- |
| | | Control | 0 | --- | 0 | 0.0027 | --- | 0 | --- |
| 06-2250 | Chinook Bend | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 06-2277* | Upper Klickitat | Impact | 0 | --- | 0 | 0 | --- | 0 | --- |
| | | Control | 0 | --- | 0 | 0 | --- | 0 | --- |
| 07-1519* | Reecer Creek | Impact | --- | --- | --- | --- | --- | 0.0018 | --- |
| | | Control | --- | --- | --- | --- | --- | 0 | --- |
| 07-1691 | Lockwood Creek | Impact | 0 | --- | 0.0091 | 0.2152 | --- | 0.1381 | --- |
| | | Control | 0.0533 | --- | 0.0188 | 0.2877 | --- | 0.1719 | --- |
| 10-1765* | Eschbach Park | Impact | 0.0298 | --- | 0 | --- | 0 | --- | --- |
| | | Control | 0.1470 | --- | 0 | --- | 0 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 0.2380 | 0.0011 | --- | --- | --- | --- | --- |
| | | Control | 0.0944 | 0.0310 | --- | --- | --- | --- | --- |
| 12-1307* | Billy's Pond | Impact | 0 | --- | --- | --- | 0 | --- | --- |
| | | Control | 0 | --- | --- | --- | 0 | --- | --- |
| 12-1438* | Lower Nason | Impact | 0 | --- | 0 | --- | --- | --- | --- |
| | | Control | 0 | --- | 0 | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 0 | --- | 0 | --- | 0 | --- | --- |
| | | Control | 0 | --- | 0 | --- | 0 | --- | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 0 | --- | 0 | --- | 0 | --- | --- |
| | | Control | 0 | --- | 0 | --- | 0 | --- | --- |

* denotes sites that all years of data were not included in the analysis

**Table E-9.** Juvenile steelhead densities (fish/m$^2$) in the impact and control reach for all sampling years for floodplain enhancement projects. Missing values were not measured in that year of sampling for a particular site.

| Site ID | Site name | Reach | Year 0 | Year 0* | Year 1 | Year 2 | Year 3 | Year 5 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|
| 02-1561CC* | Edgewater Park | Impact | 0 | --- | 0 | 0 | --- | 0 | 0 |
| | | Control | 0 | --- | 0 | 0 | --- | 0 | 0 |
| 02-1625 | SF Skagit Levee Setback | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 04-1461 | Dryden | Impact | 0 | --- | 0 | 0 | --- | 0.0010 | 0 |
| | | Control | 0.0031 | --- | 0.0011 | 0.0024 | --- | 0.0334 | 0 |
| 04-1563* | Germany Creek | Impact | 0 | --- | 0 | 0 | --- | 0 | --- |
| | | Control | 0 | --- | 0 | 0.0082 | --- | 0.0121 | --- |
| 04-1573 | Lower Washougal | Impact | 0 | --- | 0 | 0 | --- | 0 | 0 |
| | | Control | 0 | --- | 0.0001 | 0 | --- | 0.0017 | 0 |
| 04-1596 | Lower Tolt River | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 05-1398 | Fenster Levee | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 05-1466 | Lower Boise Creek | Impact | 0.0071 | --- | 0 | --- | 0.1127 | 0.2347 | --- |
| | | Control | 0.0080 | --- | 0 | --- | 0.0836 | 0.1367 | --- |
| 05-1521 | Raging River | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 05-1546 | Gagnon | Impact | 0 | --- | 0 | 0 | --- | 0 | 0 |
| | | Control | 0.0547 | --- | 0.0007 | 0.0158 | --- | 0.0334 | 0 |
| 06-2190* | Riverview Park | Impact | 0 | --- | 0 | 0 | --- | --- | --- |
| | | Control | 0.0021 | --- | 0.0003 | 0 | --- | --- | --- |
| 06-2223 | Greenwater River | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 06-2239CC* | Fender Mill | Impact | 0 | --- | 0 | 0 | --- | 0 | --- |
| | | Control | 0.0011 | --- | 0.0019 | 0.0053 | --- | 0.0011 | --- |
| 06-2250 | Chinook Bend | Impact | --- | --- | --- | --- | --- | --- | --- |
| | | Control | --- | --- | --- | --- | --- | --- | --- |
| 06-2277* | Upper Klickitat | Impact | 0 | --- | 0.1672 | 0.1263 | --- | 0 | --- |
| | | Control | 0.0658 | --- | 0.0374 | 0.0027 | --- | 0.0123 | --- |
| 07-1519* | Reecer Creek | Impact | --- | --- | --- | --- | --- | 0 | --- |
| | | Control | --- | --- | --- | --- | --- | 0 | --- |
| 07-1691 | Lockwood Creek | Impact | 0 | --- | 0.0195 | 0.1004 | --- | 0.0429 | --- |
| | | Control | 0.0012 | --- | 0.0137 | 0.0367 | --- | 0.0116 | --- |
| 10-1765* | Eschbach Park | Impact | 0.0275 | --- | 0 | --- | 0 | --- | --- |
| | | Control | 0.0346 | --- | 0 | --- | 0 | --- | --- |
| 11-1354* | Lower Dosewallips | Impact | 0.0175 | 0.0153 | --- | --- | --- | --- | --- |
| | | Control | 0.0183 | 0.0171 | --- | --- | --- | --- | --- |
| 12-1307* | Billy's Pond | Impact | 0 | --- | --- | --- | 0 | --- | --- |
| | | Control | 0 | --- | --- | --- | 0 | --- | --- |
| 12-1438* | Lower Nason | Impact | 0 | --- | 0.3537 | --- | --- | --- | --- |
| | | Control | 0 | --- | 0 | --- | --- | --- | --- |
| 12-1657 | George Creek | Impact | 0.1478 | --- | 0.1590 | --- | 0.0407 | --- | --- |
| | | Control | 0.2065 | --- | 0.1894 | --- | 1.7344 | --- | --- |
| Tucannon PA-26 | Tucannon PA-26 | Impact | 0.1452 | --- | 0.1225 | --- | 0.2931 | --- | --- |
| | | Control | 0.1055 | --- | 0.1612 | --- | 0.2367 | --- | --- |

* denotes sites that all years of data were not included in the analysis

# APPENDIX F: MC-8 DIVERSION SCREENING PROJECT DATA

**Table F-1.** Diversion screen summary for NOAA compliance. nt = screen not operating at time of survey to assess. n/a = screen standards do not apply. Please see the MC-8 Diversion Screening Protocol for a description of the metrics. All data are from the 2009 Annual Report (Tetra Tech 2008).

| Site ID | Site name | Year code | Parallel flow to screen | Approach velocity[a] | Uniform flow | Sweep velocity > approach velocity[b] | Sweep velocity decrease[b] | Screen mesh[c] | Corrosion resistant | Gaps sealed | Maximum withdrawal (< 3 cfs) | Debris accumulation device present | Clearance[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 02-1540* | Touchet River Screens | 1 | n/a | Y | Y | n/a | n/a | Y | Y | Y | Y | Y | Y |
| 02-1543 | Walla Walla Fish Screening | 1 | Y | Y | Y | n/a | Y | Y | Y | Y | Y | Y | Y |
| 02-1543 | Walla Walla Fish Screening | 2 | Y | Y | Y | n/a | Y | Y | Y | Y | Y | Y | Y |
| 02-1544 | Tucannon River Screens | 1 | Y | Y | Y | n/a | N | Y | Y | Y | Y | Y | Y |
| 02-1544 | Tucannon River Screens | 2 | Y | Y | Y | n/a | Y | Y | Y | Y | Y | Y | Y |
| 02-1656 | Dry/Cabin Creek Fish Screening | 1 | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | N |
| 02-1656 | Dry/Cabin Creek Fish Screening | 2 | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| 04-1373 | Indian Creek – McDaniels 1 | 1 | Y | nt | nt | n/a | nt | Y | Y | Y | nt | Y | Y |
| 04-1373 | Indian Creek – McDaniels 1 | 2 | Y | nt | nt | n/a | Y | Y | Y | Y | nt | Y | N |
| 04-1373 | Indian Creek – McDaniels 2 | 1 | nt | nt | nt | nt | nt | Y | Y | Y | Y | nt | n/a |
| 04-1373 | Indian Creek – McDaniels 2 | 2 | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| 04-1373 | Indian Creek – Roy | 1 | N | Y | Y | n/a | Y | Y | Y | Y | Y | Y | N |
| 04-1373 | Indian Creek – Roy | 2 | N | Y | Y | n/a | Y | Y | Y | Y | Y | Y | N |
| 04-1508* | Jones-Shotwell Screen & Diversion | 1 | Y | Y | Y | n/a | Y | Y | Y | Y | Y | Y | Y |
| 04-1568 | Garfield County Screening – Deadman | 1 | Y | Y | Y | n/a | Y | Y | Y | Y | Y | N | N |
| 04-1568 | Garfield County Screening – Deadman | 2 | Y | Y | N | n/a | Y | Y | Y | Y | Y | N | N |
| 04-1568 | Garfield County Screening – Meadow | 1 | Y | Y | Y | n/a | N | Y | Y | Y | Y | N | N |
| 04-1568 | Garfield County Screening – Meadow | 2 | Y | Y | N | n/a | Y | Y | Y | Y | Y | N | N |

* denotes site was only monitored for one year after project implementation

[a] <0.4 ft/s active, <0.2 ft/s passive screens

[b] for screens >6 ft length

[c] circular: <$^3/_{32}$ inch diameter & smooth, slotted: <1.75 mm, square: <$^3/_{32}$ inch

[d] screen submerged ≥ one radius from minimum water surface and ≥ one radius from natural or constructed features

# APPENDIX G: MC-10 HABITAT PROTECTION PROJECT DATA

**Table G-1.** Vertical pool profile area ($m^2$) at habitat protection projects. Missing values are from estuarine sites where data were not collected. Values reported in this table were from the summary tables provided by Tetra Tech and do not reflect values reported in the 2008 Annual Report (Tetra Tech 2009).

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 287.1 | 270.4 | 252.9 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 0 (dry) | 1.2 | 0 (dry) |
| 00-1841 | Metzler Park Side Channel Acquisition | 27.0 | 40.2 | 75.7 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 4.9 | 7.1 | 9.4 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 92.3 | 90.6 | 107.1 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 49.3 | 34.3 | 50.3 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 9.7 | 44.8 | 34.5 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |

**Table G-2.** Mean residual profile depth (cm) at habitat protection projects. Missing values are from estuarine sites where data were not collected. Values reported in this table were from the summary tables provided by Tetra Tech and do not reflect values reported in the 2008 Annual Report (Tetra Tech 2009).

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 61.1 | 54.1 | 50.6 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 0 (dry) | 0.8 | 0 (dry) |
| 00-1841 | Metzler Park Side Channel Acquisition | 10.8 | 16.1 | 30.3 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 3.3 | 4.7 | 6.3 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 18.5 | 18.1 | 21.4 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 15.9 | 11.1 | 16.2 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 1.9 | 9.0 | 6.9 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |

**Table G-3.** Volume of LWD ($m^3$) at habitat protection projects. Missing values are from estuarine sites where data were not collected.

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 0.87 | 1.17 | 1.22 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 1.02 | 0.12 | -1.86 |
| 00-1841 | Metzler Park Side Channel Acquisition | 0.55 | -0.17 | 0.95 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | -0.26 | 0.89 | 0.07 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 1.28 | 0.97 | 1.39 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 0.57 | 0.68 | 1.32 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 0.71 | 0.47 | 1.08 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |

**Table G-4.** Percent fines (<6 mm) at habitat protection projects. Missing values are from estuarine sites where data were not collected.

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 26 | 22 | 2 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 32 | 48 | 0 |
| 00-1841 | Metzler Park Side Channel Acquisition | 16 | 4 | 26 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 0 | 0 | 4 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 0 | 8 | 8 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 0 | 20 | 0 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 0 | 0 | 0 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |

**Table G-5.** Embeddedness (%) at habitat protection projects. Missing values are from estuarine sites where data were not collected.

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 67 | 70 | 61 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 88 | 61 | 27 |
| 00-1841 | Metzler Park Side Channel Acquisition | 52 | 49 | 48 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 7 | 36 | 12 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 36 | 56 | 34 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 45 | 70 | 33 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 9 | 20 | 20 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |

**Table G-6.** Bank erosion (%) at habitat protection projects. Missing values are from estuarine sites where data were not collected. nm = site was visited, but metric was not measured at time of monitoring.

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 29 | 42 | 12 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | nm | 9 | 7 |
| 00-1841 | Metzler Park Side Channel Acquisition | 3 | 12 | 25 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 19 | 10 | 0 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | nm | 12 | 4 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 2 | 25 | 5 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 23 | 4 | 28 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |

**Table G-7.** Bank canopy cover (0-17) at habitat protection projects. Missing values are from estuarine sites where data were not collected.

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 10 | 7 | 9 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 17 | 17 | 17 |
| 00-1841 | Metzler Park Side Channel Acquisition | 17 | 17 | 17 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 16 | 17 | 17 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 13 | 14 | 10 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 15 | 15 | 16 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 10 | 12 | 10 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |

**Table G-8.** Riparian vegetation structure (%) at habitat protection projects. Missing values are from estuarine sites where data were not collected.

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 59 | 59 | 100 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 96 | 100 | 96 |
| 00-1841 | Metzler Park Side Channel Acquisition | 100 | 100 | 96 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 96 | 100 | 86 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 82 | 100 | 55 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 86 | 100 | 96 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 100 | 82 | 100 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |

**Table G-9.** Conifer basal area ($ft^2$/acre) and density (stem count/acre) at habitat protection projects. Values reported in this table were from the summary tables provided by Tetra Tech and do not reflect values reported in the 2008 Annual Report (Tetra Tech 2009).

| | | Basal area | | | Density | | |
|---|---|---|---|---|---|---|---|
| Site ID | Site name | Year 0 | Year 3 | Year 8 | Year 0 | Year 3 | Year 8 |
| 00-1669 | Entiat River Habitat Acquisition | 0 | 0 | 0.4 | 0 | 0 | 11 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 89.2 | 107.5 | 163.3 | 401 | 390 | 288 |
| 00-1841 | Metzler Park Side Channel Acquisition | 16.1 | 16.9 | 5.4 | 86 | 36 | 24 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 52.3 | 53.1 | 59.9 | 127 | 54 | 57 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | 180.4 | 236.0 | 200.6 | 194 | 176 | 140 |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 208.3 | 266.3 | 249.2 | 222 | 208 | 200 |
| 02-1592 | Curley Creek Estuary Acquisition | 101.7 | 96.2 | 134.8 | 60 | 62 | 72 |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 158.5 | 184.0 | 179.9 | 126 | 118 | 118 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 0.8 | 2.0 | 1.7 | 8 | 13 | 6 |
| 04-1335 | Piner Point on Maury Island | 7.5 | 7.5 | 0 | 4 | 4 | 0 |

**Table G-10.** Deciduous basal area (ft$^2$/acre) and density (stem count/acre) at habitat protection projects. Values reported in this table were from the summary tables provided by Tetra Tech and do not reflect values reported in the 2008 Annual Monitoring Report (Tetra Tech 2009).

| | | Basal area | | | Density | | |
|---|---|---|---|---|---|---|---|
| **Site ID** | **Site name** | **Year 0** | **Year 3** | **Year 8** | **Year 0** | **Year 3** | **Year 8** |
| 00-1669 | Entiat River Habitat Acquisition | 0 | 0 | 50.4 | 0 | 0 | 670 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 4.4 | 7.4 | 3.7 | 157 | 243 | 44 |
| 00-1841 | Metzler Park Side Channel Acquisition | 160.6 | 155.5 | 128.4 | 316 | 172 | 240 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 85.5 | 60.9 | 103.1 | 237 | 138 | 192 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | 0 | 0 | 0 | 0 | 0 | 0 |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 13.1 | 13.1 | 12.0 | 98 | 180 | 92 |
| 02-1592 | Curley Creek Estuary Acquisition | 96.5 | 139.5 | 100.8 | 140 | 160 | 86 |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 30.7 | 59.7 | 22.6 | 30 | 32 | 50 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 216.2 | 283.5 | 158.0 | 212 | 190 | 621 |
| 04-1335 | Piner Point on Maury Island | 232.9 | 239.2 | 124.3 | 128 | 110 | 234 |

**Table G-11.** Non-native herbaceous average percent cover and relative percent cover at habitat protection projects. Values reported in this table were from the summary tables provided by Tetra Tech and do not reflect values reported in the 2008 Annual Monitoring Report (Tetra Tech 2009).

| | | Average % cover | | | Relative % cover | | |
|---|---|---|---|---|---|---|---|
| **Site ID** | **Site name** | **Year 0** | **Year 3** | **Year 8** | **Year 0** | **Year 3** | **Year 8** |
| 00-1669 | Entiat River Habitat Acquisition | 37.1 | 18.8 | 25.9 | 27.9 | 14.2 | 25.1 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 5.4 | 3.0 | 1.0 | 1.5 | 1.3 | 0.6 |
| 00-1841 | Metzler Park Side Channel Acquisition | 37.8 | 9.5 | 7.3 | 4.1 | 4.7 | 4.0 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 36.8 | 3.2 | 0.5 | 18.5 | 4.2 | 0.5 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | 1.4 | 0 | 0 | 0.4 | 0 | 0 |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 0.1 | 0 | 0 | 0 | 0 | 0 |
| 02-1592 | Curley Creek Estuary Acquisition | 0.1 | 0 | 0 | 0 | 0 | 0 |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 68.0 | 68.1 | 36.8 | 30.4 | 27.7 | 29.7 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 24.8 | 3.3 | 0.8 | 17.8 | 8.8 | 13.0 |
| 04-1335 | Piner Point on Maury Island | 0 | 0 | 0.1 | 0 | 0 | 0.1 |

**Table G-12.** Non-native shrub average percent cover and relative percent cover at habitat protection projects. Values reported in this table were from the summary tables provided by Tetra Tech and do not reflect values reported in the 2008 Annual Monitoring Report (Tetra Tech 2009).

| | | Average % cover | | | Relative % cover | | |
|---|---|---|---|---|---|---|---|
| **Site ID** | **Site name** | **Year 0** | **Year 3** | **Year 8** | **Year 0** | **Year 3** | **Year 8** |
| 00-1669 | Entiat River Habitat Acquisition | 0 | 0 | 0 | 0 | 0 | 0 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 6.6 | 0 | 0 | 1.8 | 0 | 0 |
| 00-1841 | Metzler Park Side Channel Acquisition | 84.7 | 5.9 | 5.3 | 9.1 | 2 | 2.9 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 0 | 0 | 0 | 0 | 0 | 0 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | 0.8 | 0 | 0.1 | 0.2 | 0 | 0 |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 0.1 | 0 | 0 | 0.1 | 0 | 0 |
| 02-1592 | Curley Creek Estuary Acquisition | 0.5 | 0.8 | 0.1 | 0.3 | 1.2 | 0.1 |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 0 | 0 | 0 | 0 | 0 | 0 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 0 | 0 | 0 | 0 | 0 | 0 |
| 04-1335 | Piner Point on Maury Island | 0 | 6.4 | 3.5 | 0 | 2.8 | 1.7 |

**Table G-13.** Juvenile Chinook salmon densities (fish/m$^2$) at habitat protection projects. Missing values are from estuarine sites where data were not collected.

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 0 | 0 | 0.0124 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 0 | 0 | 0 |
| 00-1841 | Metzler Park Side Channel Acquisition | 0.0047 | 0 | 0.0006 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 0 | 0 | 0 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 0.0084 | 0.0380 | 0.0171 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 0.0020 | 0.0007 | 0.0017 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 0.0005 | 0.0004 | 0.0031 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |

**Table G-14.** Juvenile coho salmon densities (fish/m$^2$) at habitat protection projects. Missing values are from estuarine sites where data were not collected.

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 0 | 0 | 0.0019 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 0 | 0 | 0 |
| 00-1841 | Metzler Park Side Channel Acquisition | 0.0537 | 0.0051 | 0.2897 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 0 | 0 | 0 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 0.0554 | 0.0305 | 0.2060 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 0.2980 | 0.1018 | 0 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 0 | 0 | 0 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |

**Table G-15.** Juvenile steelhead densities (fish/m$^2$) at habitat protection projects. Missing values are from estuarine sites where data were not collected.

| Site ID | Site name | Year 0 | Year 3 | Year 8 |
|---|---|---|---|---|
| 00-1669 | Entiat River Habitat Acquisition | 0 | 0.0005 | 0.0046 |
| 00-1788 | Rock Creek/Ravensdale Retreat Protection Project | 0 | 0 | 0 |
| 00-1841 | Metzler Park Side Channel Acquisition | 0.0230 | 0.0398 | 0.2431 |
| 01-1353 | Logging Camp Canyon (Phase 1) Acquisition | 0.0625 | 0.0071 | 0.4806 |
| 02-1485 | Chimacum Creek Estuary Riparian Acquisition | --- | --- | --- |
| 02-1535 | WeyCo Mashel Shoreline Acquisition | 0.1060 | 0.0455 | 0.2298 |
| 02-1592 | Curley Creek Estuary Acquisition | --- | --- | --- |
| 02-1622 | Issaquah Creek Log Cabin Reach Acquisition | 0.0925 | 0.1091 | 0.0687 |
| 02-1650 | Methow Critical Riparian Habitat Acquisition | 0.0023 | 0.0019 | 0.0090 |
| 04-1335 | Piner Point on Maury Island | --- | --- | --- |