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Intensively Monitored Watersheds Program: An Updated Plan to Monitor Fish and Habitat Responses to Restoration Actions in the Lower Columbia Watersheds

by Mara Zimmerman, Kirk Krueger, Bill Ehinger, Phil Roni, Bob Bilby, Jason Walters, and Tim Quinn

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Intensively Monitored Watersheds Program: An Updated Plan to Monitor Fish and Habitat Responses to Restoration Actions in the Lower Columbia Watersheds

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Abstract

The Lower Columbia Intensively Monitored Watersheds (IMW) program is designed as a Before-After Control-Impact (BACI) study in order to determine whether and how habitat restoration activities influence abundance of salmon and steelhead. The study is conducted in Mill, Abernathy, and Germany creeks which flow into the lower Columbia River downstream of Longview, Washington. The goal of this updated monitoring plan is to summarize results from baseline ("pre-treatment") monitoring, use baseline information to determine whether fish responses should be detectable, and identify the types of fish and habitat data necessary to test hypothesized responses to restoration activities. Results from 8 years of baseline monitoring have demonstrated that annual smolt production is correlated among watersheds, enabling use of the BACI design for detecting future changes in the treatment (i.e., "impact") populations. Results also suggest that over-winter survival is an important limiting life stage for coho salmon in these watersheds. A 47 to 82% increase in the freshwater production of coho and steelhead is likely to be detected after 5 years of post-treatment monitoring. We demonstrate that this level of increase may be expected given the currently proposed projects for these watersheds and the magnitude of fish responses to habitat restoration elsewhere in Washington State. In the last section of this updated plan, we hypothesize the mechanisms by which culvert replacement, in-channel large woody debris placement, off channel reconnection, and nutrient enhancement may influence fish and habitat in these watersheds, and we describe the types of data that will be used to identify these mechanisms. Cause and effect will be demonstrated by combining the population response (e.g., more smolts in treatment stream) and a causal mechanism (e.g., increased growth or over-winter survival in treatment stream). The success of the IMW program will be based on the ability to determine whether and why fish populations respond to habitat restoration efforts. This result relies on BACI study design and on successful monitoring of key life stages and habitat hypothesized to respond to restoration actions.

Introduction

The Intensively Monitored Watersheds (IMW) program uses a Before-After Control-Impact study design (BACI; Downes et al. 2002; Roni et al. 2005) in order to evaluate whether and how restoration activities increase salmon and steelhead production. The IMW Program was funded by the Salmon Recovery Funding Board (SRFB) in response to recommendations by the "Comprehensive Monitoring Strategy and Action Plan for Watershed Health and Salmon Recovery" (Crawford et al. 2002), requested by the Washington State Legislature in 2001. In 2006, the IMW program was reviewed by an Independent Science Panel (ISP) at the request of the SRFB. The ISP concluded that the IMW program "could represent the beginning of a state-of-the-art intensive monitoring program to test and validate contemporary salmon habitat improvement strategies at the watershed scale." The ISP recommended that three criteria be met in order for the IMW program to be successful (Currens et al. 2006):

(1) Production must be measured with sufficient precision and duration to detect changes,

(2) Restoration activities must be sufficient to affect a detectable change in production, and

(3) Environmental variability must be measured to account for its effects on production.

The premise of the IMW program is that the complex relations between salmon production, watershed conditions, and restoration activities can be best understood by concentrating research efforts on a few, carefully selected watersheds. The BACI study design (Downes et al. 2002; Roni et al. 2005) relies on correlations between neighboring watersheds to account for environmental variability and temporal trends and thus improves the ability to detect effects of restoration activities (Smith et al. 1993). Watersheds were selected for the IMW program because they were large enough to provide habitats required for the study species while being small enough to allow sufficient sampling of habitat and fish. Selected study watersheds also had existing fish data, a range of human disturbance histories, and high potential for successful restoration.

This document is an updated study plan for the Lower Columbia River IMW stream complex. This document builds on the previous study plan (Ehinger et al. 2007) in order to ensure that monitoring efforts are coordinated with the prioritized restoration actions. Objectives of the updated study plan are to:

(4) Describe current results from the Lower Columbia IMW program,

(5) Predict fish and habitat responses to prioritized restoration actions, and

(6) Develop hypotheses associated with fish and habitat responses to restoration and identify the metrics necessary to test these hypotheses.

Terminology

Throughout the document, freshwater stages of salmon are described as "fry", "parr", "smolt", and "spawner". This terminology represents specific life history stages and implies the types of interactions between fish and their freshwater environment.

Fry.—Recently emerged juvenile salmonids. Physically, fry have a disproportionally large head and a slight body. Ecologically, fry have absorbed their yolk sac and are beginning to feed.

Parr.—Juvenile salmonids that have fed in freshwater for several months. Physically, parr are larger with a more steam-lined body than fry. They have vertical parr markings but do not have the silver coloration of smolts. Parr range in age from sub yearling to three years of age. Ecological impacts of the freshwater environment on this life history stage occur over a 3-month to 3-year period, depending on the length of freshwater residency.

Smolt.—Juvenile salmonids that have fed in freshwater and are undergoing physiological changes required for saltwater living. The visual cue for the smolt process is a silvery coloration of the fish. Physically, smolts are larger than fry or parr (typically >90-mm fork length). Ecological impacts of the freshwater environment on this life history are cumulative through the fry and parr stages.

Outmigrant.—Juvenile salmonids in process of leaving the watershed and are presumed to be migrating towards the ocean. Depending on species, outmigrants may be at the "fry", "parr", or "smolt" life stage.

Spawner.—Adult salmonids that return from the ocean to the river. Salmon and steelhead spawners are large (>35-cm fork length) and colorful. They move throughout the watershed, pair up, and lay their eggs in self-dug gravel pits called redds. Salmon do not feed during this life stage and die shortly after reproduction. Following reproduction, a portion of steelhead spawners resume feeding and return to saltwater for another growing season.

Lower Columbia Study Sites

In the Lower Columbia, the IMW program includes three adjacent watersheds - Mill, Abernathy, and Germany creeks. Mill, Abernathy and Germany creeks are located in the Elochoman Water Resource Inventory Area (WRIA 25) in Cowlitz and Wahkiakum counties, Washington (Figure 1). These creeks flow into the Columbia River west of Longview, Washington at river mile (RM) 53.8, 54.2, and 56.2 respectively. Mill Creek is the reference stream where no restoration actions are planned. Abernathy and Germany creeks are the treatment streams.

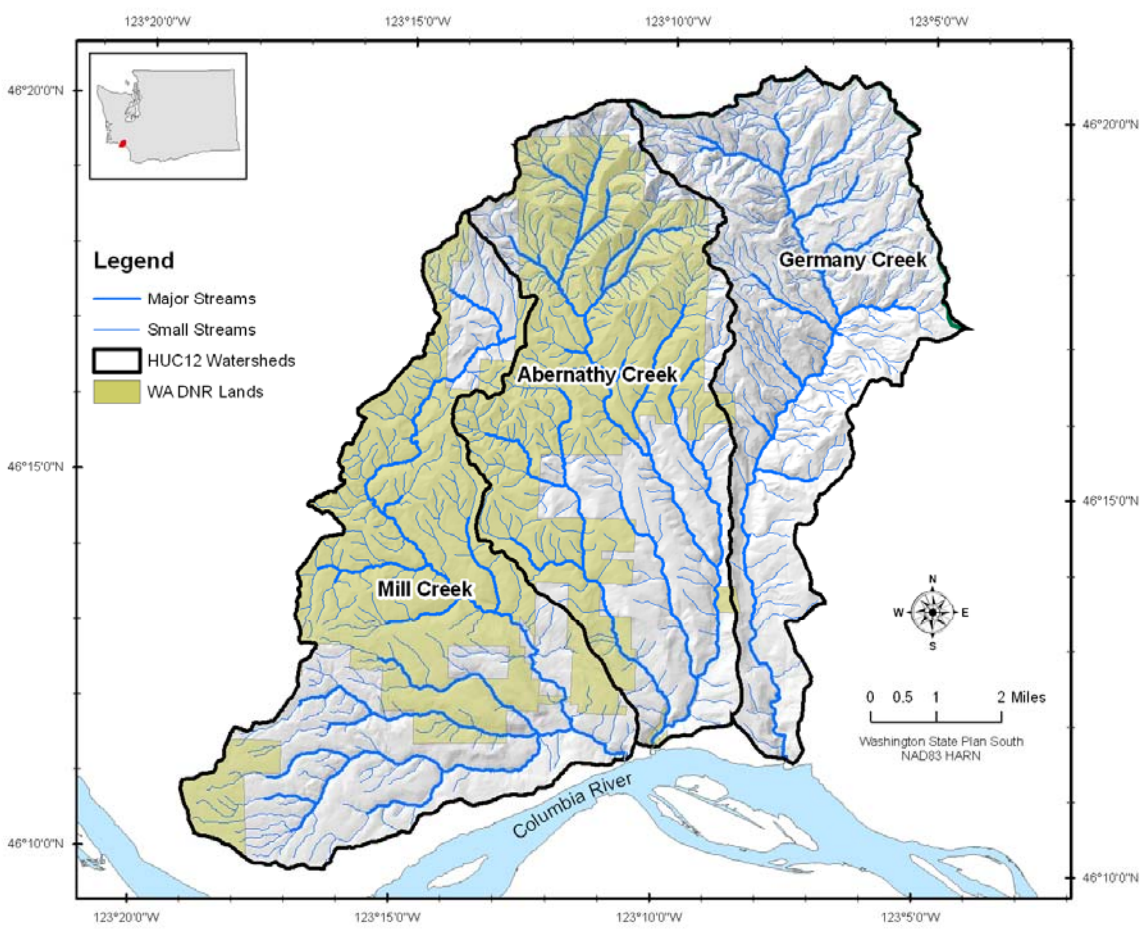

Figure 1.─Lower Columbia Complex. Land managed by the Washington Department of Natural Resources is shaded green. Nearly all of the remaining land is privately owned timberland.

Commercial forestry is the predominant land use in the upper portions of all three watersheds. Commercial forest land in Germany Creek watershed is privately owned while in Mill and Abernathy watersheds much of the land is managed by the Washington Department of Natural Resources (DNR). The lower portions of all three basins are a mix of small forest landowners, agriculture, and rural residential development.

The diversity of salmonid species and life histories makes the Lower Columbia IMW complex an excellent location for studying the effectiveness of restoration activities. Salmonid species in these creeks include "tule" fall Chinook salmon (Marshall et al. 1995), coho salmon, cutthroat trout, and winter-run steelhead (LCFRB 2004; Myers et al. 2006). Chum salmon are also observed in low numbers. Chinook and coho populations are listed as *threatened* under the Endangered Species Act and are part of the Coastal Major Population Group for the Lower Columbia Evolutionary Significant Unit (ESU). Chum populations are also ESA listed as *threatened* and are part of the coastal Major Population Group for the Columbia River chum ESU. Winter-run steelhead are not listed under the Endangered Species Act and are considered part of the Southwest Washington distinct population segment (DPS) (http://nwr.noaa.gov/ESA-Salmon-listings/Salmon-Populations/Steelhead/Index.cfm).

FISH MONITORING STUDIES

Coho, Chinook, and steelhead are the focal species for monitoring in these watersheds (Kinsel et al. 2009). Abundance of coho is measured at three life stages (parr, outmigrant, and spawner). Abundance of Chinook and steelhead are measured at two life stages (outmigrant, spawner). Coho and steelhead outmigrants have been monitored since 2001; Chinook outmigrants have been monitored since 2005. Over this time period, production of coho has been highest in Mill Creek and lowest in Germany Creek while steelhead production has been highest in Germany Creek and lowest in Mill Creek (Figure 2). No apparent trend exists for Chinook production across watersheds. In all three watersheds, inter-annual variation in Chinook production has been higher than that of coho or steelhead.

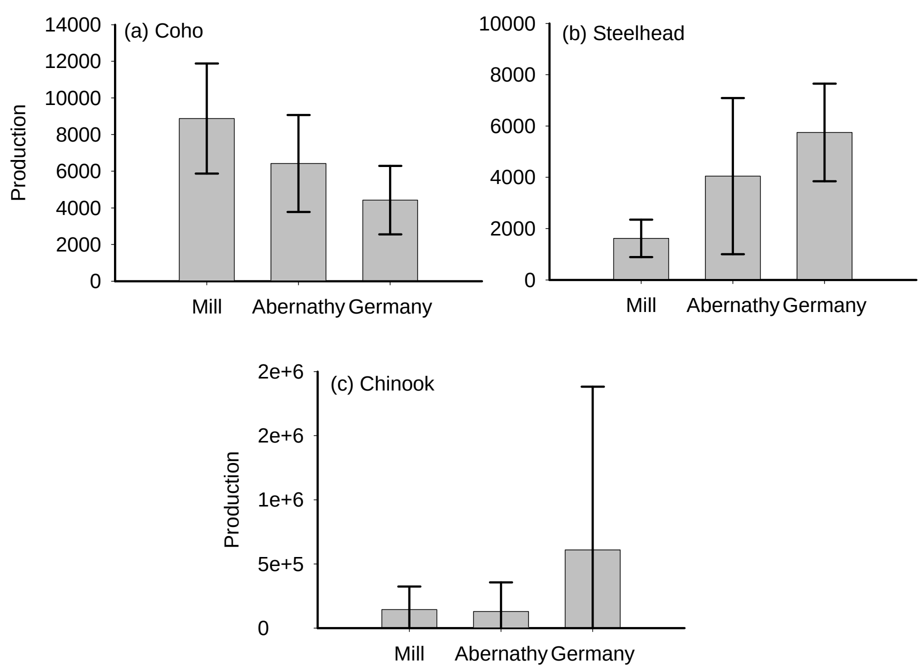

Figure 2.—Juvenile outmigrants of coho, steelhead, and Chinook in Lower Columbia IMW watersheds. Data are mean and standard deviation of annual production for each watershed. Coho and steelhead data are for 2001-2009. Chinook data are for 2005-2009.

The trends observed across watersheds have several implications for habitat restoration. First, relative species composition may be naturally influenced by the characteristics of each watersheds. For example, stream gradient may impact relative abundance of coho and steelhead. Coho typically rear in pool habitats that are more abundant in low gradient streams like Mill Creek than higher gradient streams like Germany Creek. Second, limiting factors may differ among species. For example, summer flows and overwinter off-channel habitat may limit coho and steelhead production whereas escapement and incubation flows may limit Chinook production. Early life history of all species will be impacted by escapement, spawning flows, and incubation flows. However, coho and steelhead rear for a longer period in freshwater and are further impacted by interactions in their summer and winter freshwater habitats. The number of coho and steelhead outmigrants is more consistent across years than the number of Chinook outmigrants (Figure 2), suggesting that the capacity of summer and winter rearing habitats may override any initially large variation caused by fluctuations in egg deposition and egg-to-fry survival.

Over-winter survival appears to be an important determinant of coho production in the Lower Columbia IMW watersheds, highlighting the importance of over-winter habitat when planning restoration efforts. For example, the importance of over-winter habitats was illustrated by coho parr-to-smolt survival for the 2006 brood year. During summer stream surveys associated with this brood year, coho parr abundance in Mill Creek was two times greater than that in Abernathy and Germany creeks. However, seven months later, the number of coho outmigrants in Mill Creek was two times that in Abernathy Creek and three times that in Germany Creek (Table 1). The higher smolt production resulted from differences in parr-to-smolt survival. Apparent survival between the parr and smolt stage in Mill Creek (14.4%) was more than five times the survival rate in Abernathy (2.8%) or Germany (1.8%) creeks. Based on these and previously published results (Cederholm et al. 1997), habitat restoration projects that enhance over-winter refugia should increase the number of coho smolt outmigrants in Abernathy and Germany creeks.

Table 1.—Life stage specific abundance and survival of coho salmon in Lower Columbia IMW watersheds, brood year 2006 (data from Kinsel et al. 2009).

Watershed	Parr Abundance	Parr-to-smolt survival	Smolt production
Mill	69,628	14.4%	10,930
Abernathy	161,069	2.8%	5,699
Germany	183,535	1.8%	3,982

HABITAT MONITORING STUDIES

Habitat attributes are monitored in order to describe the effects of restoration activities on habitat. Habitat attributes can also be used as covariates in the BACI analysis. Habitat monitoring follows protocols provided by the SRFB (Crawford 2008a; Crawford 2008b; Crawford 2009). These protocols were development based on the United States Environmental Protection Agency, Environmental Monitoring and Assessment Protocol (EMAP; (Kaufmann et al. 1999). The EMAP protocol uses a series of cross-section measurements of bank-full width and wetted channel, as well as tallies of large wood and substrate size to characterize and detect changes in physical structure of the stream. SRFB protocols suggest using reference sites to improve detection of change due to restoration actions. Reference sites for the Lower Columbia IMW watersheds will be selected randomly from locations that are currently used in the EMAP surveys.

Detecting and Predicting Responses

The goal of habitat restoration activities is to improve ecosystem function and produce more fish. Although much effort and funding has supported habitat restoration in the Pacific Northwest (NRC 1996), little is known about the efficacy of these efforts for increasing salmon production (Katz et al. 2007; Miller and Hobbs 2007). An evaluation of population-level responses will provide valuable feedback on questions such as how much restoration is needed to improve freshwater production? What time frame is needed to detect production? And, which species are most responsive to different types of restoration actions?

The Lower Columbia Fish Recovery Board (LCFRB) has identified channel stability, habitat diversity, sediment load, water temperature, and flow as factors that likely limit salmon production in Abernathy, and Germany creeks using the Ecosystem Diagnosis and Treatment (EDT, Lestelle et al. 1996; Lichatowich et al. 1995) and Integrated Watershed Assessment (IWA) models (LCFRB 2004). In addition, chronically low spawner escapements can deplete the watershed of marine-derived nutrient inputs having detrimental effects on salmon growth and survival (Bilby et al. 1996; Gresh et al. 2000) and ecosystem function (Helfield and Naiman 2001; Naiman et al. 2002; Reimchen et al. 2003). Restoration activities proposed for Abernathy and Germany creeks include a culvert replacement, in-channel woody debris placement, and off-channel habitat restoration and reconnection (HDR_Inc and Cramer_Fish_Sciences 2009). Nutrient enhancement treatments began in Germany Creek in the fall of 2010.

Monitoring activities designed to evaluate these restoration activities are needed to evaluate whether and how restoration actions have impacted fish populations (Smith et al. 1993; Solazzi et al. 2000). Specifically, one needs to consider (1) the magnitude of change required to detect an effect and (2) the magnitude of effect expected. We address the first question using a power analysis based on existing monitoring data and the second question using literature values and a list of restoration actions planned for a watershed. This analysis was conducted for the outmigrant life stage, as an increase in freshwater production is expected to be the most immediate response to improvements in freshwater conditions.

Detectable Change in Freshwater Production

The magnitude of change needed to detect a response in juvenile outmigrants was evaluated for coho, steelhead, and Chinook. A power analysis was conducted to determine how many more juvenile outmigrants (Δ) would be needed to detect a difference in production before and after restoration activities (Cohen 1988). The analyses were performed based on 5 to 15 years of data and assumed that the power to detect a difference was 90% ($\beta = 0.9$) with a Type I error rate of 10% ($\alpha = 0.1$, one-tailed t-test). Variance of each data set (species by watershed) included inter-annual variation and measurement error. Inter-annual variation (CV_r) accounted for natural variability in juvenile outmigrants and measurement error (CV_m) represents the uncertainty of the abundance estimate. Inter-annual variability was the standard deviation of annual production estimates. The two error estimates were combined as (Gerrodette 1987):

Equation 1

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

Application of the BACI design will further increase the power to detect population-level changes. Correlations among watersheds are necessary to apply the BACI design (Roni et al. 2005). At the outset of the IMW study, abundances of adjacent populations were assumed to be correlated due to synchronous regional variables (i.e., escapement or rainfall); however, actual correlations only become apparent after several years of monitoring data are available. If no correlation exists, the response to restoration is analyzed with a Before-After comparison. When correlations exist, the BACI comparison improves the ability to detect changes because a portion of the inter-annual variation can be accounted for by the correlation between treatment and reference watersheds. In the Lower Columbia IMW watersheds, the number of juvenile outmigrants was correlated between the treatment and reference streams with the exception of Germany Creek coho, which was not correlated with coho outmigrants in Mill Creek (Figure 3). Therefore, a BACI design was used to determine detectable changes of juvenile outmigrants for all populations except Germany Creek coho.

The power analysis indicated that, after five years of post-treatment monitoring, detectable increases in the number of coho outmigrants should be 63% in Abernathy Creek and 82% in Germany Creek (Figure 4). If post-treatment monitoring continues for 10 years, a smaller increase should be detectable in Abernathy (43%) and Germany (55%) creeks. Detectable increases in the number of steelhead outmigrants after five years of post-treatment monitoring were 58% in Abernathy Creek and 47% in Germany Creek. In comparison with coho and steelhead, detectable increases for Chinook outmigrants were quite large. After five years of post-treatment monitoring, the detectable increase in the number of Chinook outmigrants required a 361% increase in Abernathy Creek and 426% increase Germany Creek.

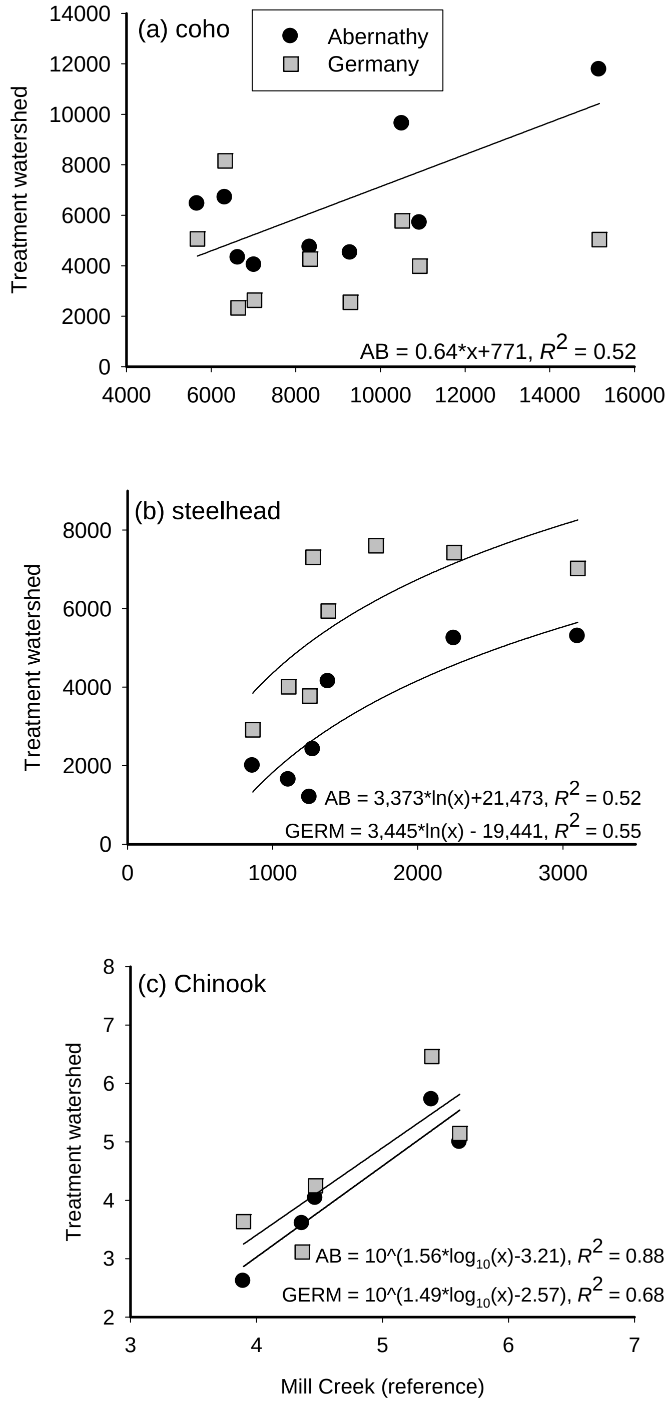

Figure 3.—Inter-annual correlations between freshwater production of coho (*a*), steelhead (*b*), and Chinook (*c*) in Lower Columbia IMW watersheds. Treatment watersheds (Abernathy, Germany) are regressed on the reference watershed (Mill Creek). Chinook production is presented on a $\log_{10}$ scale for ease of interpretation.

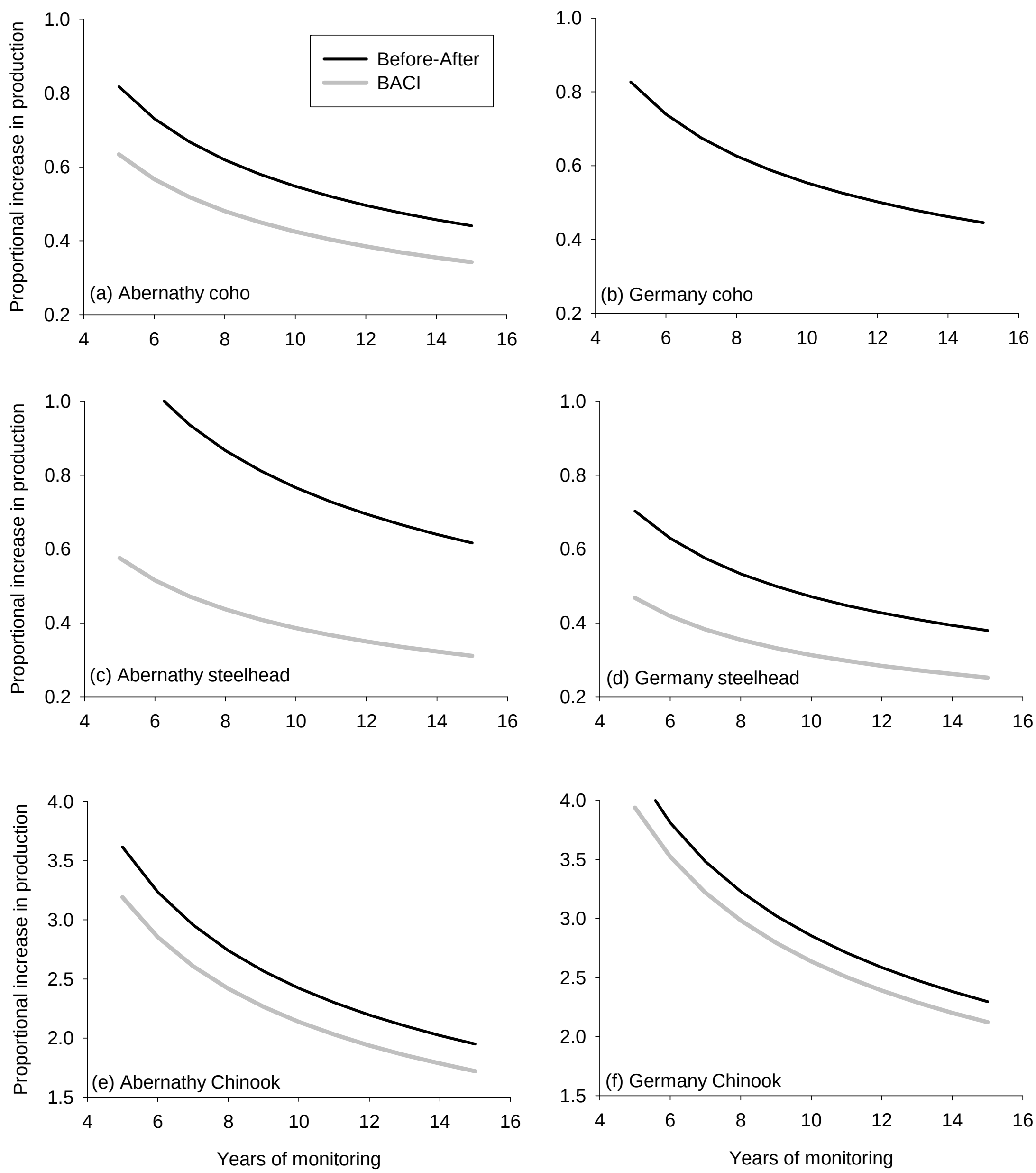

Figure 4.─Increase in juvenile outmigrants that can be detected for coho (*a, b*), steelhead (*c, d*), and Chinook (*e, f*) in Lower Columbia IMW watersheds. Detectable increase is presented as a proportion which is the change in abundance (Δ) identified in the power analysis divided by the current average production. Power analysis assumed a Type I error rate of 10% (α = 0.1), a Type II error of 90% (β = 0.9), and a sample size (*n*) of 5 to 15 years.

PREDICTED CHANGE IN FRESHWATER PRODUCTION

Predicted increases in coho salmon smolts in response to proposed restoration actions in Germany and Abernathy creeks were derived from published values (Table 2; Roni et al. 2010). These values were based on measured increases in coho densities associated with large woody debris (Roni and Quinn 2001), engineered log jams (Pess et al. Unpublished), and off-channel habitat restoration or creation (Roni et al. 2006).

Table 2.─Coho salmon response to restoration techniques used in Monte Carlo simulation.

Technique	Mean increase in smolts	Standard deviation
LWD Placement	0.213 smolts/m	0.331
Engineered Logjams	0.257 smolts/m	0.313
Off-channel habitat	0.368 smolts/m^2	0.361

These data were used in a Monte Carlo simulation to estimate the mean and the range of possible increases in coho smolt production from the two watersheds (Manly 2006). Inputs to the simulation model were the mean and standard deviation of coho salmon response for each restoration technique. The distribution of possible outcomes for each restoration technique was estimated with 10,000 model runs of a Monte Carlo simulation. The results for each technique were then multiplied by the area to be restored in each watershed and the results for each habitat restoration type were combined to calculate the range of possible increases in coho.

The modeling effort predicted that, if all proposed projected were implemented (large woody debris placement, engineered logjams, and off-channel restoration), these activities would lead to an additional 20,808 coho smolts per year in Abernathy Creek (Table 3) and 11,850 additional coho smolts in Germany Creek (Table 4). Variation in the predicted response resulted from the mean and standard deviation associated with each technique (Figure 5). The broad range of predicted responses suggested that results could be potentially higher or lower depending on level of success of restoration efforts. In addition, estimates of fish response to riparian planting, bank protection and other techniques were not available. The predictions may be conservative if these treatments also lead to changes in fish production. Similarly, these predictions should be used with caution as a number of other factors could influence response of fish to restoration actions in these watersheds.

Table 3.—Predicted increase in the number of coho outmigrants in response to all three phases of habitat restoration planned for Abernathy Creek. Predicted increase is the average change predicted by a Monte Carlo simulation of the treatment effects. The current average number of coho outmigrants for Abernathy Creek is provided for comparison.

	Treatment length or area					
Phase	Large Woody Debris (*m*)	Engineered Log Jams (*m*)	Off channel (m^2)	Predicted increase in coho production	Current average coho production	Percent increase
1	6,255	1,761	38,535	15,995	6,421	249%
2	1,299	366	1,394	887	6,421	14%
3	2,334	0	9,290	3,926	6,421	61%
Total	9,887	2,127	49,218	20,808	6,421	324%

Table 4.—Predicted increase in coho outmigrants in response to all three phases of habitat restoration planned for Germany Creek. Predicted increase is the average change predicted by a Monte Carlo simulation of the treatment effects. The current average number of coho outmigrants for Germany Creek is provided for comparison.

	Treatment length or area					
Phase	Large Woody Debris (*m*)	Engineered Log Jams (*m*)	Off channel (m^2)	Predicted increase in coho production	Current average coho production	Percent increase
1	3,786	0	18,998	7,817	4,421	177%
2	2,626	0	5,332	2,532	4,421	57%
3	5,374	0	929	1,502	4,421	34%
Total	11,786	0	25,260	11,850	4,421	268%

SYNTHESIS

The predicted increase in the number of coho outmigrant in response to the first phase of habitat restoration is greater than the statistically detectable increase after five years of post-treatment monitoring (Table 3, 4, Figure 4). Predicted responses for steelhead outmigrants could not be determined due to a lack of published values enumerating restoration effects on this species. While the coho results are encouraging, an important caveat is that the analysis assumes a step-like response to habitat restoration (before versus after). If the response is more gradual or requires the stream hydrology or ecosystem processes to re-equilibrate, the response timing may be far more gradual.

In addition, given results of the power analysis, detectable increases in Chinook production are unlikely unless production nearly triple in the Abernathy and Germany watersheds. As a result, evaluation of the Chinook data will focus on the expression of the two life history strategies (fry and parr migrant). At present, most Chinook emigrate as fry migrants from each of the three Lower Columbia IMW watersheds. However, the parr migrant strategy is commonly observed in other populations of ocean-type Chinook (Topping et al. 2009; Zimmerman et al. In prep) and might be expected in freshwater rearing habitat improves in these watersheds.

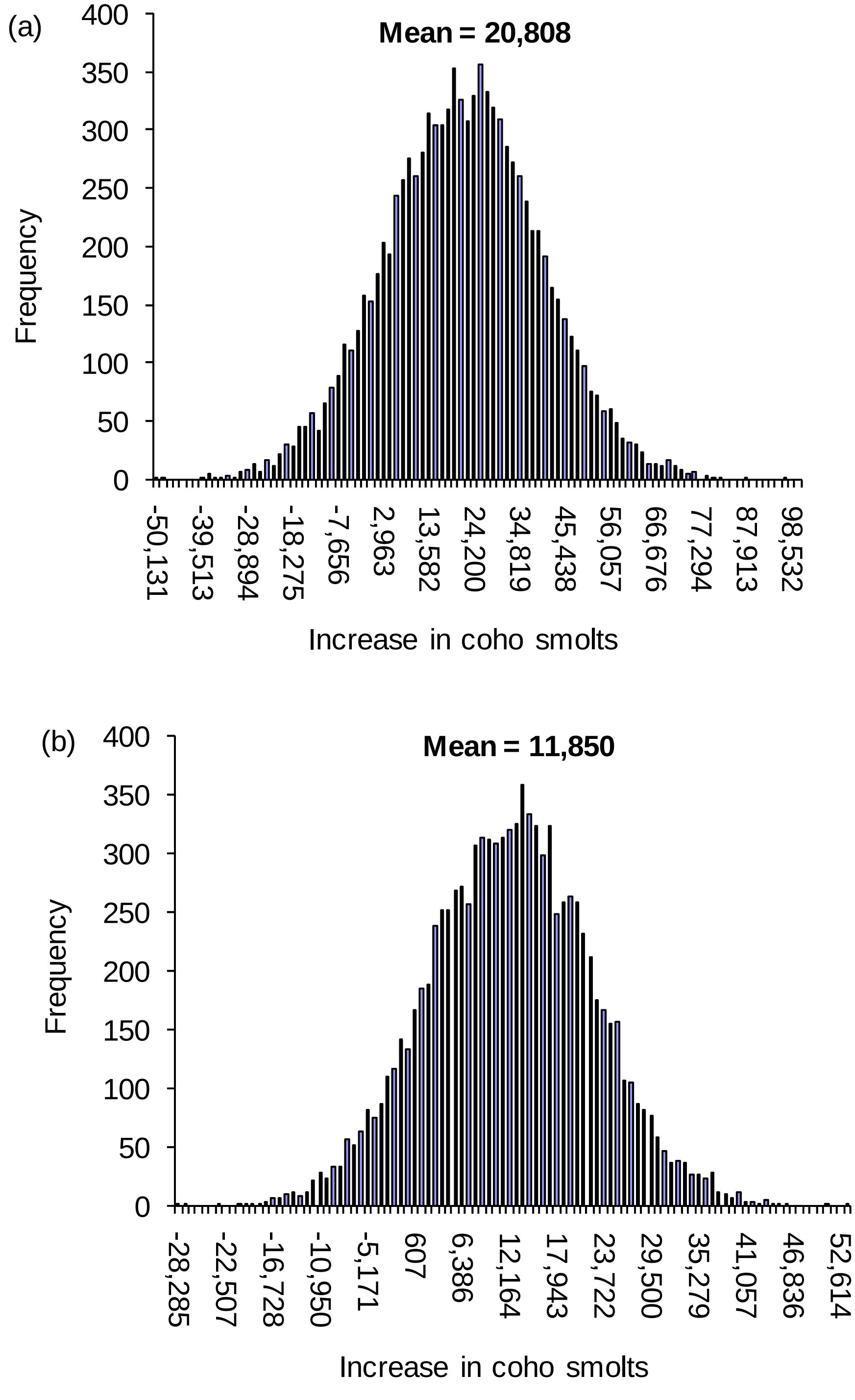

FIGURE 5.—Frequency of predicted increased coho smolt production in response to proposed restoration actions in Abernathy (*a*) and Germany Creek (*b*) based on 10,000 runs of simulation model.

Hypotheses and Measures for Fish and Habitat

The monitoring program on the Lower Columbia IMW watersheds intends to document and explain salmonid responses to restoration actions. Objectives of the program are to:

1) Determine if the number and life history of coho, Chinook, and steelhead outmigrants change in response to restoration activities,
2) Describe the relative importance of watershed processes (i.e., mechanisms) that affect changes in salmon freshwater production or diversity, and
3) Determine whether salmon responses to restoration activities are maintained over time.

These objectives are best addressed at multiple spatial and temporal scales. For example, changes in freshwater production (Objective 1) are best addressed by monitoring the numbers of smolts and spawners over a sufficient time period to detect changes before and after habitat restoration. In comparison, the effects of restoration activities on habitat and fish use (Objective 2) are best measured at the restoration sites within a relatively short time period. Maintenance of the effects of restoration over time (Objective 3) requires a post-treatment time series of sufficient duration to detect long-term trends.

This section details the project-specific and watershed-level monitoring that will be used to evaluate fish iand habitat responses to each project. Project-specific monitoring addresses whether the project produced the intended outcome (e.g., flood plain was reconnected and used by fish). Watershed-level monitoring will evaluate the cumulative effect of restoration projects (e.g., fish survival and production increased in a given year). The impact of each project on overall production and survival cannot be evaluated independently as restoration activities are expected to occur concurrently. Together, project and watershed-level monitoring will produce the information used to develop a "cause and effect" assessment of the impacts of habitat restoration. This section describes the hypotheses and corresponding metrics used to identify changes in freshwater processes linked to freshwater survival and production.

Culvert Replacement

One culvert (bridge) replacement is planned for Abernathy Creek on an abandoned section of Abernathy Road. This treatment is intended to improve fish passage into the upper watershed of Abernathy Creek. The culvert replacement project will be evaluated following the methods described in Protocol for Monitoring Effectiveness of Fish Passage Projects MC-1 (Crawford 2009). Relevant habitat and fish attributes (Table 5) will be measured prior to implementing the project and one year and five years after project completion. These measures will be compared to data from reference sites selected randomly from locations that are currently used in the EMAP surveys.

Culvert replacement should increase the quantity of habitat available for spawning and rearing. Improved fish passage will be important to Chinook salmon that spawn during low flow periods and to coho and steelhead salmon that use the upper most extents of the watershed for spawning (Table 6). Upstream distribution of coho and steelhead spawners may also increase the number of outmigrants through an increase in rearing habitat available to juveniles.

Table 5.—Project-specific monitoring for the culvert replacement activity will answer the following questions.

Question	Habitat Metric	Fish Metric
(1) Does base flow depth increase?	Change in mean depth	Fish presence

Table 6.—Watershed-level monitoring for culvert replacement 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	↑	↑	↑

IN-CHANNEL LARGE WOOD DEBRIS PLACEMENT

Large wood placements, including engineered log jams, are planned for twelve locations in Germany Creek and eleven locations in Abernathy Creek. These treatments are intended to slow stream velocity and sediment transport during high water events, increase the amount of in-channel rearing habitat, and improve cover during the rearing period. Large wood debris placement projects will be evaluated following the methods described in Protocol for Monitoring Effectiveness of In-stream Habitat Projects MC-2 (Crawford 2008b). Relevant habitat and fish attributes (Table 7) will be measured prior to implementing the project and one year and five years after project completion. These measures will be compared to data from reference sites selected randomly from locations that are currently used in the EMAP surveys.

The anticipated changes in habitat conditions are expected to improve fish survival at several life stages – incubation, summer parr, and overwinter parr (Table 8). Sediment retention by woody debris structures should decrease bed-load transport and improve survival during egg incubation. Pool and backwater formation resulting from wood debris placement should increase rearing habitat for the parr life history stage, especially coho parr that prefer slower waters of moderate depths (Beecher et al. 2002). Pool and backwater formation may also result in expression of the later-timed "parr" migrant life history strategy for Chinook salmon (Hayman et al. 1996). Delayed increase of in-stream flows during high water events should reduce the number of overwintering coho and steelhead parr that are involuntarily swept downstream or out of the system. Woody debris may also increase cover during summer low flow periods, providing a refuge for coho and steelhead parr by limiting interactions with larger fish or mammal predators.

Migration timing is of particular interest for Chinook salmon. Chinook outmigrants are predominantly sub yearlings; however, later migrants are larger and have reared for 3-4 months in the creeks prior to emigration. The relative abundance of these late-timed, larger migrants in the Lower Columbia IMW populations is low (Kinsel et al. 2009) and may be one population-level response expected if available rearing habitat were increased.

Table 7.—Project-specific monitoring for the large woody debris placement activities will answer the following questions.

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

Table 8.—Watershed monitoring for large wood debris placement 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 leading to increased incubation survival	Distribution of substrate types	Egg-to-parr survival	↑	↑	↑
(2) Increased pool formation increases quality of rearing habitat	Number and size of pools	Parr abundance	↑	↑	↔
		Parr condition	↑	↔	↔
(3) Wood debris slows localized stream flows and increases fish retention during high winter flow events.	None	Parr-to-smolt survival	↑	↔	↑
(4) Cumulative increase in juvenile outmigrants	None	Outmigrant abundance	↑	↔	↑
		Outmigrant condition	↑	↔	↑

OFF CHANNEL RESTORATION AND RECONNECTION

Off-channel and side-channel (hereafter off-channel) projects are planned at twelve locations in Germany Creek and nine locations in Abernathy Creek. These treatments are primarily intended to increase coho rearing habitat. The effectiveness of off-channel restoration and reconnection will be evaluated following the methods described in Protocol for Monitoring Effectiveness of Channel Connectivity, Off Channel Habitat, and Wetland Restoration Projects MC-6 (Crawford 2008a). Relevant habitat and fish attributes (Table 9) will be measured prior to implementing the project and one year and five years after project completion. These measures will be compared to data from reference sites selected randomly from locations that are currently used in the EMAP surveys.

The restoration and reconnection of off-channel habitats is expected to improve the quality of over-winter rearing habitat for juvenile salmonids, with the largest impacts to coho salmon (Table 10). In other systems, coho have been observed moving downstream and into off channel habitats during the late fall and winter months (e.g., Bradford and Irvine 2000). The winter and early spring months are associated with high stream flows, a phenomenon that reduces the optimal rearing habitat in the main stem channels (Cederholm et al. 1997), increases access to off-channel habitat, and affects overwinter survival of coho parr.

Table 9.—Project-specific monitoring for off-channel habitat restoration and reconnection will answer the following questions.

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

Table 10.—Watershed monitoring for off-channel restoration and reconnection 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	↑	↔	↔

NUTRIENT ENHANCEMENT

Nutrient enhancement is planned for 12 miles of Germany Creek beginning in fall 2010. Nutrient enhancement will involve distribution of up to 0.5 kg/m^2 of carcass analogs (based on the bank-full width). These plans exceed loading densities of previous analog enhancement studies (Pearsons et al. 2007; Shaff and Compton 2009) and natural carcass loading rates with a demonstrated effect on fish growth (Bilby et al. 1998; Wipfli et al. 2004). An analysis of 26 sites in western Washington demonstrated that parr consumption becomes saturated at a level of 0.15 kg of carcass/m^2 (Bilby et al. 2001). Analogs will be distributed in September and October. This timing was selected because it balanced mimicry of existing spawning cycles (i.e., Chinook and coho spawning) and effective monitoring windows (i.e., access during safe flows).

In the short-term, the effectiveness of carcass analog treatments will be evaluated by assessing their retention in the system, fish growth, and the uptake of the analog stable isotope signature into the stream food web (periphyton, macroinvertebrates, and juvenile fish, Table 11). Analog treatments are expected to increase growth and condition of juvenile fish. Because the ratios of carbon and nitrogen isotopes vary between marine derived sources (salmon carcasses) and freshwater derived sources (allocthonous inputs), the nitrogen and carbon isotope signature should differ if no uptake occurs, if juvenile fish are feeding directly on the analogs, and if juvenile fish are feeding on invertebrate production resulting from the nutrient addition (Vander Zanden and Rasmussen 1999). Sampling will occur at representative sites in the lower, middle, and upper reaches of the reference and treatment watersheds before and after analog placement. Because the timing of response is unknown, post-treatment sampling will occur multiple times beginning 4-6 weeks after the analog treatment. Periphyton will be collected from native rocks. Macroinvertebrates will be collected with a Surber sampler and composited by feeding guild. Fin clips will be non-lethally collected from coho salmon and steelhead. A minimum of 0.4 mg dry tissue is needed for stable isotope analysis, corresponding to approximately 4% of the caudal fin of a 65-mm fish (Sanderson et al. 2009).

In the long-term, productivity of the entire stream food web is expected to change in response to nutrient enhancement (Table 12). Fish responses will be measured as the number of outmigrants as well as survival in freshwater. Stream productivity will be measured as whole stream metabolism and food web uptake of added nutrients. Nutrient enhancement treatments are expected to increase survival from egg-to-parr or parr-to-smolt. The mechanism may be a direct response to consuming the analogs (Bilby et al. 1998; Mesa et al. 2007; Shaff and Compton 2009) or an indirect response to food web changes in primary production, macroinvertebrate production, and fish consumption (Bilby et al. 1996; Naiman et al. 2002; Walter et al. 2006). These mechanisms will be distinguished by examining how and when changes in isotopic signatures are detected at different levels of the food web.

Whole stream metabolism is expected to increase in response to nutrient enhancement. Whole stream metabolism will be measured (following Marzolf et al. 1994) in the 1 km stream reach above the existing Washington Department of Ecology stream gages (Mill Creek #25F060, Germany Creek #25D050). Hydrolab in situ sensors will be deployed at the upstream and downstream ends of the measured reach for at least a 36 hour period to measure dissolved oxygen concentration and the passing of the rhodamine plume. Rhodamine dye will be injected approximately 300m above the reach to allow for through mixing. The rhodamine will be used to estimate travel time. Simultaneously propane gas will be injected through a diffuser at the same site. After the passing of the rhodamine plume at the downstream sensor, water samples will be collected and analyzed for propane concentration. The difference in concentration will be used to estimate the re-aeration rate over the reach (Kilpatrick et al. 1989; Grace and Imberger 2006). Measurement will be made in the spring, summer, and fall in Germany Creek and Mill Creek (reference stream).

Table 11.—Project-specific monitoring of carcass analog nutrient enhancement .

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 $\delta^{15}N$ signal present in periphyton and invertebrates?	Is enriched $\delta^{15}N$ signal present in juvenile salmonids?

Table 12.—Watershed monitoring for 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. This table includes the proposed mechanism of change, the appropriate 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	↑	↔/↑ 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.			

Summary

The success of the IMW program will be based on the ability to determine whether and why fish populations respond to habitat restoration efforts. This result relies on BACI study design and on successful monitoring of key life stages and habitat hypothesized to respond to restoration actions. The program is designed to determine whether a fish response has occurred and then to use the combination of fish and habitat data to identify why or why not. This type of study is distinguished from less intensive fish abundance monitoring by providing an explanation for observed responses. For example, if no response is observed, we will be able to identify whether this occurred because a project did not result in more of the intended habitat complexity or whether the fish survival did not change even with the newly available habitat complexity. If a response is observed, we will be able to identify which aspects of the fish ecology or life history were improved by the restoration actions. Because the potential for ecological interactions may vary by the geomorphology of a watershed, understanding these mechanisms are important when extrapolating results from the Lower Columbia watersheds to restoration activities in other watersheds.

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