Prepared for the Washington Salmon Recovery Funding Board Monitoring Panel

Intensively Monitored Watersheds Program: Lower Columbia River Study Plan Update, 2015

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Executive Summary

The purpose of the Intensively Monitored Watersheds (IMW) program is to evaluate whether and how restoration activities increase salmon and steelhead production. A Before-After Control-Impact (BACI) study design was selected to maximize the ability to detect changes in salmon production as a result of habitat restoration treatments while minimizing the probability of detecting spurious inter-annual effects. This document provides an update on current activities and results from the lower Columbia River IMW stream complex. The lower Columbia River IMW stream complex includes three watersheds – Mill Creek is the control (reference) watershed and Abernathy, and Germany creeks are the impact (treatment) watersheds. Watershed-scale monitoring of fish, habitat, and water quality has been conducted since 2005. Target species of anadromous salmonids are tule fall Chinook Salmon, Coho Salmon, and Steelhead Trout. Consistent with the intended study design, annual habitat and flow metrics were highly correlated among watersheds during the baseline monitoring period. Smolt abundances of Chinook Salmon and Steelhead Trout, but not Coho Salmon, were correlated among watersheds. As a result, a BACI or a Before-After design will be used for analyzing post-treatment data as appropriate. A power analysis suggested that, with 10 years of post-treatment monitoring, detectable increases in smolt abundances will range from 42 to 47% for Coho Salmon, 30 to 52% for Steelhead Trout, and 78 to 99% for Chinook Salmon ($\alpha = 0.10$, $\beta = 0.90$).

Baseline monitoring revealed several interesting patterns among the three watersheds. For example, Coho Salmon smolt abundance is consistently highest in Mill Creek and lowest in Germany Creek whereas Steelhead Trout smolt abundance is consistently highest in Germany Creek and lowest in Mill Creek. For both species, smolts in Abernathy Creek are intermediate in abundance. Watershed differences in smolt abundance do not reflect the patterns of adult abundance across watersheds (with the exception of Steelhead Trout in Mill and Germany creeks) suggesting that characteristics of the freshwater environment is an important annual determinants of freshwater production. Apparent over-winter survival of Coho Salmon is highest in Mill Creek and lowest in Germany Creek and this over-winter life stage contributes to the differences in Coho Salmon smolts observed among watersheds. Growth and location of summer rearing are both linked to subsequent survival to the spring smolt stage; however, a fall migrant life history of Coho Salmon appears to occur and will require additional investigation.

In 2009, the Lower Columbia Fish Recovery Board developed a Treatment Plan for Abernathy and Germany creeks. The Treatment Plan lays out a three-phase process for implementing restoration projects. Although habitat treatments in multiple project categories are planned for both Abernathy and Germany creek, currently implemented projects represent just 8-14% of the stream miles included in the first phase of the Treatment Plan. When currently funded and proposed projects are implemented, habitat treatments will increase to 100% of the phase 1 projects in Abernathy Creek and 63% of the phase 1 projects in Germany Creek. Monitoring included in the Lower Columbia IMW study is designed to address hypotheses associated with three general project categories: fish passage, large woody debris (instream habitat), off-channel. Nutrient enhancement, which was not considered when developing the Treatment Plan, has been the first watershed-scale treatment to be implemented. Three

fall treatments of salmon carcass analogs (SCA) were implemented in Germany Creek (2011-2013) and three spring SCA treatments have been implemented in Abernathy Creek (2013-2015). Monitoring associated with the nutrient enhancement will answer two questions related to the effectiveness of SCA treatments: Is there a population-level response? What is the difference in response to fall versus spring SCA treatments? Preliminary results show a stronger ecosystem response to spring than fall treatments of SCA. In all years, ecosystem responses were temporary and neither spring nor fall treatments changed the number or body size of Coho, Steelhead, of Chinook smolts.

Recommendations for the Lower Columbia River IMW study are:

- Implement additional habitat restoration treatments. To accomplish IMW objectives, prioritization of projects should minimize the importance of recovery tiers assigned to each reach and emphasize reaches where projects are logistically feasible and where hypotheses associated with changes in fish and habitat conditions can be tested.
- The 2015 spring SCA treatment is the last planned nutrient enhancement treatment. Implement increased treatment intensity and include coverage of tributary reaches of Abernathy Creek.
- Continue discussions with restoration planners/practitioners on identifying high-use and low-use rearing reaches for the purpose of selecting additional habitat projects to test specific hypotheses on restoration approaches.
- Continue analysis of baseline data. Identify connections of water quality and habitat covariates with freshwater growth and survival in order to explain baseline differences among watersheds and increase power for detecting responses to habitat treatments.
- Complete and publish analysis linking summer rearing areas to spring smolts of Coho Salmon.
- Identify winter rearing areas for juvenile Coho Salmon that emigrate as spring smolts.
- Verify that “fall movers” in Abernathy Creek are indeed “fall migrants”. Explore options for understanding the importance of fall migrant life history in these watersheds.

Background

Since the 1990s, many populations in the Pacific Northwest have become listed under the U.S. Endangered Species Act and millions of dollars have been dedicated to the restoration of freshwater habitat (NRC 1996). Despite the substantial investment of funding and effort towards the restoration of freshwater habitats, little is known about the efficacy of these efforts for increasing salmon production (Roni et al. 2002, Katz et al. 2007). Fish responses to restoration actions are difficult to isolate because restoration projects typically happen as localized projects in large watersheds with many additional factors contributing to annual variation in salmon abundance. Understanding the cumulative effect of local habitat projects on the anadromous salmonid life cycle requires a carefully selected study design and a long-term investment in research.

The purpose of the Intensively Monitored Watersheds (IMW) program is to evaluate whether and how restoration activities increase salmon and steelhead production. The rationale and need for the IMW program was outlined in the Washington Comprehensive Monitoring Strategy and Action Plan for Watershed Health and Salmon Recovery (Crawford et al. 2002). In 2004, a group of agency and industry scientists selected four locations in western Washington for inclusion in the collaborative IMW research program (Bilby et al. 2004). A Before-After Control-Impact study design was selected to maximize the ability to detect changes in salmon production as a result of habitat restoration treatments while minimizing the probability of detecting spurious inter-annual effects (Intensively Monitored Watersheds Scientific Oversight Committee 2007). Watersheds selected for this program had a history of monitoring data and were small enough that scientists anticipated restoration actions of sufficient scale could be completed to cause a population response.

The lower Columbia River watershed complex is comprised of three adjacent tributaries (Mill, Abernathy, and Germany creeks) which enter the Columbia River near the town of Longview, Washington. These watersheds were selected to represent the populations in the southwest region of Washington State due to their relatively small watershed size and availability of baseline smolt data. Land use in these watersheds, as with many watersheds in southwest Washington, is primarily private or state owned timber lands. Percent of impervious surfaces is very low (2-2.8%; LCFRB 2010a). At present, 0% of the existing forested landscape is in a late-seral stage. While lands in the headwaters of all three watersheds continue to be managed for commercial timber harvest, implementation of new forest practices through the Department of Natural Resources' Habitat Conservation Plan (state lands) and Forest Practices Rules (private lands) is expected to substantially improve stream conditions over time. Specifically, standards of the Washington State Forest and Fish Law, passed by the Washington State Legislature in 1999, are expected to restore passage, protect riparian conditions, reduce fine sediment inputs, lower water temperatures, improve flows, and restore habitat diversity (LCFRB 2010c).

The original study plan for the IMW watersheds in western Washington was described in Bilby et al. (2004) with details specific to the lower Columbia River IMW developed by the Intensively Monitored Watersheds Scientific Oversight Committee (2007). In the lower Columbia River, an integrated watershed analysis and ecosystem diagnostic treatment model were developed as part of the recovery planning process (LCFRB 2010a; LCFRB 2010b). Results of these analyses were used by the Lower Columbia River Fish Recovery Board to identify limiting factors in the Mill, Abernathy, and Germany creek watersheds. A Treatment Plan was completed in 2009 (HDR Inc and Cramer Fish Sciences 2009) and laid out three phases of restoration. In response to the Treatment Plan, an updated study plan for the lower Columbia River complex was completed in 2012 (Zimmerman et al. 2012). This updated plan used baseline abundance data and planned restoration treatments to determine detectable levels of change in smolt abundance and developed hypotheses for types of restoration treatments being proposed. At that time, a watershed-scale nutrient enhancement project had been initiated in one of the watersheds (Germany Creek). Since 2012, substantial investment in the planning and implementation of habitat restoration projects has occurred in the Abernathy and Germany creek watersheds. Additional restoration activity has occurred in response to dedicated funding provided by the Salmon Recovery Funding Board for restoration in IMW watersheds. In 2013, the SRFB designated $2 million per year over a three year period for restoration treatments in IMW complexes. Habitat projects awarded under this funding allocation are slated for implementation between 2014 and 2016.

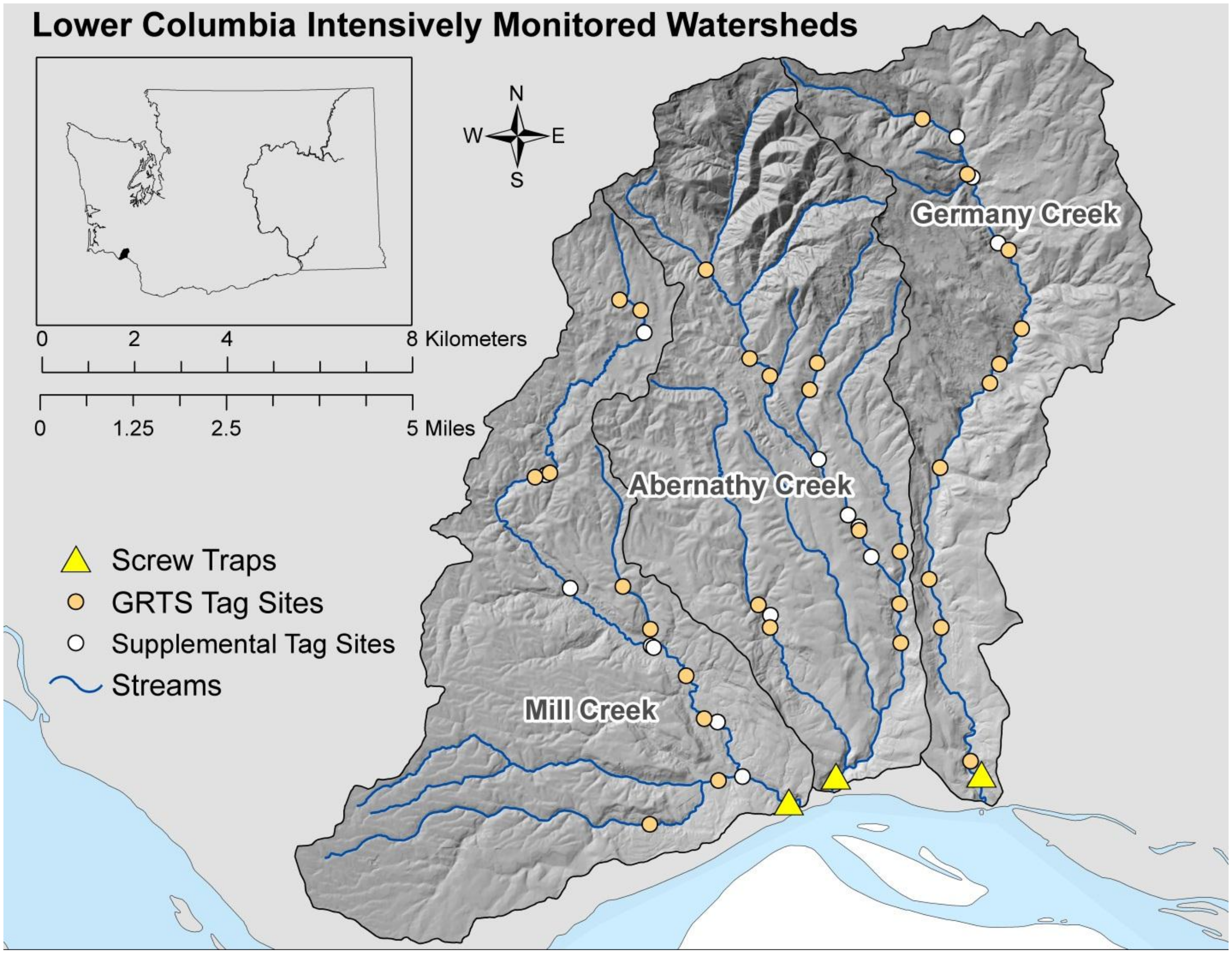
This document provides an update on current activities and results from the lower Columbia River IMW stream complex. The first section provides an overview of the study system, experimental design, and fish and habitat metrics. The second section describes several key lessons learned from baseline monitoring conducted in the watersheds. The third section provides a description of restoration treatments, hypotheses regarding fish and habitat responses to these treatments, and a preliminary evaluation of the nutrient enhancement treatments. Finally, we provide recommendations for future monitoring and research in the lower Columbia River IMW.

Study Overview

Study System

Mill, Abernathy, and Germany creeks drain south out of the Willapa Hills into the Columbia River near the town of Longview (Figure 1). Drainage area of each watershed ranges from 59 km^2 (Germany) to 75 km^2 (Mill, Abernathy). The hydrology is rain dominant with peak winter flows occurring between November and March and summer low flows occurring in the month of September. Snow accumulation in the headwaters results in rain-on-snow freshets that are of substantial magnitude in some years. Maximum elevation is 273 m in Mill Creek, 285 m in Abernathy Creek, and 362 m in Germany Creek. The upper portions of each watershed are managed for commercial timber harvest. Ownership of managed forest lands is public on Mill and Abernathy creeks (Washington Department of Natural Resources) and private on Germany Creek (Sierra Pacific). In the lower alluvial stream segments of each watershed, land use is a combination of agriculture and residential.

Figure 1. Map of Mill, Abernathy, and Germany creeks in southwest Washington. Rotary screw traps are operated annually at the mouth of each creek. A resistance board weir is operated at the mouth of Abernathy Creek just downstream from the smolt trap. Summer surveys of fish and habitat are conducted at spatially representative (Generalized Random Tessellation Stratified) and Supplemental sites.



In each watershed, stream channels are comprised of a diversity of riffle-pool, forced pool-riffle, cascade, and canyon sections with long stretches of exposed bedrock. Beaver activity in low gradient reaches has resulted in wetland areas in the headwaters of Mill Creek and several tributaries to Abernathy Creek. At low flows, a 10-foot (3 m) falls at river kilometer 5.6 of Abernathy Creek is a partial barrier to migration. At this location, a portion of anadromous salmonids access upper Abernathy Creek by means of a fish ladder. An electric weir is seasonally operated by the Abernathy Fish Technology Center (AFTC) at river kilometer 5 on Abernathy Creek. Of the fish diverted into the AFTC facility, a portion of the Steelhead Trout are retained for broodstock, while the remainder of Coho Salmon and Steelhead Trout are released to upper Abernathy Creek above the falls.

Five species of salmonids are supported by the Mill, Abernathy, and Germany creek watersheds. Each species is managed as a single population across all three watersheds for the purpose of recovery (LCFRB 2010c). Tule fall Chinook Salmon and Coho Salmon are part of the Lower Columbia River

Evolutionary Significant Unit (ESU) and both are listed as *threatened* under the Endangered Species Act. Chinook Salmon are considered a primary population and Coho Salmon a contributing population for salmon recovery. Chum Salmon are part of the Columbia River ESU. Chum Salmon are listed as *threatened* under the Endangered Species Act and the Mill/Abernathy/Germany population is considered a primary population for salmon recovery. Steelhead Trout are part of the Southwest Washington Distinct Population Segment and are not listed under the Endangered Species Act. Other fish species in these watersheds include Coastal Cutthroat Trout and Pacific Lamprey.

Anadromous salmonids access several major tributaries in both Mill and Abernathy creeks whereas their distribution is primarily limited to the main stem of Germany Creek. Tule fall Chinook Salmon spawn primarily in the months of September and October and outmigrate as subyearlings between January and June. The outmigration is predominantly unimodal (fry outmigrants; Kinsel et al. 2009) contrasting with other fall Chinook Salmon populations where a second pulse of larger subyearlings is typically observed (Topping and Zimmerman 2012; Lamperth et al. 2014; Zimmerman et al. 2015). Coho Salmon spawn primarily between the months of October and January. Juvenile Coho Salmon spend a year rearing in freshwater and outmigrate as spring smolts between March and June. Potential fall migrants of Coho Salmon subyearlings are discussed in the Baseline Monitoring section. Steelhead Trout have been observed to spawn between the months of February and June. Juvenile Steelhead Trout spend one to three years rearing in freshwater and outmigrate as spring smolts between March and May.

Historically, hatchery fish were directly planted into these watersheds to provide additional harvest opportunity. In recent years, hatchery planting activities throughout the lower Columbia River have been eliminated or reduced in response to funding reductions and concern about negative interactions with natural-origin salmonids. On Germany and Mill creeks, a limited hatchery program for winter-run Steelhead Trout and Coho Salmon was discontinued in the late 1990s. On Abernathy Creek, annual hatchery plants of fall Chinook Salmon and winter-run Steelhead Trout were discontinued in 1999. The AFTC has implemented a winter-run Steelhead Trout brood stock program on Abernathy Creek since 2003 as part of an ongoing relative (hatchery versus wild) reproductive success study (USFWS 2013). Initial brood stock for this program was derived from juvenile *Oncorhynchus mykiss* collected in Abernathy Creek. All Steelhead Trout from the AFTC program are adipose clipped to distinguish them from wild fish. The presence of hatchery Coho Salmon and Chinook Salmon from out-of-basin programs is monitored during adult surveys. Due to mass marking of hatchery production in the lower Columbia River region, hatchery and wild Coho Salmon could be distinguished beginning in 2001 and hatchery and wild tule fall Chinook Salmon could be distinguished beginning in 2011.

Limiting Factors

Primary limiting factors, identified in the Lower Columbia Fish and Wildlife Recovery Plan (LCFRB 2004), can be summarized as channel stability, habitat diversity, key habitat quality, sediment load, water temperature, and flow. Data sources used to determine limiting factors included the Ecosystem Diagnosis and Treatment (EDT) model (LCFRB 2010a) and Integrated Watershed Assessment models (LCFRB 2010a) both of which scored watershed conditions based on a range of local and watershed factors linked to salmonid spawning and rearing conditions in each watershed.

Other studies have linked these limiting factors to altered habitat forming processes that have resulted from altered watershed processes (i.e., sediment delivery, hydrology, and riparian conditions). Historical timber harvest practices were the major land use change from pre-settlement conditions contributing to the altered watershed processes in Mill, Abernathy, and Germany creeks (Pacific Water Resources Inc. 2004). Basin hydrology is one watershed process altered when lands are managed for timber harvest or converted to other land covers. Specifically, an increase in the magnitude of peak flows during intermediate-size events and higher summer flows (Pacific Water Resources Inc. 2004). Channel morphology changes in response to this type of altered flow regime, including increased size of sediments, decreased sinuosity (channel migration), and vertical channel degradation (incision; HDR Inc and Cramer Fish Sciences 2009). As a result of channel incision, the historical floodplain and side channels require increasingly high flows to become active and the horizontal connections between in-stream and off-channel habitats become less frequent over time. In addition to hydrology,

Over the past two decades, timber harvest practices have evolved in response to new regulations and land use requirements laid out in the Washington State Forest and Fish Law and Habitat Conservation Plans. Commercial timber production is still the dominant land use in all three basins but small farms and rural residential development are also present in the lower watershed (LCFRB 2010c). Changes to timber harvest practices include the protection of a riparian buffer along the stream channel. Over time, reconnection between riparian function and stream processes should provide long-term sustainable benefits for salmonids in these watersheds. However, responses of the stream channel to changes in land management may take decades if not centuries to be realized. The current riparian buffers in the Mill, Abernathy, and Germany creek watersheds are in an early successional stage, dominated by hardwoods with very few mature or understory conifer trees. Recent recruitment of large woody debris to the stream channel has primarily been deciduous trees (i.e., alder; HDR Inc and Cramer Fish Sciences 2009). Conifers, which dominate in later successional forest stages, are known to increase bank stability (stronger root systems than deciduous trees) during high flow events and form longer lasting channel-forming structures (slower decay rate than deciduous trees). Both of these characteristics are connected to habitat forming processes that impact the structural diversity and substrate characteristics of the channel (LCFRB 2010a).

Treatment Plan

A Treatment Plan for Abernathy and Germany Creeks (HDR Inc and Cramer Fish Sciences 2009) was finalized and submitted to the Lower Columbia Fish Recovery Board (LCFRB) in 2009. The goal of this plan was to complete a basin-wide treatment for Abernathy and Germany creeks as part of the IMW experimental design. The Treatment Plan focused on restoration projects that would address the limiting factors identified in the LCFRB six-year habitat work schedule (LCFRB 2008). The plan identified sixty potential projects and outlined a potential approach that included three phases with two-year implementation of twenty projects each.

To assist with project implementation, the Treatment Plan further prioritized the proposed projects based on four criteria provided by the LCFRB: (1) species targeted and importance to ESU recovery, (2) estimated current or potential value of target reach to performance of target species, (3) species life stage and associated limiting factor, (4) anticipated improvement in quality and quantity of habitat. This approach prioritized “primary populations” (e.g., Steelhead Trout and Chum Salmon) over “contributing populations” (e.g., Coho Salmon and Chinook Salmon). At the time that the Treatment Plan was written, Coho Salmon and Chinook Salmon were considered “contributing populations” for ESU recovery (the Chinook Salmon population in the Mill/Abernathy/Germany watersheds has subsequently been changed to “primary” status for recovery).

The project prioritization process in the Treatment Plan followed a solid logic with respect to salmon recovery in that greatest fish benefits were assumed for Tier-1 reaches (high priority reaches for primary populations) and lower fish benefits were assumed for Tier-2 reaches (high priority reaches for contributing populations, moderate priority for primary populations). However, with respect to the IMW objective of measuring population-level responses of all salmonid species, the Treatment Plan prioritized reaches where restoration actions would have the most benefit for Steelhead Trout, which are designated a primary population in these watersheds. Although benefits to all focal species might also be expected from improvements to stream channel function in these reaches, the location and characteristics of the Tier-1 reaches were selected based on the biology of Steelhead Trout not Coho Salmon (designated are a contributing population) or Chinook Salmon (designated as a contributing population at the time of the Treatment Plan, now a primary population). For example, prioritized reaches in the Treatment Plan are all main stem habitat and do not focus on the tributary and headwater areas where Coho Salmon are observed to spawn and rear. Analyses of baseline monitoring data show that the smaller tributary habitats are important summer rearing areas for juvenile Coho Salmon that survive through the spring smolt outmigration (see Baseline Monitoring section; Johnson et al. 2015). Therefore, as planning for restoration projects continues, projects that benefit Tier-2 reaches may be as important to meeting the IMW objectives as projects that benefit Tier-1 reaches.

Experimental Design

The IMW study combines information obtained from project effectiveness monitoring (i.e., was there a site-specific change following restoration treatments?) with population-level monitoring (i.e., do site-specific changes translate into population change following restoration treatments?). Although several life stages are included in the population-level monitoring, the number and size of emigrating smolts represents the cumulative effect of all freshwater conditions. Inter-annual variability in the number and body size of smolts is caused by a number of interacting factors. In order to isolate the contribution of the habitat restoration from these factors, the Lower Columbia River IMW study was set up to be evaluated with a Before-After Control-Impact design (Smith 2002; Roni et al. 2005). This design includes the selection of control (hereafter reference) and impact (hereafter, treatment) watersheds. Mill Creek was selected as the reference watershed and Abernathy and Germany creeks were selected as the treatment watersheds. If annual fish metrics are correlated between the two watersheds prior to restoration occurring, this design provides additional statistical power to detect responses of the treatment watersheds by accounting for co-variation between the treatment and reference watershed due to non-restoration related factors. Alternately, measures of environmental conditions such as stream flows, pool frequencies, or large woody debris counts were incorporated into the sampling efforts to account for failures to meet the assumptions of the experimental design (Bendetti-Cecchi

2001; Steinbeck et al. 2005) and to strengthen the analyses by revealing mechanisms that affect freshwater production.

Annual Data Collection Methods and Metrics

Annual life cycle metrics for Coho Salmon, Chinook Salmon, and Steelhead Trout are collected at the spawner and spring outmigrant life stages (Table 1). Observations of Chum Salmon are noted at both of these life stages; however, the numbers of Chum Salmon are currently so low that additional metrics beyond raw counts are not calculated. Additional information on the density and abundance of summer parr are collected for Coho Salmon and Steelhead Trout. Data collection methods follow standard monitoring protocols of the American Fisheries Society (Crawford et al. 2007a; Crawford et al. 2007b; Volkhardt et al. 2007). Additional references pertaining to data collection protocols and data management are provided in Appendix A.

Observed patterns in fish abundance vary among species. For Coho Salmon, consistent watershed differences in smolt abundance are observed each year with Mill Creek producing the highest number of spring smolts and Germany Creek producing the fewest number of spring smolts (Figure 2). In comparison, adult Coho Salmon spawners are typically more abundant in Abernathy Creek than the other two watersheds. In early years of the monitoring efforts, a conversion of Coho Salmon redds to total spawners was based on weir mark-recapture estimates (Abernathy Creek); however, in recent years logistical issues have prevented successful weir operation and an alternative approach for the redd conversion is underway. In recent years, the proportion of Coho Salmon spawners of hatchery origin has ranged between 10 and 20% (T. Buehrens, WDFW, personal communication; Rawding et al. 2014). Steelhead Trout also have consistent differences in smolt abundance among watersheds with Germany Creek producing the highest number of smolts and Mill Creek producing the fewest number of smolts. Adult spawners are also the fewest in Mill Creek compared to Abernathy and Germany Creek. Steelhead spawning in Abernathy Creek is partially supplemented by an experimental hatchery program run by the USFWS Abernathy Fish Technology Center. Outmigrant abundance of tule fall Chinook Salmon is highly variable among years with no consistent differences among watersheds. In comparison, adult spawner abundance in Mill Creek is typically higher than the other two watersheds. The majority of Chinook Salmon spawners are of hatchery origin (80-94%, J. Wilson, WDFW, personal communication; Rawding et al. 2014) even though there is no current Chinook Salmon hatchery program in these watersheds.

Table 1. Annual fish metrics derived for Mill, Abernathy, and Germany creek watersheds, 2005-2014. Information differs based on species life history, CO = Coho, ST = Steelhead, CH = Chinook.

	Summer parr	Spring Smolts	Spawners
Abundance	CO	CO, ST, CH	CO, ST, CH
Proportion Hatchery			CO, ST, CH
Diversity (Length, Age)	CO, ST	CO, ST, CH	CO, ST, CH
Spatial Distribution			CO, ST, CH
Reach Densities	CO, ST		CO, ST, CH
Timing		CO, ST, CH	CO, ST, CH

Habitat data are collected at spatially representative sites in each watershed between the months of June and September. The habitat sampling plan and field data are adapted from the US Environmental Protection Agency, Environmental Monitoring and Assessment Program (EMAP, http://www.epa.gov/emap). Sampling locations were identified in the first year of study based on a random, spatially balanced design (Stevens and Olsen 2004) stratified by stream order (Strahler 1957). Habitat metrics derived from these data include wetted width, thalweg depth, in-bankfull wood, pool frequencies, and percent fine substrate (Figure 3). Several habitat metrics are consistently different among the watersheds. For example, wetted width and thalweg depth are greatest in Abernathy Creek and least in Mill Creek and fine substrate is highest in Mill Creek and lowest in Germany Creek. Other metrics, such as in-stream large woody debris counts (LWD) and pool frequency were highly variable among years with minimal differences among watersheds.

Water quantity and quality data are collected at stream gages operated near the creek mouth and include continuous flow, temperature and turbidity, and monthly water chemistry analysis. These follow standard operating protocols established by the Washington Department of Ecology (http://www.ecy.wa.gov/programs/eap/quality.html). Water flow metrics of interest with respect to salmonid rearing in these watersheds include the magnitude and duration of summer (low) and winter (high) flows. For summer flows, the magnitude (September median) and duration (minimum of 60-day average flow March to September) metrics were highly correlated among watersheds (Figure 4). In general, Mill Creek has the highest summer low flows and Germany Creek the lowest. Watershed metrics were also highly correlated for winter flows, including the magnitude (maximum mean daily flow) and duration (proportion of days between October and March where flow exceeded the 75th percentile of the long-time series). In general, winter flow durations are longer in Abernathy Creek than the other two watersheds. The magnitude of peak winter flows appears to be the least correlated among the flow metrics; however, this measure is also the least accurate as flow gages lose accuracy once flows exceed bankfull of the channel.

Figure 2. Abundance of outmigrants and spawners in Mill, Abernathy, and Germany creeks, 2005-2014. Graphs show Coho Salmon, Steelhead Trout, and tule fall Chinook Salmon. Box plot shows median (horizontal line), 25% and 75% quartiles (box), range (whiskers), and outliers (open points). Note the natural log scale used to show Chinook Salmon outmigrant abundance.

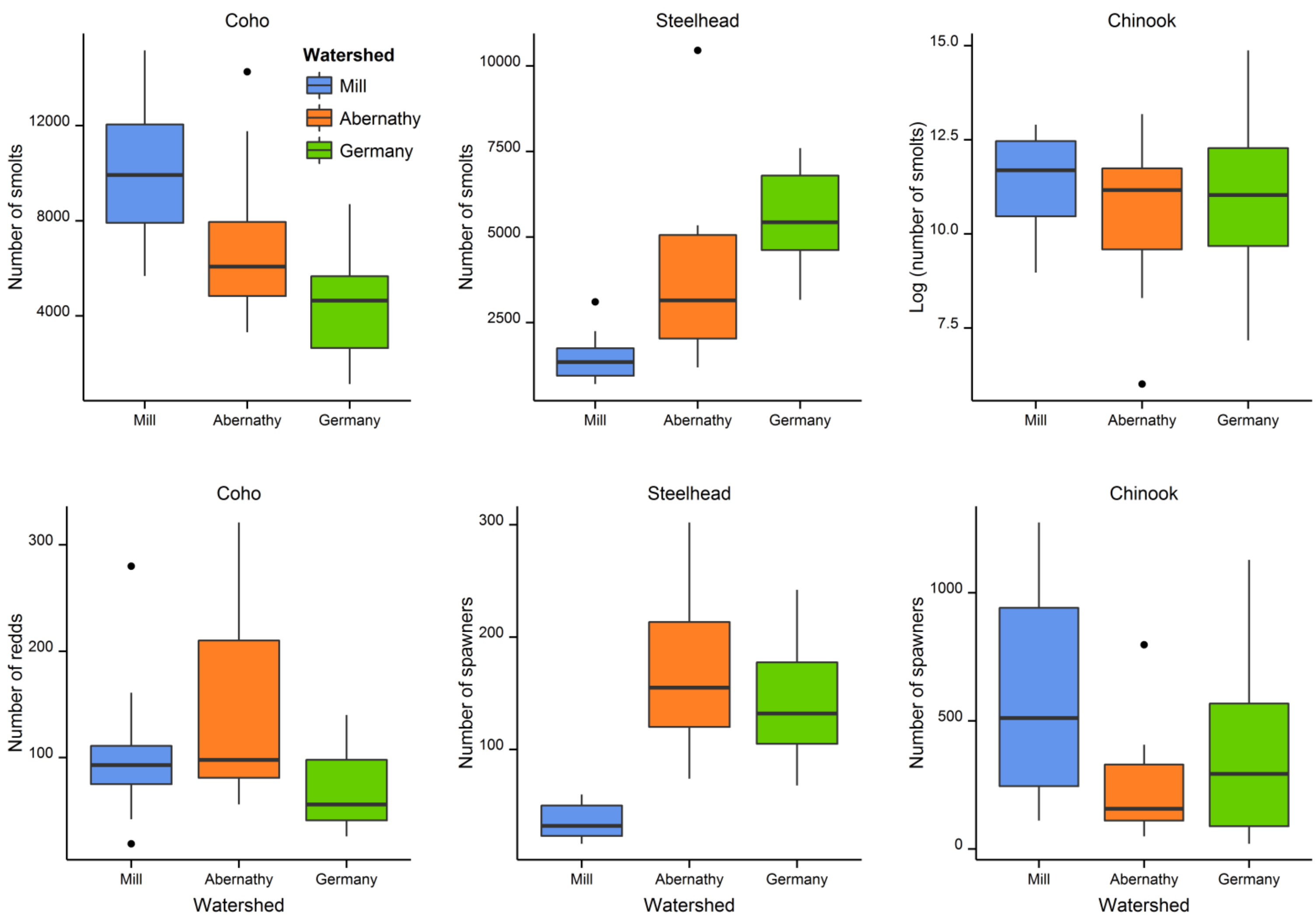


Figure 3. Annual time series of selected basin-scale habitat metrics for Mill, Abernathy, and Germany creeks, 2006-2014.

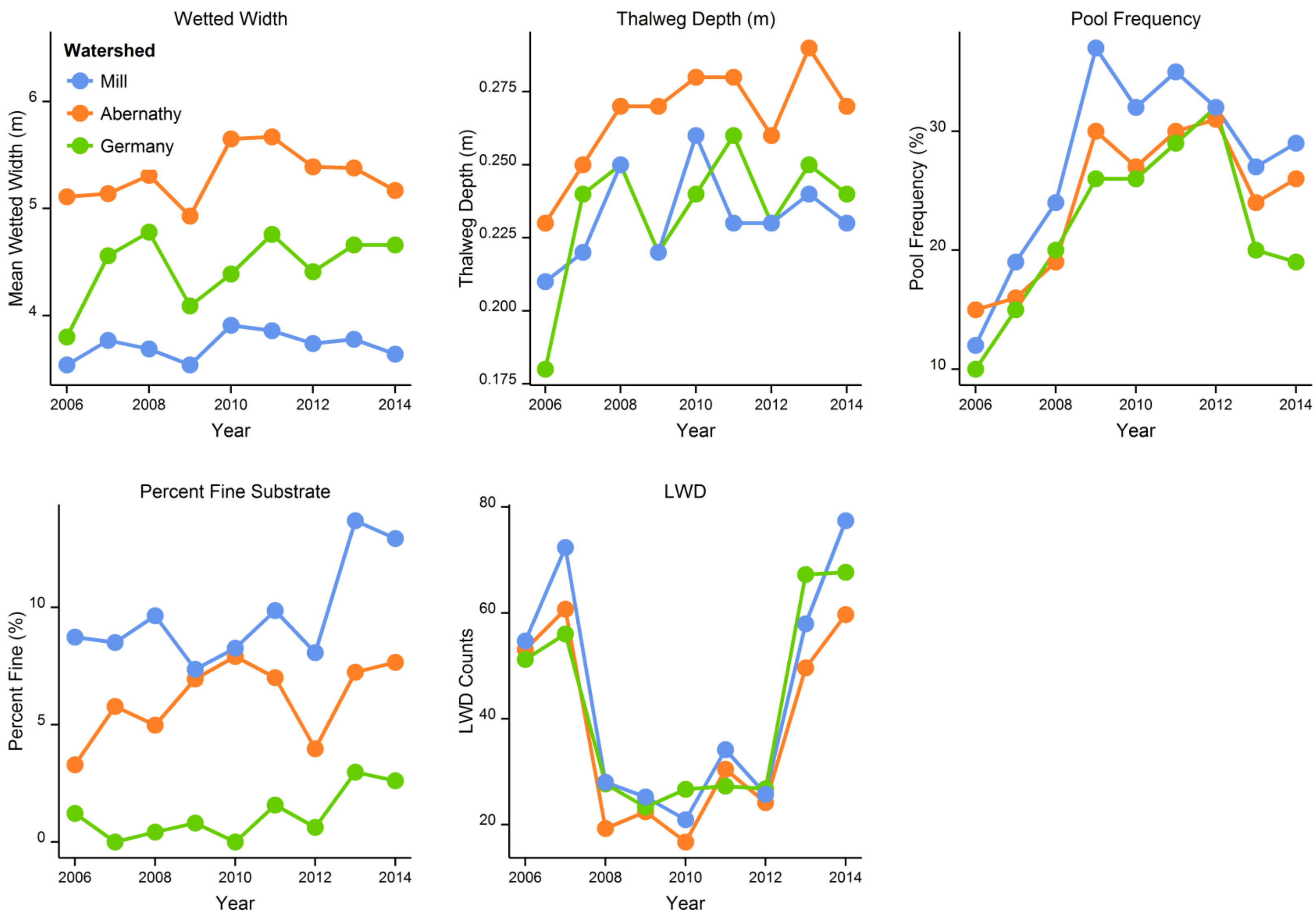
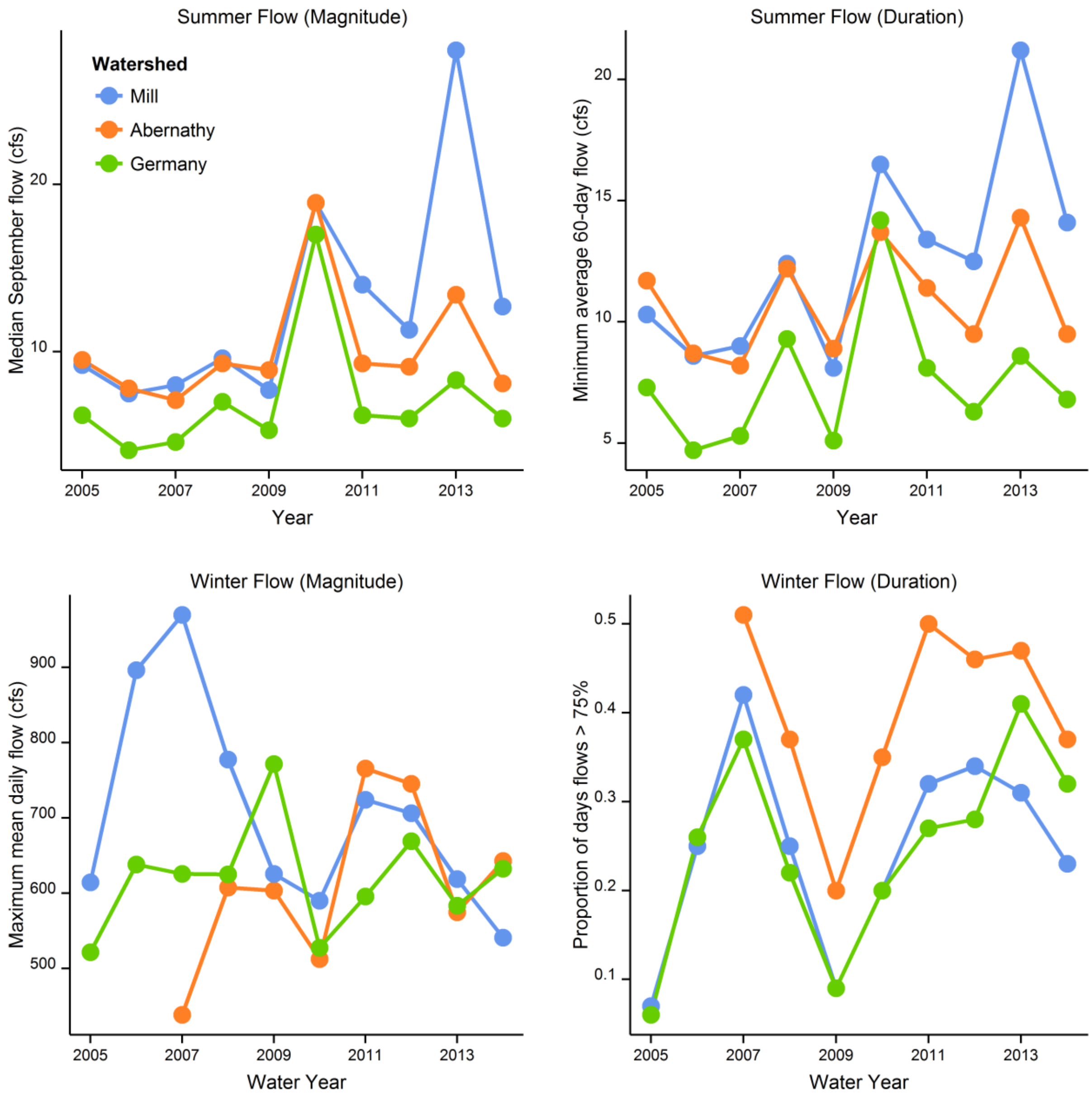


Figure 4. Annual time series of selected flow metrics in Mill, Abernathy, and Germany creeks, 2005-2014. Metrics include summer flows (magnitude, duration) and winter flows (magnitude, duration).



Lessons from Baseline Monitoring

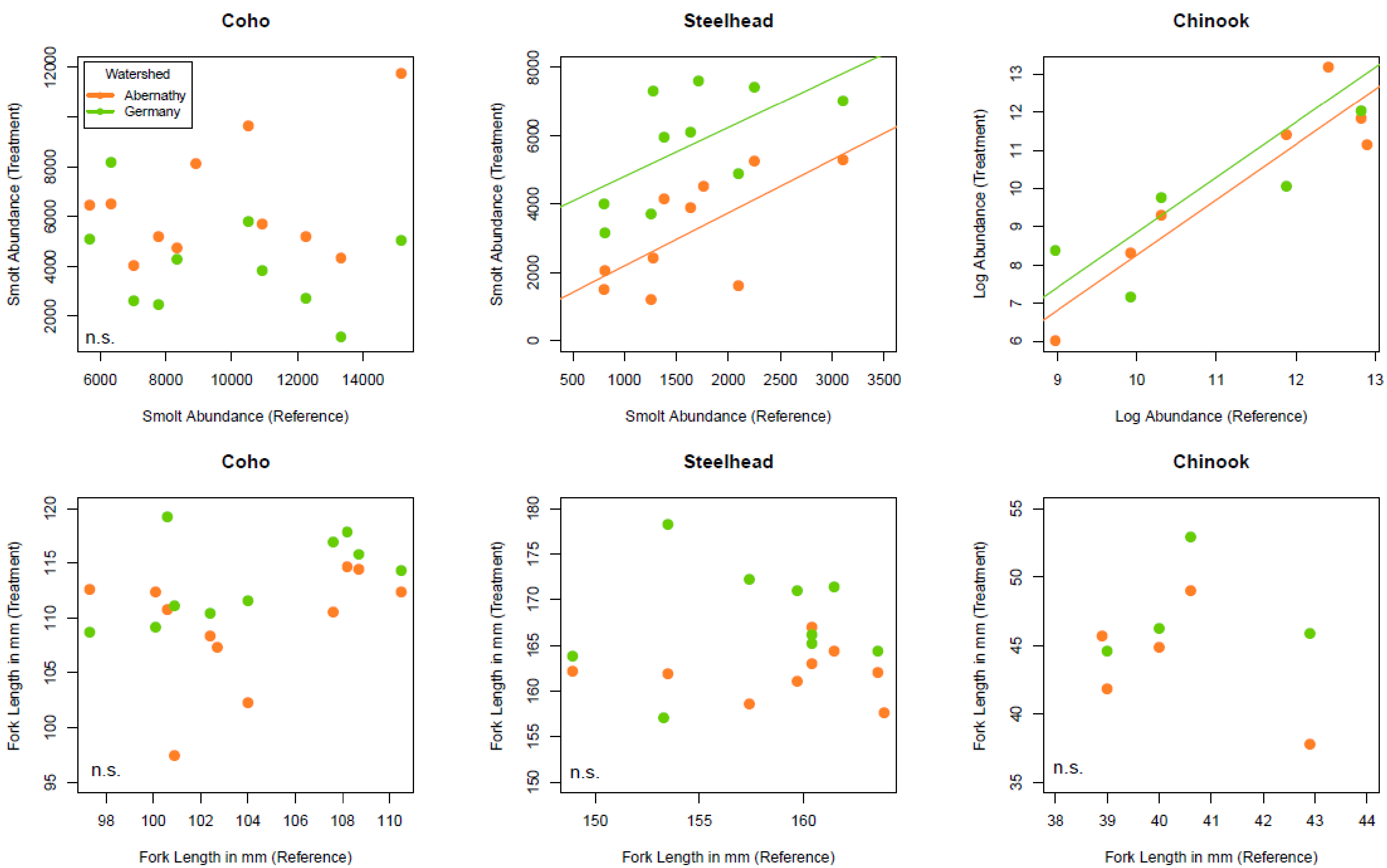
In Abernathy Creek, the baseline monitoring periods extends from 2001 to 2012, corresponding to the first large-scale instream habitat project that was implemented in summer of 2012. In Germany Creek, the baseline monitoring period extends from 2001 to 2011, corresponding to the first watershed-scale nutrient enhancement treatment in fall of 2011. With the exception of smolt abundance data which begins in 2001, all other data sets begin in 2005. Results from this baseline period are used to evaluate the adequacy of the original study design, determine the detectable level of population change, and identify factors contributing to existing bottlenecks in freshwater survival.

BACI Design

Baseline correlations (prior to habitat treatment) between the treatment and reference watersheds were evaluated in the 2012 study plan (Zimmerman et al. 2012). The previous analysis indicated that, prior to restoration, outmigrant abundances of Steelhead Trout and Chinook Salmon were significantly correlated between treatment and reference watersheds and that the BACI design was appropriate for analyzing these data. The previous analysis also suggested that outmigrant abundance of Coho Salmon in Abernathy, but not Germany Creek, was correlated with the reference watershed; therefore, a before-after analysis would be the most appropriate method for analyzing Coho Salmon data from Germany Creek.

In this updated study plan, we include additional years of annual smolt estimates to the previous correlation analysis and also examine correlations among annual estimates of body size (Figure 5). The baseline period is not expected to change after this updated study plan, as restoration treatments have been initiated. An analysis of the expanded data set revealed that a BACI design continues to be appropriate for analyzing outmigrant abundance of Steelhead Trout and Chinook Salmon. For Coho Salmon, however, neither treatment watershed (Abernathy, Germany) was correlated with smolt abundance in the reference watershed (Mill); therefore, a before-after analysis will be the most appropriate method for evaluating the response of Coho Salmon smolts to habitat treatments in all watersheds. Outmigrant body size was not correlated between treatment and reference streams for any of the three species indicating that a before-after analysis will be the most appropriate methods for evaluating a growth response to habitat restoration treatments in each watershed.

Figure 5. Baseline correlations between treatment (Abernathy, Germany) and reference (Mill) watersheds (2001-2011). Plots show annual estimates of outmigrant abundance and fork length of Coho Salmon, Steelhead Trout, and Chinook Salmon. Significant correlations ($p < 0.05$) are indicated by a linear regression line. "n.s." indicates lack of a significant correlation.



Detectable Change

The power to detect changes in smolt abundance depends on the magnitude of inter-annual variation and correlation between reference and treatment watersheds during the baseline monitoring period. Power analysis results presented in the 2012 study plan update calculated detectable levels of change for smolt abundance of all three species (Zimmerman et al. 2012). This analysis is repeated here with additional years of baseline monitoring data.

Following the methods developed in the 2012 study plan update, the power analysis determined how many juvenile outmigrants (Δ) would be needed to detect a difference in production at a watershed scale after restoration treatments were implemented (Cohen 1988). The analyses were based on 5 and 10 years of data (pre- and post-treatment), using power to detect a difference of 90% (β = 0.9) with a Type I error rate of 10% (α = 0.1, one-tailed t-test). Variance used for the power analysis included inter-annual variation and measurement error. Inter-annual variation (CV_r) was the coefficient of variation of the point estimates among years. Measurement error (CV_m) was the average coefficient of variation among years. For the BACI design, CV_r was the mean-square error of the regression between treatment and reference streams divided by the average abundance for that species and watershed. CV_r for the BACI design was lower than a BA design because inter-annual variation explained by the correlation with the reference watersheds was removed. The two error estimates were combined for the power analysis (Gerrodette 1987):

$$CV = \sqrt{CV_m^2 + CV_r^2 + CV_m^2 * CV_r^2}$$

Detectable increases in Coho Salmon smolt abundance ranged between 61% and 68% of mean baseline abundance with five years of post-treatment monitoring and between 42% and 47% of baseline abundance with ten years of post-treatment monitoring (Table 2). For Steelhead Trout, detectable increases in smolt abundance ranged between 43% and 76% with five years of post-treatment monitoring and between 30% and 52% with ten years of post-treatment monitoring. For Chinook Salmon, detectable increases in outmigrant abundance ranged between 114% and 144% with five years of post-treatment monitoring and between 78% and 99% with ten years of post-treatment monitoring.

An important caveat is that the power analysis demonstrates detectable change *if change occurs*. Our analysis assumes that change occurs in an immediate and step-like manner following the restoration treatment. In reality, there are many types of changes which may occur following restoration and the time frame for changes in fish survival is unknown. For this reason, multiple biological metrics (abundance, size, age structure, migration timing) are included in the monitoring methods. Alternately, changes in smolt abundance may occur as changes in correlation patterns with the reference stream rather than a difference between treatment and reference stream. For example, in the Hood Canal IMW complex, Coho Smolt abundance in Little Anderson Creek was not correlated with the reference stream until after a bridge/culvert replacement (Kinsel and Zimmerman 2011).

Table 2. Detectable levels of increased spring smolt abundance in Abernathy and Germany creeks after five and ten-years of post-treatment monitoring. Data are percent increase in smolts from the baseline monitoring period (corresponding number of smolts in parentheses).

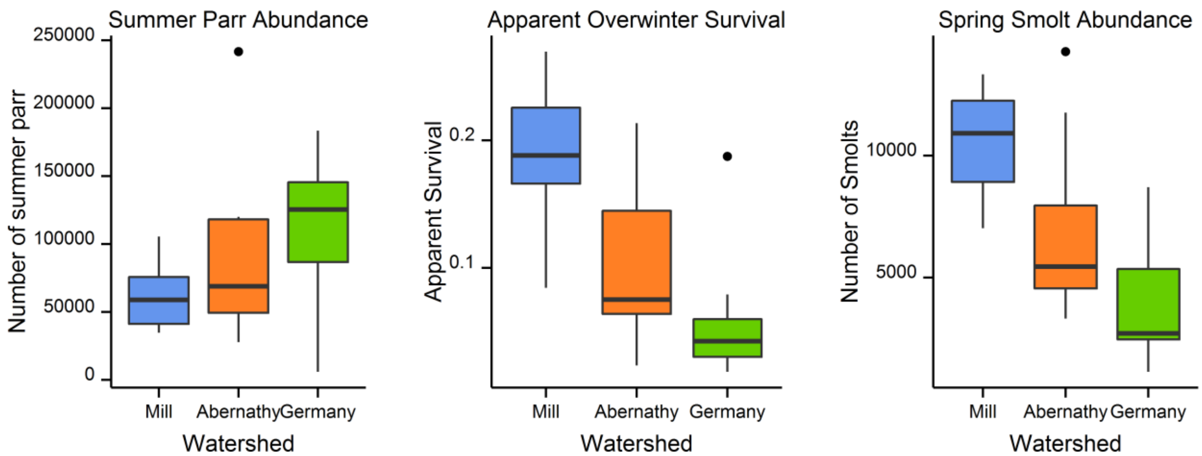
		Abernathy		Germany	
Species	Design	5-Year	10-Year	5-Year	10-Year
Coho Salmon	Before-After	61% (4,388)	42% (3,005)	68% (3,167)	47% (2,169)
Steelhead Trout	Before-After Control-Impact	76% (2,583)	52% (1,769)	43% (2,435)	30% (1,668)
Chinook Salmon	Before-After Control-Impact	114% (142,889)	78% (97,849)	144% (132,286)	99% (90,589)

Apparent Overwinter Survival for Coho Salmon

The life cycle framework used for baseline monitoring has provided a rich data set to explore factors influencing survival associated with the two major hydrological periods (summer, winter) in these watersheds. Recent analyses have explored factors contributing to apparent overwinter survival of Coho Salmon. Results from these analyses may be useful for informing discussions on additional habitat treatments in Abernathy and Germany creeks.

Apparent overwinter survival is the summer parr abundance divided by the spring smolt abundance the following year; survival is “apparent” because the estimate represents both survival and emigration during the overwinter period. On average, apparent overwinter survival is nearly four times higher in Mill Creek than Germany Creek and appears to determine the overall watershed differences in spring smolt abundance of Coho Salmon (Figure 6). In order to evaluate factors that may be contributing to these differences we used recoveries of juvenile Coho Salmon that were tagged with passive integrated transponder (PIT) tags at spatially representative locations near the end of the summer low flow period. Approximately 3,000 (1,000 per watershed) Coho Salmon parr were PIT tagged each year and a portion of these were recovered at smolt traps the following spring, interrogated at instream arrays (PIT arrays at rkm 0.5 and 5 in Abernathy Creek, operated by the AFTC), or recovered at various sampling locations in the Columbia River. Two major results that are relevant to understanding patterns of apparent overwinter survival are 1) the role of summer location and growth in determining probability of detection as spring smolts, and 2) the potential for fall migrant life history of Coho Salmon (Johnson et al. 2015).

Figure 6. Life stage metrics of Coho Salmon in Mill, Abernathy, and Germany creeks, brood year 2004-2012.



The factors contributing to apparent overwinter survival were recently presented at the PSMFC PIT Tag conference in January 2015 by project staff (http://www.ptagis.org/resources/pit-tag-workshops/2015-workshop). A generalized linear model with a binomial distribution (logit link) was used to investigate factors that influenced apparent overwinter survival. Explanatory variables were body size (length) and location (stream size represented by watershed area above the sampling site) at the end of the summer rearing period. The multiplicative value of trap efficiency and apparent-overwinter survival were included as an offset value in the glm model to account for overall differences among years and watersheds.

Juvenile Coho Salmon that were larger at the end of the summer rearing period (time of tagging) were more likely to be detected as spring smolts than their smaller counterparts (Figure 7). Depending on the watershed, a 20-mm increase in size corresponded to an increased odds of 2.03 to 2.39 of surviving to the spring smolt stage. In addition, juvenile Coho Salmon rearing in headwaters and tributaries during the summer rearing period (smaller watershed area above sampling location) were more likely to be detected as spring smolts than their counterparts from summer rearing locations lower in the watershed (Figure 7). Depending on the watershed, a 25-km^2 increase in watershed area above the sampling location decreased the odds of surviving to the spring smolt stage by 0.44 to 0.69. Additional study is needed to connect overwinter rearing reaches with spring smolts and we are currently exploring an approach using mobile PIT technology to further explore this connection. The connection between watershed locations and surviving smolts raises an important question related to habitat restoration – given limited restoration funding, what is the benefit of improving habitat in areas that juvenile fish are currently successful versus improving habitat in areas that are marginal or not currently used? This question should be explored with the regional recovery board and could be developed as testable hypotheses associated with remaining habitat treatments in these watersheds.

Additional insight into apparent overwinter survival has come from the interrogation of PIT tagged juvenile Coho Salmon at two instream arrays in Abernathy Creek. These arrays are operated as part of the AFTC steelhead reproductive success study; information gleaned from tagged Coho Salmon has been incidental and these arrays were not designed specifically to answer questions related to the IMW study. A single array (no directionality of movement) has been operated year-round since 2001 at river kilometer 5 with intermittent interruptions. A second array has been operated between the months of March and June since 2009 at river kilometer 0.4. Annual fall and spring movements of juvenile Coho Salmon have been observed at the upper array throughout this time period (Figure 8). Fall migrant life histories of Coho Salmon have recently been described in other systems, including the Juan de Fuca IMW complex (Roni et al. 2012; Bennett et al. 2014). Given these studies and the current observations, a careful examination of Coho Salmon migrant life histories is warranted in the lower Columbia River streams. In Abernathy Creek, fall movements detected at the upper array (rkm 5) in the months of September and October occurred prior to winter flow events suggesting that the observed movements are voluntary. Because tagging locations are known, we know that the majority of the fall movements have been in a downstream direction. Very few (< 3%) of the "fall movers" were subsequently detected at the lower array the following spring suggesting that the fall movers may indeed be "fall migrants" that are leaving the creeks to overwinter in the Columbia River or beyond. We are currently exploring a collaborative effort with AFTC staff to extend operation of the lower array into the early fall months in order to determine whether "fall movers" are indeed "fall migrants" moving out of the creek into the Columbia River. However, a more comprehensive understanding of the fall migrant life history with respect to different apparent overwinter survival among watersheds will require additional investment in PIT array infrastructure in these watersheds.

Figure 7. Probability of detection as a spring smolt for Coho Salmon based on growth (fork length in mm) and rearing location (watershed area above sampling location) the previous summer in the Mill, Abernathy, and Germany creek watersheds.

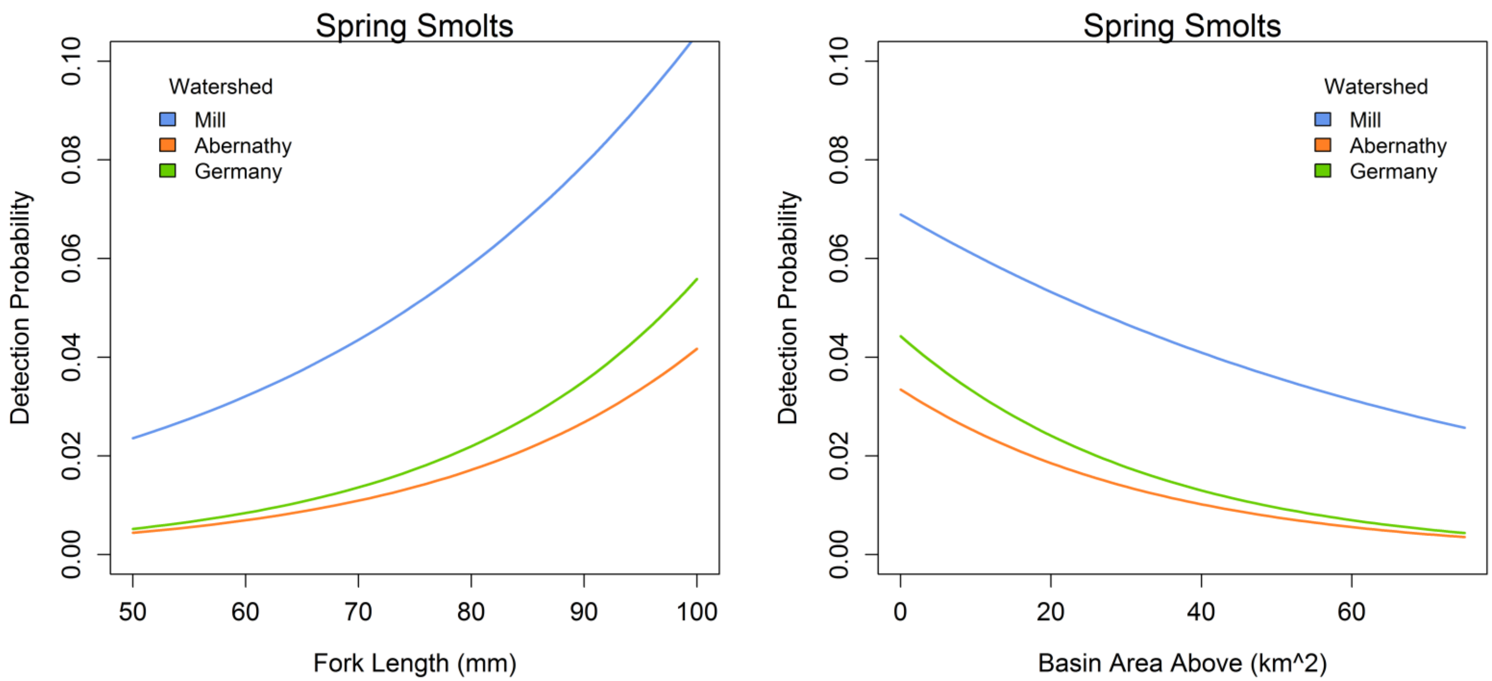
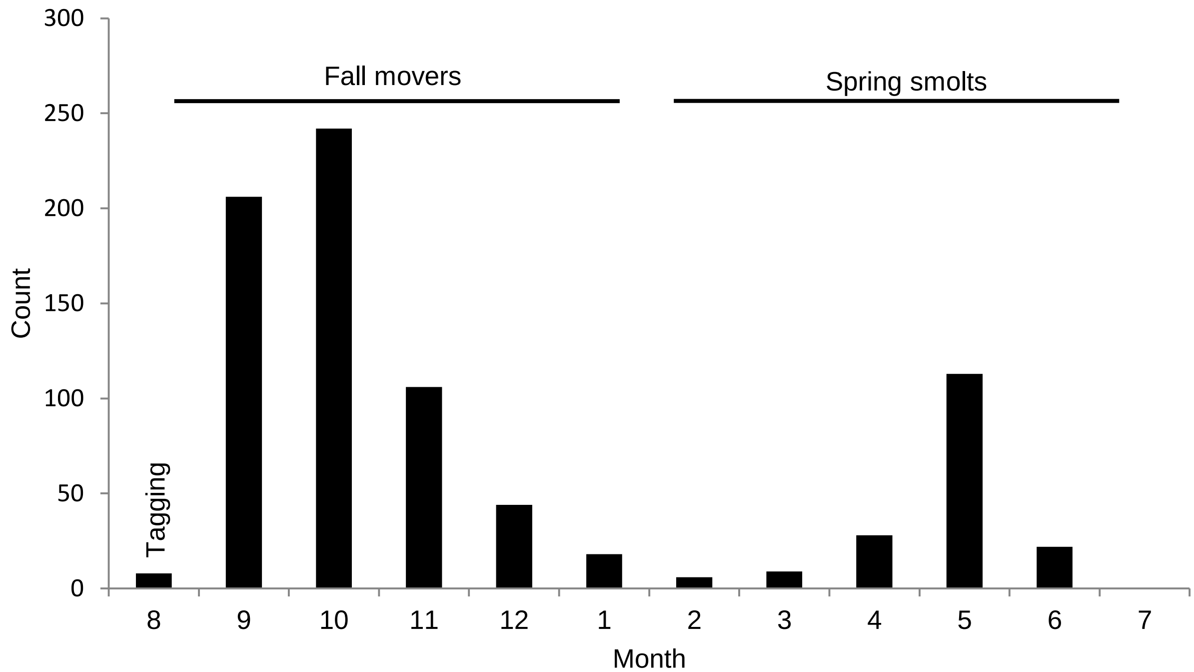


Figure 8. Seasonal detections of PIT tagged Coho Salmon at river kilometer 5 on Abernathy Creek. 2005-2013 detections are summed by month. Tagging occurred in the month of August.



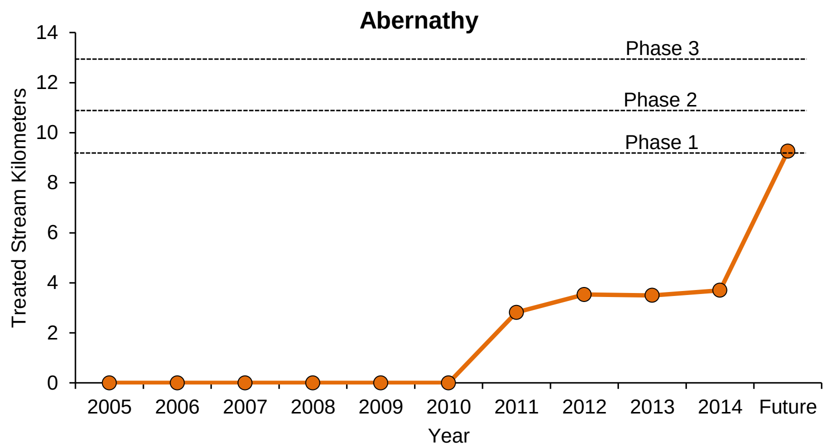
Restoration Actions and Response

Habitat Treatments

Treatment Implementation: A total of seven habitat restoration projects have currently been completed in Abernathy and Germany creeks (Table 3). An additional four projects are funded and four projects are proposed for the current funding cycle of the Salmon Recovery Funding Board. As of spring 2015, completed projects yield a total of 3.7 kilometers of restoration effort in Abernathy Creek and 0.4 kilometers of restoration effort in Germany Creek (Figure 9). This corresponds to 14% (Abernathy) and 8% (Germany) of the phase 1 restoration levels described in the treatment plan. Successful implementation of funded and proposed projects would increase this effort level 9.3 kilometers of restoration effort in Abernathy Creek (100% phase 1) and 2.8 kilometers of restoration effort in Germany Creek (63% phase 1).

Projects fall into a variety of categories including improvements to riparian condition, instream habitat, bank stabilization, floodplain function, off/side channel connections, and fish passage improvement (Table 3). Of these, instream habitat is the most common category. Progress towards metrics associated with each project category is tracked through Lower Columbia Fish Recovery Board project tracking system (http://www.lowercolumbiasalmonrecovery.org/projects/projectlist). A full description of the pre-restoration, planned restoration, and completed state of each metric are not yet available for most projects. However, two examples of recently completed projects are provided in Figures 10 and 11..

Figure 9. Total stream kilometers of habitat restoration in Abernathy and Germany creeks as compared to phase 1, 2, and 3 projects outlined in the Treatment Plan for these watersheds. Stream kilometers shown include completed, funded, and proposed projects.



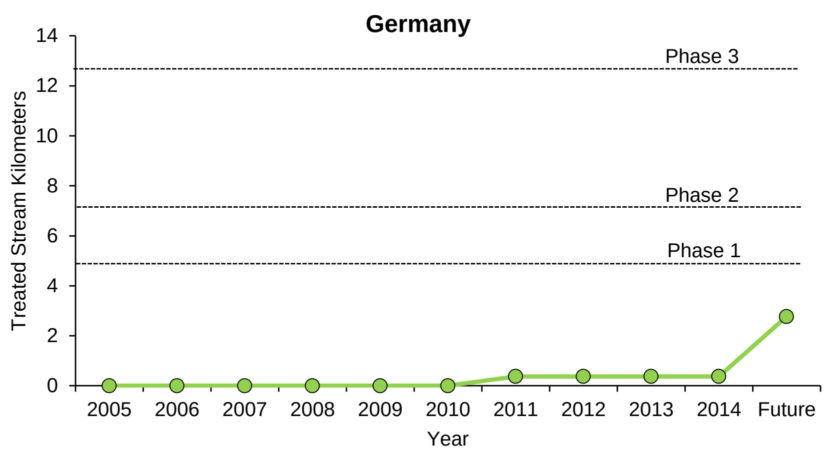


Table 3. Restoration projects for Abernathy and Germany creek watersheds. Project status included completed (C), Funded (F), and Proposed (P). Project categories are denoted with an "X". Acquisition and design projects are not included in this table.

Watershed	PRISM ID	Project Name	Project Status	Riparian conditions	Instream habitat	Bank Stabilize	Floodplain function	Off/Side Channel	Fish Passage
Abernathy	02-1498	Abernathy Creek Riparian Restoration	C	X					
	07-1675	Abernathy Habitat Restoration and Riparian Protect	C		X	X			
	11-1329	Abernathy Creek Bridge Removal Project	C				X		
	11-1386	Abernathy Creek Two Bridges	C		X				
	12-1333	Abernathy 5A Side Channel Project	C					X	
	PCSRF	Abernathy Sitka Spruce	F	X	X				
	14-1296	Abernathy Creek Davis Site	F	X	X			X	
	PCSRF	Abernathy Creek Wisconsin Site Project (upstream)	F		X				
	14-1311	Abernathy Creek Cameron Site	F	X	X			X	
	15-1125	Erick Creek Fish Passage	P						
	15-1127	Abernathy Creek Headwaters Implementation	P		X				
Germany	05-1563	Germany Creek Conservation and Restoration 1	C	X	X				
	09-1378	Germany Creek Conservation and Restoration 2	C	X	X				
	15-1039	Germany Creek Restoration Smith Site	P	X	X	X	X	X	
	15-1040	Germany Creek Andrews Site	P		X				X

Figure 10. Restoration site on the mainstem of Abernathy Creek located in EDT Reach 9. The "Two Bridges" project was completed in the summer of 2012. Mainstem channel meander signatures were excavated within the footprint of the former roadbed. Combined with log jams in the main channel, the goal was to allow the river to naturally occupy a new meander pattern during high flows, thereby increasing sinuosity, pool-riffle frequency, and overall habitat complexity and connectivity. Two additional log jams were used to split the main channel flow into existing meander scars that have been abandoned. Pictures show the site prior to (A) and after (B) restoration project. Pre-project photo was taken by the Cowlitz Tribe. Post-project photo was taken in November 2012. The project treated 2,250 feet (686 meters) of stream. Planned metrics were to increase the number of pools from two to eight, create ten log jams, and anchor 100 individual logs.

Figure 11. Restoration site on the mainstem of Abernathy Creek located in EDT Reach 5. The “Abernathy 5A” project was completed in the summer of 2014. The project was focused on off-channel habitat creation within the river-left floodplain. The intent was to emulate lost historical habitat complexity that will no longer be created on its own due to site constraints. The side-channel portion of the created habitat was designed to be seasonally active in order to increase availability and quality of over-wintering off-channel habitat and high flow refugia. Pictures show the site prior to (A) and after (B) restoration project. Pre-project photo was taken by the Cowlitz Tribe. Post-project photo was taken by the USFWS Abernathy Fish Technology Center in October 2014. The project treated 18,000 square feet (1672 square meters) of off-channel area. Planned metrics were to provide connection between the off-channel and mainstem during winter base flows, create two log jams, and anchor 40 individual logs.

Hypotheses and Metrics—Habitat treatments planned for Abernathy and Germany address fish passage, instream habitat, and offchannel/side channel connectivity. Hypotheses and metrics used to evaluate the project-specific (Table 4, 6, and 8) and watershed-level (Table 5, 7, and 9) responses by focal fish species to these treatments are summarized below (see Zimmerman et al. 2012 for details).

Table 4. Project-specific monitoring for the fish passage treatments will answer the following questions.

Question	Habitat Metric	Fish Metric
(1) Does base flow depth increase?	Change in mean depth	N/A
(2) Are anadromous fish able to access available habitat?	N/A	Fish presence (Juvenile or Adult)

Table 5. Watershed-level monitoring for fish passage treatments includes habitat and fish metrics. This table includes the hypothesized mechanisms for change, the appropriate metrics for these mechanisms, and anticipated species-specific responses. Species-specific responses are an increase (↑), decrease (↓), or no change (↔).

Mechanism	Habitat Metric	Fish Metric	Coho	Chinook	Steelhead
(1) Improved fish passage	Fish presence above culvert	Spawner distribution	↑	↑	↑
(2) Increase in rearing habitat quantity	None	Parr abundance and distribution	↑	↔	↑
(3) Cumulative increase in freshwater production	None	Outmigrant abundance	↑	↑	↑

Table 6. Project-specific monitoring for the large woody debris placement treatments will answer the following questions.

Question	Habitat Metric	Fish Metric
(1) Does LWD increase pool depth?	Residual pool depth	Increased juvenile fish density

Table 7. Watershed monitoring for large wood debris placement treatments includes habitat and fish metrics. This table includes the hypothesized mechanisms for change, the appropriate metrics for these mechanisms, and anticipated species-specific responses. Species-specific responses are an increase (↑), decrease (↓), or no change (↔).

Mechanism	Habitat Metric	Fish Metric	Coho	Chinook	Steelhead
(1) Decreased bed-load transport and more sorting of substrate by size leading to increased incubation survival	Distribution of substrate types	Egg-to-parr survival	↑	↑	↑
(2) Increased pool formation increases quantity and quality of rearing habitat	Number and size of pools	Parr abundance	↑	↑	↔
		Parr condition	↑	↔	↔
(3) Wood debris creates more heterogeneity in stream flows increasing turbulence in some areas and increasing slow water refuges in other areas.	None	Parr-to-smolt survival	↑	↔	↑
(4) Cumulative increase in juvenile outmigrants	None	Outmigrant abundance	↑	↔	↑
		Outmigrant condition	↑	↔	↑

Table 8. Project-specific monitoring for off-channel habitat restoration and reconnection treatments will answer the following questions.

Question	Habitat Metric	Fish Metric
(1) Is habitat connected to channel?	Wetted channel connection present	Juvenile fish density
(2) Is off-channel depth increased?	Residual pool depth	Juvenile fish density

Table 9. Watershed monitoring for off-channel restoration and reconnection treatments includes habitat and fish metrics. This table includes the hypothesized mechanisms for change, the appropriate metrics for these mechanisms, and anticipated species-specific responses. Species-specific responses are an increase (↑), decrease (↓), or no change (↔).

Mechanism	Habitat Metric	Fish Metric	Coho	Chinook	Steelhead
(1) Off-channel habitat provides refuge during high winter flow events	Number and size of off-channel areas	Parr-to-smolt survival	↑	↔	↔
		Outmigrant abundance	↑	↔	↔
		Outmigrant condition	↑	↔	↔

Methods—Responses to the habitat treatments will be measured at the project and population level in order to test the two sets of hypotheses. Population-level monitoring includes fish abundance and biological characteristics at each life stage outlined in the hypotheses. Project-level monitoring will use established methodologies for evaluating project effectiveness in Washington State. Fish passage projects will be evaluated following methods described in "Protocol for Monitoring Effectiveness of Fish Passage Projects MC-1" (Crawford 2009). Instream habitat projects will be evaluated following methods described in "Protocol for Monitoring Effectiveness of In-Stream Habitat Projects MC-2" (Crawford 2008c). Off-channel projects will be evaluated following methods described in "Protocol for Monitoring Effectiveness of Channel Connectivity, Off Channel Habitat, and Wetland Restoration Projects MC-6"(Crawford 2008a). Relevant fish and habitat metrics associated with each project category are measured prior to and at one and five years following the habitat treatment. These measures will be compared to data from reference sites selected randomly from locations that are currently used in the watershed-scale (EMAP) habitat surveys.

Response to Habitat Treatments—Responses to habitat treatments are likely to be detected after sufficient levels of treatment have been completed and an adequate number of years of post-project monitoring have been conducted. The sum total of treatments (completed, funded, and proposed) approach Phase 1 levels of the Abernathy Creek Treatment Plan and are about half of the Phase 1 levels of the Germany Creek Treatment Plan. Previous analyses suggested that the fish responses to Phase 1 projects are expected to be within detectable population responses determined with the power analysis (Zimmerman et al. 2012).

Nutrient Enhancement Treatments

Marine derived nutrients (MDN) were not specifically considered in the Treatment Plan developed for the LCFRB. However, numerous studies have demonstrated the importance of MDN for both aquatic (Bilby et al. 1998; Wipfli et al. 2003) and terrestrial (Bilby et al. 1996; Helfield and Naiman 2002) ecosystems and scientists have voiced concern over the ecosystem consequences of declining salmon abundances that annually import MDN (Gresh et al. 2000; Naiman et al. 2002). Decaying salmon carcasses provide annual pulses of marine-derived nutrients (MDN) to freshwater systems. In the absence of large runs of wild fish, options for nutrient enhancement include placement of salmon carcasses, carcass analogs and delayed release fertilizers (Michael Jr. 2005). In the lower Columbia River, use of salmon carcasses for nutrient enhancement (i.e., returning carcasses of hatchery fish to the rivers) has been limited by concerns for disease transmission and the sheer logistical challenges of transporting large numbers of decaying carcasses. Salmon carcass analogs (SCA) were developed as an alternative method of treating the freshwater environment with MDN (Pearsons et al. 2007). Analogs are salmon carcasses that are pasteurized, ground into fish meal, and formed into pellets. Controlled experiments have demonstrated the potential for SCA treatments on juvenile salmon growth (Wipfli et al. 2003). A recent meta-analysis of SCA treatments across multiple tributaries in the Columbia River basin demonstrated an immediate ecosystem level response following the treatments (Kohler et al. 2012). However, the authors also show that this response was not sustained one-year following the treatments suggesting that the benefits of the SCA treatment will require continual treatments over time. As a result, SCA treatments may require a different management approach than habitat treatments. Habitat treatments are typically managed as a short-term treatment expected to cause long-term changes for the freshwater ecosystem. In comparison, results to date suggest that SCA treatments should be managed as long-term treatments expected to cause short-term changes on the freshwater ecosystem. Given the potential for long-term investment in SCA treatments, continued evaluation is needed to explore uncertainties associated with these treatments.

For SCA to be considered effective as a restoration strategy, localized changes to fish growth and density in laboratory and field studies must translate into increased numbers of fish in the watershed. In addition, current evaluations of SCA treatments have primarily been fall treatments that mimic the timing of fall spawning salmon (e.g., Chinook, Chum, and Coho salmon). Evaluations of spring treatments are less common. Iteroparous spring spawners such as steelhead bring lower levels of nutrient imports than fall spawning salmon (Moore et al. 2011). The potential historical nutrient additions resulting from other spring spawners (e.g., lamprey, smelt, and peamouth) of freshwater tributaries are unknown. Potential benefits of spring treatments occur because the spring timing coincides with the emergence of salmon fry and a descending hydrograph and this timing may improve analog retention when compared to the ascending hydrograph during fall treatments.

<u>Treatment Implementation</u>—Watershed scale additions of salmon carcass analogs were initiated in 2010. Analogs used in the initial treatments in Germany Creek (fall of 2010 and spring of 2011) quickly disintegrated following the treatment due to a faulty binder used to form the pellets. A different manufacturer was selected for subsequent treatments. Three fall treatments were implemented in Germany Creek between 2011 and 2013 (Table 10). SCA were spread over 12-19 km of main stem of the creek from the headwaters to mouth during the months of September and October. Two spring treatments were implemented in Abernathy Creek in 2013-2014 and a third treatment is planned for spring of 2015 (Table 10). SCA were spread over 5-12 km of main stem creek during the months of May and June.

Analog densities of the treatments were between 0.08 and 0.17 kg/m^2 of the bankfull surface area. Nutritional analysis indicated that the analogs were approximately 70% crude protein (T. Meyer, LCFEG).

Using the carcass equivalent conversion equation (1 kg analog = 5 kg carcass) provided by Pearsons et al. (2007), analog nutrient inputs corresponded to a carcass equivalent of 0.4 to 0.85 kg/m^2. This treatment density was well above the 0.15 kg of carcass/m^2 densities observed to saturate uptake of juvenile coho parr (Bilby et al. 2001).

Mill Creek received no analogs and is considered the reference stream for both fall and spring treatments. Two major tributaries of Abernathy Creek (Weist and Cameron creeks) also received no analogs in 2013 and 2014 and are considered reference streams for the Abernathy Creek treatments.

Table 10. Watershed-scale application of salmon carcass analogs in the fall and spring (May, June) in Germany and Abernathy Creeks, 2010-2015. Analog and distance calculations are the total coverage summed over all treatments during a season. Density (kg/m^2) is calculated using a 6-m bankfull width based on annual habitat surveys in these watersheds.

Watershed	Year	Season	Analog (kg)	Distance (m)	Density (kg/m^2)	Comments
Germany	2010	Fall	9,630	12.1	0.13	Disintegrated
	2010	Spring	5,987	12.2	0.08	Disintegrated
	2011	Fall	11,567	18.7	0.10	Two treatments (September, October)
	2012	Fall	10,206	18.7	0.14	Two treatments (October, November)
	2013	Fall	7,257	18.7	0.08	One treatment (October)
Abernathy	2013	Spring	5,126	5.1	0.17	Two treatments (May, June)
	2014	Spring	6,532	12.7	0.09	Two treatments (May, June)
	2015	Spring				TBD

Hypotheses and Metrics—Nutrient enhancement treatments in the lower Columbia River IMW complex address two questions related to the success of SCA as a restoration strategy: (1) Is there a population-level response to SCA treatments? (2) What is the difference in response to fall versus spring SCA treatments? Project-specific (Table 11) and watershed-scale (Table 12) hypotheses and metrics are summarized below (see Zimmerman et al. 2012 for details).

Table 11. Project-specific metrics for evaluating salmon carcass analog treatments.

Question	Habitat Metric	Fish Condition Metric
(1) Are analogs retained in the system?	Are analogs visible at time of survey?	None
(2) Are nutrients from the analogs converted into food web biomass?	Is enriched δ^{15}N signal present in periphyton and invertebrates?	Is enriched δ^{15}N signal present in juvenile salmonids?

Table 12. Watershed-scale metrics for evaluating salmon carcass analogs treatments. Uptake of nutrients from the analogs will be tracked with stable isotopes (SI). Fish response will be measured as growth, condition, survival, and number of outmigrants. Table includes the proposed mechanism of change, the metrics, and anticipated responses.

Mechanism	Food Web Metric	Fish Metric	Coho	Chinook	Steelhead
(1) Direct consumption of analogs	$\delta^{15}N$ of fish and invertebrates increase (change with similar timing)	Parr length	↑	↔/↑ fall/spring	↑
		Parr condition	↑	↔	↑
		Parr-to-smolt survival	↑	↔	↑
		Outmigrant abundance	↑	↔	↑
		Outmigrant condition	↑	↔	↑
(2) Indirect transfer through food web	Increase in $\delta^{15}N$ of fish, invertebrates, and periphyton (delayed fish response) Increases in chlorophyll *a,* gross primary production, and community respiration	Similar fish response hypothesized for direct and indirect transfer mechanisms.			

<u>Methods</u>—Responses to the SCA treatments were measured at the project and population level in order to test the two sets of hypotheses. Population-level monitoring included fish abundance and body size metrics as described above. Project-level monitoring included fish body size and food web stable isotopes. The general concept for the stable isotope information was to determine whether nutrients from the analog treatments were indeed being taken up by the aquatic food web. Isotope signatures within each trophic level reflect the nutrient-source of the food they have consumed (Peterson and Fry 1987; Post 2002). Terrestrial versus aquatic sources are reflected in the carbon isotope fractionation (carbon-13 more enriched in aquatic than terrestrial sources). Freshwater versus marine sources are reflected in the nitrogen isotope fractionation (nitrogen-15 more enriched in marine than freshwater sources). Of specific interest for our study was the uptake of nitrogen isotopes by periphyton (primary production), invertebrates (primary or secondary consumers and detritivores) and fish (primary or secondary consumers). A more enriched nitrogen-15 signal would indicate uptake of additional marine-derived nutrients, provided by the SCA, into the freshwater food web.

Sampling occurred prior to and following the SCA treatments. Post-treatment sampling occurred at approximately two month intervals following the treatments and continued through the smolt outmigration period the following spring. Sampling locations were selected to represent the lower, middle, and upper mainstem of each of the three creeks. In Abernathy Creek, two tributaries (Cameron and Weist creeks) were also sampled for a total of five sampling sites in this creek. Sampling of primary production included alder leaves (terrestrial) and periphyton (aquatic). Sampling of primary consumers includes aquatic invertebrates that were sorted by functional feeding group (scraper, shredder, filterer, predator) prior to analysis. Sampling of fishes included juvenile Coho Salmon, *O. mykiss,* Cutthroat Trout, and Sculpin (*Cottus spp.*). Samples were also collected from salmon carcasses and carcass analogs. Fish collections were based on fin-clip samples, a nonlethal method recently validated for obtaining stable isotope information (Kelly et al. 2006; Sanderson et al. 2009; Hanisch et al. 2010). All samples were prepared for stable isotope analysis at the Weyerhaeuser facility in Federal Way and analyzed by Cornell University Stable Isotope Laboratory. Fish length and weight were also measured during each sampling period.

Project-Specific Response— Beginning in fall of 2011, analogs were observed to be retained in the system for at least six weeks post-treatment following each of the treatments. Anecdotal evidence suggests that direct consumption of the analogs occurred by macroinvertebrates (T. Meyer, LCFEG, personal communication). In one case, WDFW spawner survey crews observed a black bear consuming analogs in upper Abernathy Creek (L. Ronne, WDFW, personal communication). A complete statistical analysis of the stable isotope data will be conducted when monitoring of the final spring treatment is complete. A summary of the results to date and general observations are provided herein.

In general, there was minimal to no response of the food web to fall SCA treatments. The $\delta^{15}N$ values of periphyton and invertebrate samples associated with the 2011 fall treatment were nearly identical between the two watersheds before and after the SCA treatment (Figure 12). In 2012 and 2013, invertebrate $\delta^{15}N$ values were lower in Germany Creek than Mill Creek before the SCA treatment but similar between watersheds after the treatment suggesting a potential response of primary consumers to the analog treatments. The length, weight and $\delta^{15}N$ values of juvenile Coho Salmon varied among sample periods but this variation was similar between treatment and reference watersheds and did not suggest a growth or feeding response of the juvenile Coho Salmon to the analog treatment (Figure 13).

A food web response to the spring SCA treatment was more apparent than the fall treatment. For the spring treatment, we included two reference streams – Mill Creek and untreated tributaries of Abernathy Creek. Spring treatments are ongoing and stable isotope data associated with the first spring treatment (2013) are currently available for summarization. Following the 2013 spring treatment, the $\delta^{15}N$ values of periphyton and invertebrates showed an increase of approximately 5 ppm in the treatment stream that did not occur in the reference streams (Figure 14). This food web response was observed in the July sample immediately following the SCA treatment but was not in samples subsequently collected in August, December or January. Following the spring SCA treatment, body size (length and weight) of juvenile Coho Salmon was larger in the treatment than reference streams (Figure 15). Similar to the food web response, the difference in body size did not persist over time. $\delta^{15}N$ values were highly variable among individual juvenile Coho Salmon and did not appear to differ between treated and untreated streams. Taken together, these results are consistent with direct uptake into the food web following the pulse of additional nutrients provided by the spring SCA treatment.

Population-Level Response—For Coho Salmon, a before-after comparison was used to evaluate the population-level response of Coho Salmon. For Steelhead Trout and Chinook Salmon, a before-after control-impact design was used to evaluate the population-level response in abundance and a before-after design was used to evaluate the population-level response in growth. For all three species, neither abundance nor body size of the outmigrants changed in response to the fall SCA treatments (Figure 16). With only a single year of data for the spring SCA treatments, the response can not be fully evaluated; however, there was no obvious change in abundance or body size of the 2014 outmigrants in response to the spring SCA treatments (Figure 17).

Nutrient Enhancement Summary—In summary, preliminary analyses show that there was little evidence to support uptake into the food web following the fall SCA treatments but that there was likely a direct uptake at multiple trophic levels following the spring SCA treatments. Growth of juvenile Coho Salmon was observed to increase at treatment sites in comparison to reference sites for the first two sample periods following the spring SCA treatment, but increased growth during the summer rearing period did not result in larger smolts during the spring smolt outmigration. Analyses associated with the spring and fall treatments are ongoing. Future analyses of these data will include (a) evaluation of additional fish response variables, (b) comparison of response in upper, middle, lower sites (middle and lower sites overlap with Chinook spawning), and (c) whole stream metabolism response.

Figure 12. Seasonal changes in the nitrogen-15 isotope ratios of periphyton and aquatic invertebrates in response to fall treatments with salmon carcass analogs. Fall treatments in Germany Creek (green), indicated by dashed vertical line, were applied in September and October for three consecutive years (2011-2013). Mill Creek (black) was the reference watershed for this study. Plot shows mean value and 1 standard deviation.

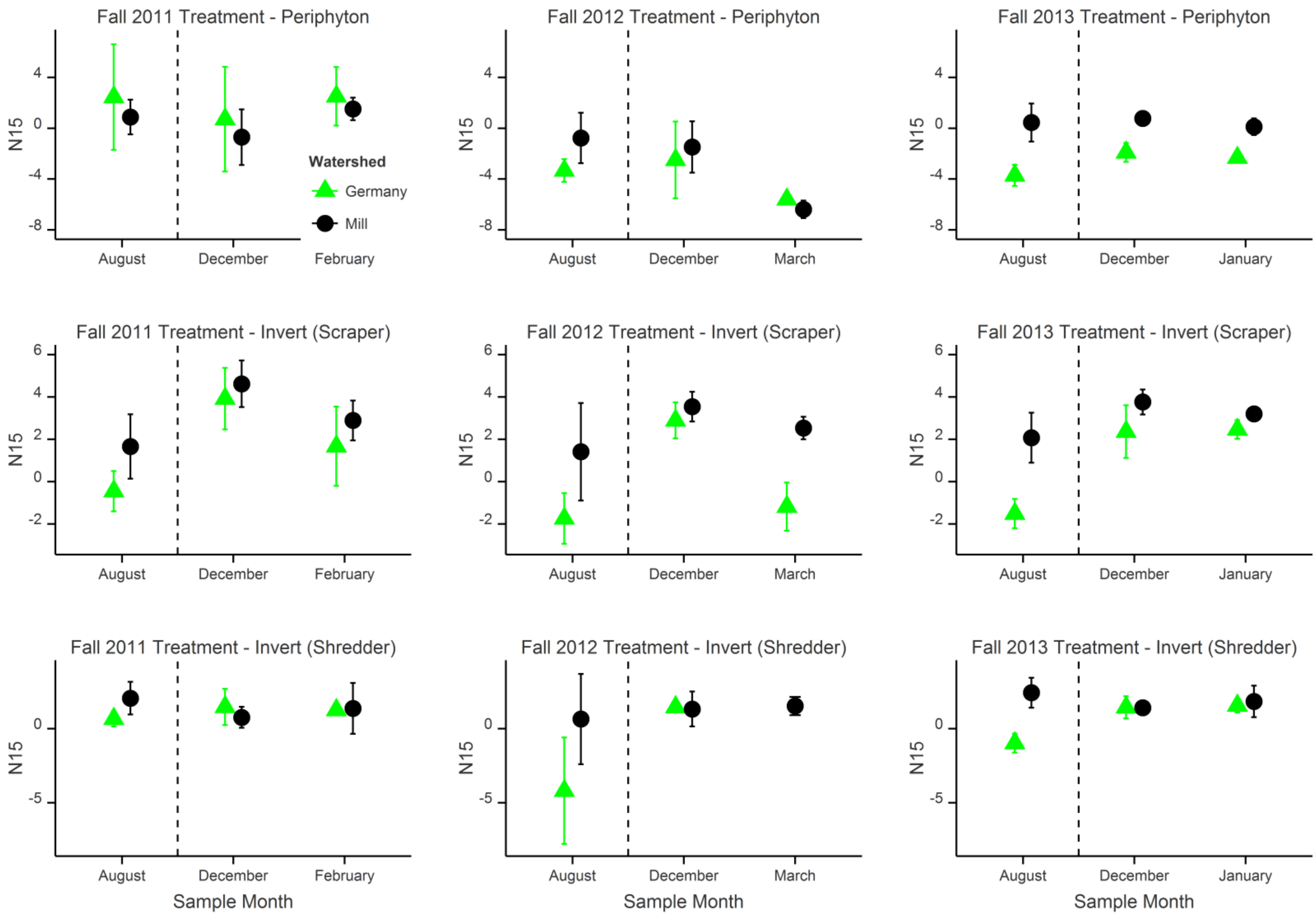


Figure 13. Seasonal changes in the length, weight, and nitrogen-15 isotope ratios of juvenile Coho Salmon in response to fall treatments with salmon carcass analogs. Fall treatments in Germany Creek (green), indicated by dashed vertical line, were applied in September and October for three consecutive years (2011-2013). Mill Creek (black) was the reference watershed for this study. Plot shows mean value and 1 standard deviation.

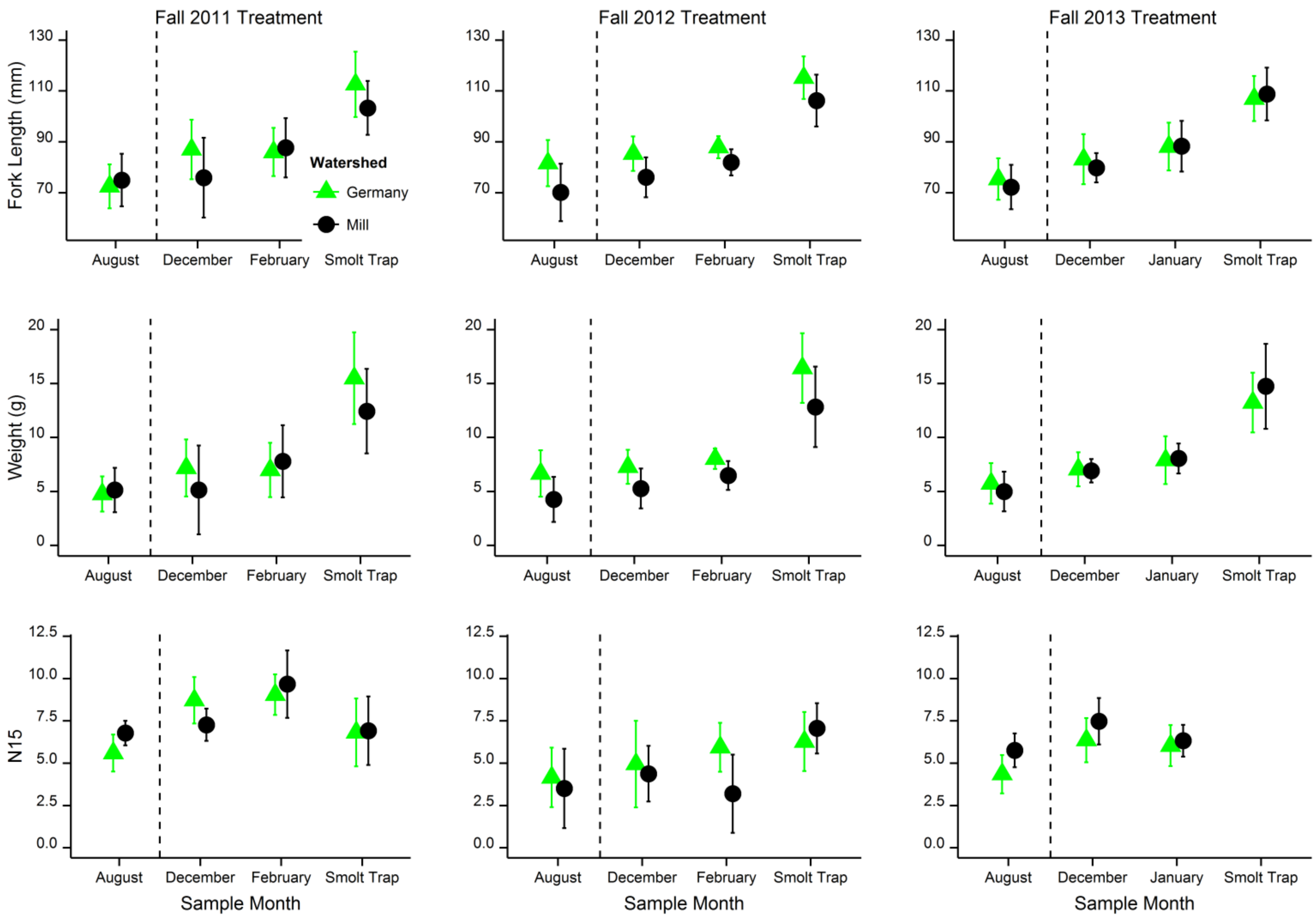


Figure 14. Seasonal changes in nitrogen-15 isotope ratios of periphyton and aquatic invertebrates in response to spring treatments of salmon carcass analogs. Spring treatments, indicated by dashed vertical line, were applied in May and June of 2013 in the mainstem of Abernathy Creek (green). Mill Creek (black) and two untreated tributaries to Abernathy Creek (gray) were the references for this study. Plot shows mean value and 1 standard deviation.

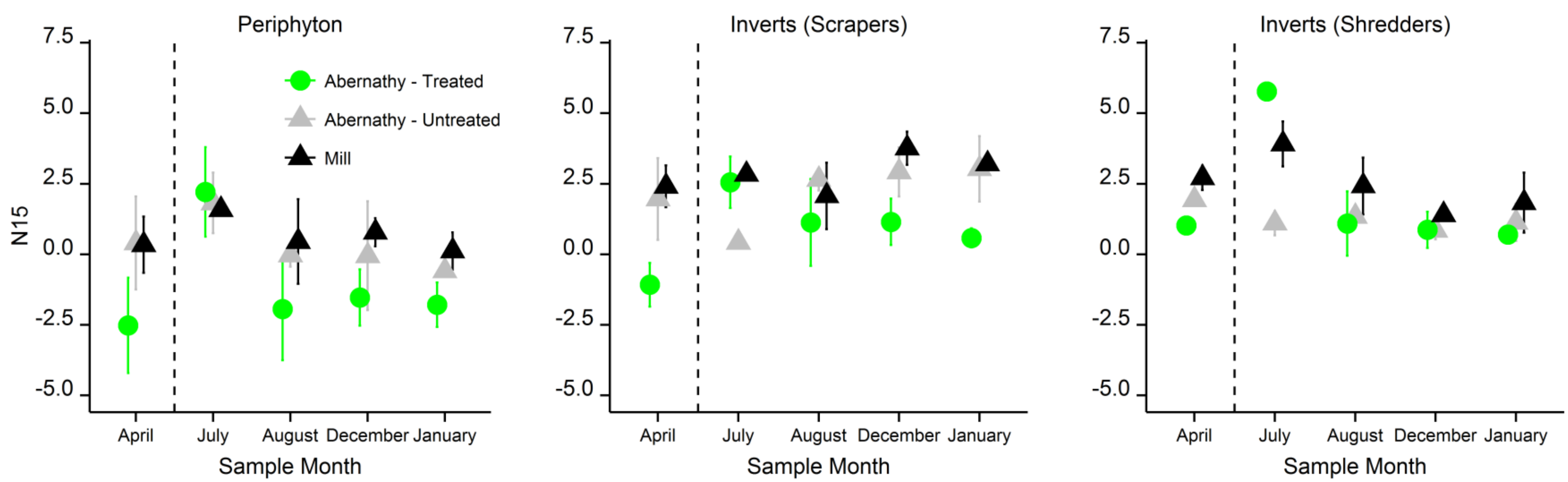


Figure 15. Seasonal changes in the length, weight, and nitrogen-15 isotope ratios of juvenile Coho Salmon in response to spring treatments with salmon carcass analogs. Spring treatments were applied in May and June of 2013 in the mainstem of Abernathy Creek (green). Juvenile Coho Salmon fry were not sampled prior to the treatment. Mill Creek (black) and two tributaries to Abernathy Creek (gray) were the references for this study. Plot shows mean value and 1 standard deviation.

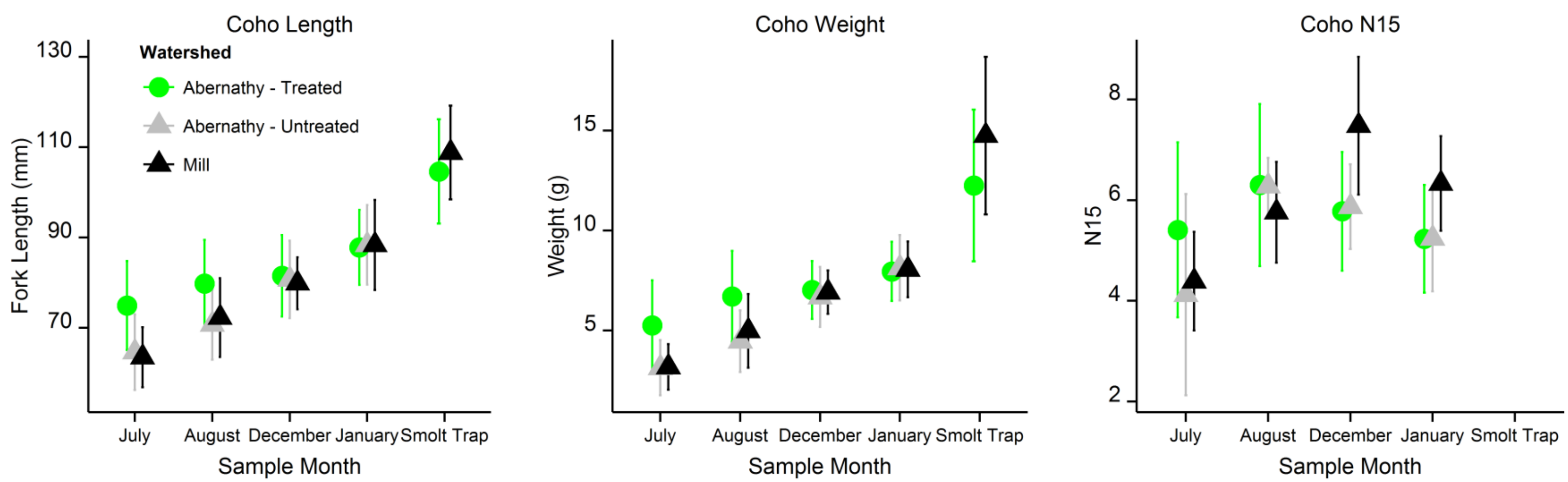


Figure 16. Population-level response of juvenile outmigrant abundance and size (fork length) to fall treatments of salmon carcass analogs in Germany Creek. For Coho Salmon smolts, a Before-After comparison was used to evaluate change in abundance and fork length. For Steelhead Trout and Chinook Salmon, a Before-After Control-Impact comparison was used to evaluate the change in abundance and a Before-After comparison was used to evaluate the change in fork length. Bar graph shows mean value and 1 standard deviation. Scatter plots shows annual estimates and regression line.

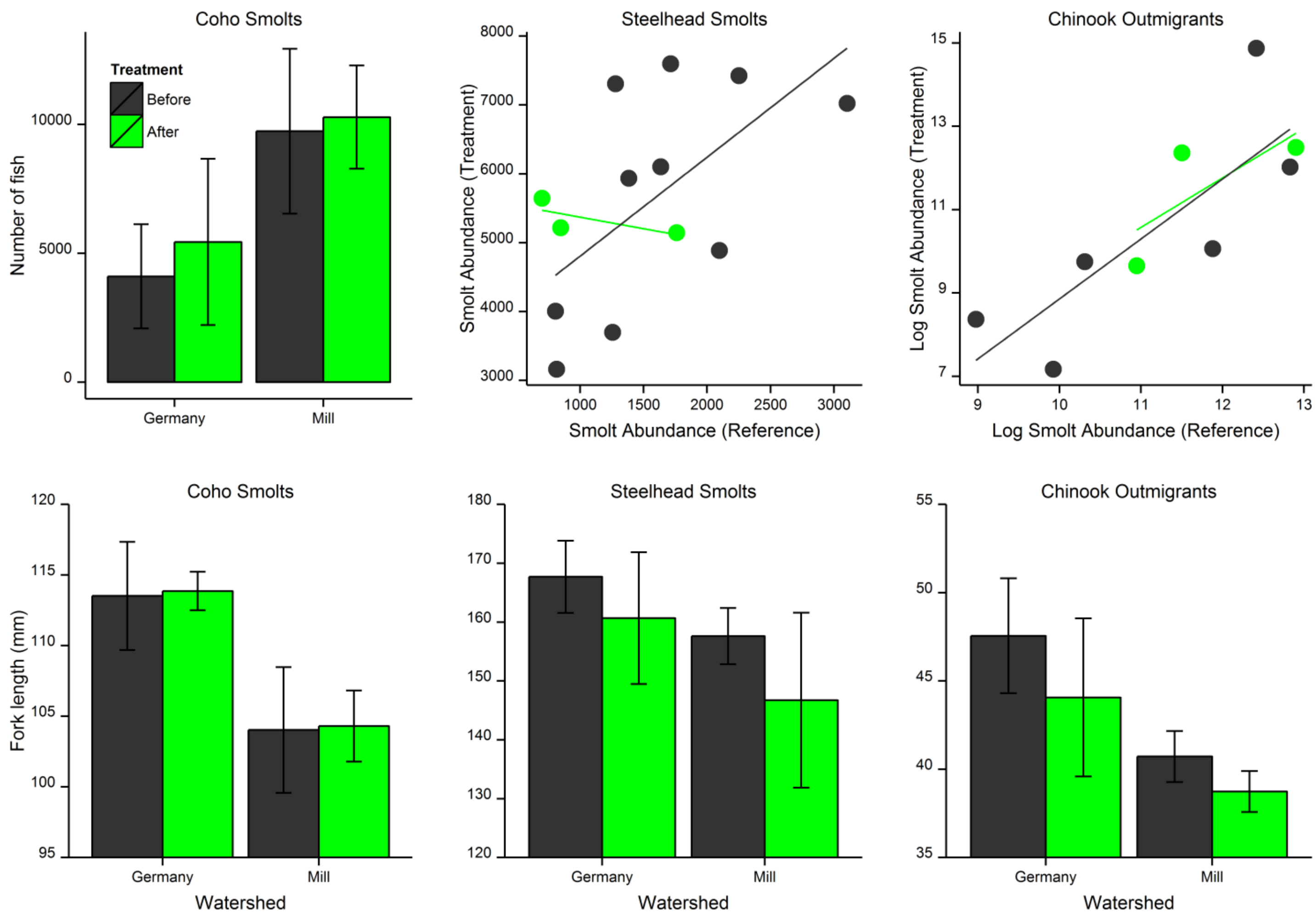
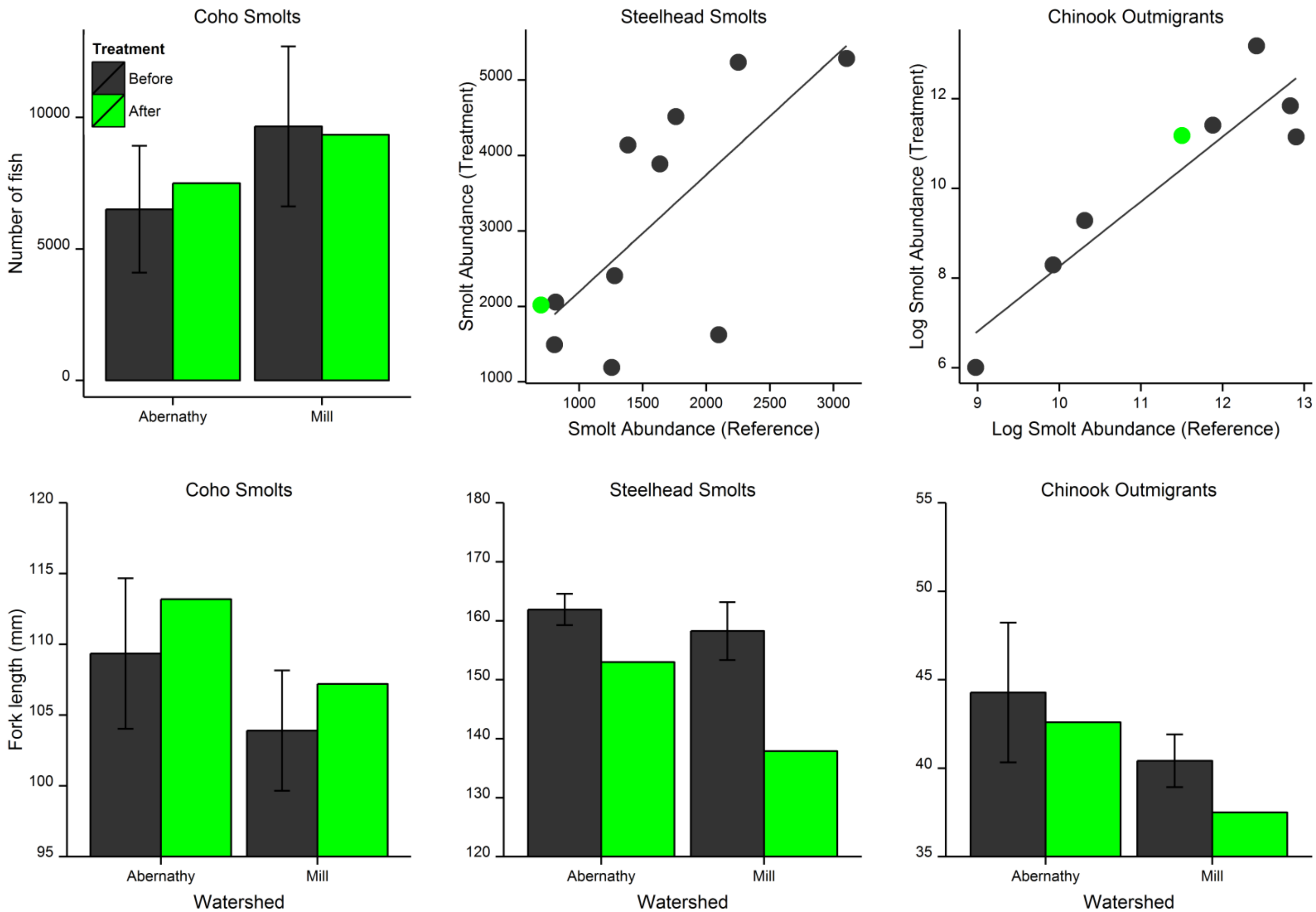


Figure 17. Population-level response of juvenile outmigrant abundance and size (fork length) to <u>spring</u> treatments of salmon carcass analogs in Germany Creek. Only one year of data from the three-year study is currently available. Bar graph shows mean value and 1 standard deviation. Scatter plots shows annual estimates and regression line.



Recommendations

The original design intended for the IMW study assumed that freshwater production (smolt abundance) would be correlated among neighboring watersheds. Baseline monitoring results show that this is generally true for Chinook Salmon and Steelhead Trout but not Coho Salmon. As a result, analysis of post-treatment data will be modified accordingly.

- Pursue synthesis of fish life cycle data with water quality and habitat covariates. Explore variability in hatchery spawners as a covariate. Identify connections between these covariates and freshwater growth and survival in order to explain baseline differences among watersheds and increase power for detecting responses to habitat treatments.
- Pursue additional understanding of the role that fall migrants contribute to Coho Salmon productivity in these watersheds. (Additional funding will be required to pursue this issue.)

Analysis of baseline monitoring data demonstrated that both summer location and fish growth contribute to the apparent overwinter survival of Coho Salmon.

- Identify winter rearing areas for juvenile Coho Salmon that survive as spring smolts.
- Verify that "fall movers" in Abernathy Creek are indeed "fall migrants". Explore options for understanding the importance of fall migrant life history in these watersheds.
- Continue discussions with restoration planners/practitioners on identifying high-use and low-use rearing reaches for the purpose of selecting additional habitat projects to test specific hypotheses on restoration approaches.

As restoration projects continue to be planned, projects that benefit Tier-2 and Tier-3 reaches may be as important to meeting the IMW objectives as projects that benefit Tier-1 reaches.

- Continue discussions between IMW scientists and restoration planners/practitioners to discuss project selection that would increase benefit to all focal fish species in these watersheds.
- Consider reprioritization of projects in the Treatment Plan. To accomplish IMW objectives, prioritization of projects should minimize the importance of recovery tiers assigned to each reach and emphasize reaches where projects are logistically feasible and where hypotheses associated with changes in fish and habitat conditions can be tested.

Currently completed habitat treatment projects represent just 14% of phase 1 treatments in Abernathy Creek and 8% of phase 1 treatments in Germany Creek.

- Implement additional habitat restoration treatments.

Preliminary results suggest that the freshwater ecosystem was more responsive to spring than fall SCA treatments but that the response was not long-lasting and did not translate into a difference at the smolt life stage. The spring 2015 SCA treatment is the final planned SCA treatment.

- Increase treatment intensity in spring 2015 to include tributaries of Abernathy Creek.
- Complete additional analysis of fish and ecosystem response to SCA treatments (WWU masters thesis planned, whole stream metabolism analysis planned).

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Appendix A: Documentation of Study Protocols and Data Management

The overall IMW program is comprised of one federal agency, two state agencies, two tribal organizations, and one private company. From the beginning we chose to use each entity's existing data management system(s) rather than construct a single system unique to the IMW program. As a result the data quality control elements identified by the ISP are in varying formats, distributed among participating entities, and are specific to a particular data stream (i.e. there is no single document that contains all this information).

As described below, data and protocols for the Lower Columbia IMW Study are developed and maintained by the Washington Department of Ecology (ECY), Washington Department of Fish and Wildlife (WDFW), Weyerhaueser (WEYCO). The Pacific States Marine Fisheries Commission maintains the PTAGIS database which stores all tag data from this study. Online links to additional information are provided at the end of this document.

WATER QUALITY

ECY uses the Environmental Protection Agency's Quality Assurance Project Plan format and has these available for both water quality and streamflow data. Finalized water quality and quantity data are publically available.

- https://fortress.wa.gov/ecy/publications/documents/0503204.pdf
- https://fortress.wa.gov/ecy/publications/documents/0303200.pdf
- https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp

ANNUAL ADULT SPAWNERS

A high level description of the methods and analytical approach applied to the Lower Columbia IMW is provided in Kinsel et al. (2009) and Rawding et al. (2014). On an annual basis, protocols are followed according to the WDFW Stream Survey Manual developed for all lower Columbia River watersheds. This document is used internally to standardize survey methods, redd identification, and biological data collection consistent with guidelines of the American Fisheries Society (Crawford et al. 2007a; Gallagher et al. 2007). Data are housed in the WDFW Traps-Weirs-Survey (TWS) database. Final adult spawner estimates are publically available through the Salmon Conservation Reporting Engine.

- http://wdfw.wa.gov/publications/00783/
- http://wdfw.wa.gov/publications/01702/
- https://fortress.wa.gov/dfw/score/score/species/species.jsp

ANNUAL SUMMER PARR

A description of the methods and analytical approach for the summer parr data is provided in Kinsel et al. (2009). On an annual basis, protocols are followed according to the Weyerhaeuser Aquatic Research Workplan. Data are maintained by WEYCO in a project database.

- http://wdfw.wa.gov/publications/00783/

ANNUAL SMOLTS

A description of the methods and analytical approach applied to the Lower Columbia IMW is provided in Kinsel et al. 2009. On an annual basis, smolt trap operation protocols are updated in a standardized format for all smolt traps statewide and are consistent with guidelines of the American Fisheries Society (Volkhardt et al. 2007). Field data, final estimates, and protocols are archived by WDFW in the JMX database. Final smolt estimates will be publically available through the WDFW Salmon Conservation Reporting Engine (coming summer 2015).

- http://wdfw.wa.gov/publications/00783/
- https://fortress.wa.gov/dfw/score/score/species/species.jsp

ANNUAL PIT TAGGING

Tagging protocols follow the "PIT Tag Marking Procedures Manual" developed by the Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee for all tagging operations in the Columbia River. Data are publically available through the PTAGIS database.

- ftp://ftp.ptagis.org/Documents/PIT_Tag_Marking_Procedures_Manual.pdf
- http://www.ptagis.org/

ANNUAL HABITAT

The habitat sampling plan and field methods are adapted from the US EPA, Environmental Monitoring and Assessment Program as described in Peck et al. (unpublished draft) and (Crawford (2008c); Crawford 2008b). Protocols follow methods recommended in the Washington Comprehensive Monitoring Strategy for Watershed Health and Salmon Recovery (Crawford et al. 2002) and meet the preliminary criteria of the Pacific Northwest Aquatic Monitoring Partnership. Note that preliminary results of the IMW habitat work, especially in the Hood Canal IMW complex, have been used to help inform the work of the PNAMP. Habitat data are maintained by WDFW in a project database.

- http://www.epa.gov/emap
- http://www.epa.gov/emap/html/pubs/docs/groupdocs/surfwatr/field/ewwsm01.html
- http://www.rco.wa.gov/documents/monitoring/MC-2_Instream_Habitat_Projects.pdf
- http://www.rco.wa.gov/documents/monitoring/MC-5&6_Floodplain_Enhancement.pdf
- http://www.pnamp.org/

EFFECTIVENESS MONITORING

Fish passage projects will be evaluated following methods described in "Protocol for Monitoring Effectiveness of Fish Passage Projects MC-1" (Crawford 2009). Instream habitat projects will be evaluated following methods described in "Protocol for Monitoring Effectiveness of In-Stream Habitat Projects MC-2" (Crawford 2008c). Off-channel projects will be evaluated following methods described in "Protocol for monitoring effectiveness of floodplain enhancement projects MC-5/6" (Crawford 2008b).

- http://www.rco.wa.gov/documents/monitoring/MC-1_Fish_Passage_Projects.pdf
- http://www.rco.wa.gov/documents/monitoring/MC-2_Instream_Habitat_Projects.pdf
- http://www.rco.wa.gov/documents/monitoring/MC-5&6_Floodplain_Enhancement.pdf

Appendix B: Contributions to the Lower Columbia Intensively Monitored Watersheds Project

	SRFB	LCFRB	Restoration Practitioners	IMW Scientists
Identify limiting factors		X	X	
Develop treatment plan		X	X	
Propose projects			X	
Select projects		X		
Fund projects	X			
Design projects		X	X	X
Implement projects			X	
Baseline monitoring				X
Evaluate response				X