PACIFIC NORTHWEST AQUATIC MONITORING PARTNERSHIP

Key Findings and Lessons Learned from Pacific Northwest Intensively Monitored Watersheds

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Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

BA	Before-After study design
BACI	Before-After Control-Impact study design
BDA	Beaver dam analog
CHaMP	Columbia Habitat Monitoring Program
ELJ	Engineered log jam
GRTS	Generalized random tessellation stratified sample
IMW	Intensively Monitored Watershed
ISEMP	Integrated Status and Effectiveness Monitoring Program
km	Kilometer
LWD	Large woody debris
NOAA	National Oceanic and Atmospheric Administration
PNAMP	Pacific Northwest Aquatic Monitoring Partnership
rkm	River kilometer

Executive Summary

To help understand progress toward and limitations to achieving salmon recovery goals in the Pacific Northwest, Intensively Monitored Watersheds (IMWs) have been implemented in many river basins during the past two decades. IMWs are long-term, large-scale research projects designed to gauge the effectiveness of stream habitat restoration for salmon and other native fish. Habitat evaluation is often coupled with fish population status and trends monitoring within IMWs to generate information about the extent to which the habitat actions contribute toward fish benefits. Several IMWs have now reached or exceeded a 10-year benchmark of study and analysis, which creates a good opportunity to review and discuss the key results and priority focus of these projects into the future. This report summarizes key findings from 16 IMWs and addresses the underlying assumption that habitat restoration improves juvenile salmonid survival and eventually leads to increased adult returns.

Information summarized in this report was obtained using a questionnaire emailed to IMW scientists that allowed them to point to existing reports that contained the desired information, as well as the opportunity to provide new information not reported elsewhere. The amount and quality of information presented within this report was affected by the ability of IMWs to dedicate staff time to contribute supporting material, especially in cases where they are no longer under contract for such work. The questionnaire was sent to the 18 known IMWs in the Pacific Northwest; two IMWs, Alsea River, OR and Carnation Creek, BC, did not have staff available to respond to the questionnaire. The 16 IMWs that did respond were somewhat uneven in the amount of detail provided for inclusion in this report, this is most apparent in the IMW Synopses section.

In all IMWs, at least one anadromous salmonid is a focal species; however, in some IMWs, Bull Trout, Cutthroat Trout, and/or Pacific Lamprey are also focal species. When selecting the IMWs, the IMW implementation teams, made up of restoration and natural resource monitoring scientists, applied a limiting factors analysis. Limiting factors such as water temperature, stream flow, connectivity between tributaries and mainstem rivers, large wood, pool habitat, and riparian habitat were identified. Based on the limiting factors analysis, each IMW implementation team developed a restoration plan focused on short and long-term recovery goals for habitat and fish and identified active and/or passive restoration approaches to restore ecosystem function. Since watershed restoration is expensive and complicated, teams implemented projects in phases. Although funding for some IMWs is at or near completion at the time of writing, some level of restoration or monitoring is still ongoing for most. Only the Methow River and Tenmile Creek IMWs have completed all the restoration and monitoring called for in their respective restoration plans, although some data analysis and summary is ongoing in those watersheds.

Most of the IMWs reviewed for this report utilize a before-after-control-impact experimental design. Monitoring is conducted hierarchically, at the local, reach, and watershed scales, following what is called for in the restoration treatment and study plan. By collecting data at these scales, researchers can report on local results for specific life stages of fish and/or local habitat outcomes. This approach is useful in developing further understanding about how restoration impacts different life stages of salmon and other fish. Study design modification has been common and is often necessary to maximize efficiencies and to fully utilize the benefits of deploying an adaptive management approach to the operation of the IMWs.

Even though most IMWs are still in early phases of habitat restoration and monitoring, the majority of the IMWs demonstrate some level of positive fish response over this timeframe. Across the 16 IMWs included here, 12 report increases in juvenile salmonid metrics and 4 IMWs report significant increases in adult salmonid metrics (Executive Summary Table I). For IMWs that focus on enhancing existing habitat, juvenile salmonid metrics (survival, density, production, growth) were likely to exhibit positive responses in the timeframe under which they were measured. To date, adult returns have increased only in cases where dams or barriers were removed; however, this is to be expected given the post-treatment time period for most IMWs considered in this report is shorter than the generation cycles of the salmon and other fish they are designed to benefit. Habitat responses to restoration often take time, and biological responses to those changes take even longer. It is reasonable to expect that watershed restoration experiments, such as IMWs, are likely to take multiple salmonid generations for widespread positive population responses to occur. The authors of this report concur with Bennett et al. (2016) assertions that the degraded state of watersheds occurred over a period of more than a century, and the time frame necessary to make habitat improvements will, in some cases, take many decades to ultimately result in watershed and fish population scale detectable results. However, many short-term positive responses in both habitat and fish have been found. While further monitoring will be necessary to fully gauge fish population responses to restoration actions, most IMWs report positive short-term responses that suggest more significant successes will build from those already measured.

Executive Summary Table I. Metrics of fish response to restoration to date for individual IMWs. This table represents a simplification of fish response and is intended to convey generalities; readers should consult the individual IMW synopses for details. In the table '↑' indicates increases to date, '↓ ' indicates decreases to date, '↔' indicates no change to date, 'NEY' indicates not evaluated yet, and blank cells indicates not reported. For metrics marked NEY, the results are in some cases forthcoming but in others are contingent on additional funding. Increases and decreases do not necessarily represent statistically significant differences.

Metric / IMW	Adult returns	Adult marine survival	Redd numbers	Juvenile density	Juvenile survival	Juvenile growth	Juvenile production	Juvenile residence time	Life history diversity
Asotin	NEY		NEY	↑	NEY	↓	NEY	NEY	NEY
Bridge				↑	↑		↑		
Elwha	↑		↑						↑
Entiat				↔	↑	↓			
Hood Canal							↑		
Keogh		↓					↓		
Lemhi							↑		
Lower Columbia						↑			
Methow				↑	↑	↑	NEY	NEY	
Middle Fork John Day			↑	↔	↔	↔	↔		
Potlach				↑					
Pudding									
Skagit	NEY	↔	NEY	↑	NEY	NEY	↑	↑	↔
Strait of Juan de Fuca	↑	↑	↔	↑	↑	↑	↑		↑
Tenmile	NEY	NEY	NEY	↔	↑	NEY	↑	NEY	NEY
Wind	↑			↑			↑		

IMW implementation teams must coordinate with multiple and sometimes numerous partners. Large-scale restoration projects in dynamic watersheds are a complex undertaking and many of the methods and techniques for habitat restoration and monitoring are being developed and tested as a key component of IMW implementation. The many and at times differing approaches and techniques used in restoration makes a sophisticated study design a necessity. The ability to build effective and clear lines of communication between multiple parties and create robust data management systems and processes are critical for success in IMWs. Regular communication between IMW implementation team members is also necessary to ensure that implementation of both restoration and monitoring is proceeding as planned and any necessary adjustments are made on a timely basis. Overwhelmingly, practitioners identify the need for broad and regular communication between team members and between different IMW teams.

In addition to identifying the importance of communication, the 16 IMWs included in this summary reported lessons learned related to most aspects of an IMW: experimental design, restoration design and implementation, monitoring design and implementation, data management and analysis, communication and collaboration, adaptive management, and funding. Because individual IMWs often face a unique set of challenges it is not surprising that the lessons learned reported are often specific to an IMW; however, there were some commonalities. One frequently reported lesson learned was the importance of adequate deliberation and documentation of the time and geographic scale over which restoration must occur to ultimately result in both habitat and fish measures of success. Another lesson learned reported by multiple IMWs was the importance of identifying and addressing the highest priority limiting factor(s). If the primary limiting factor wasn't effectively addressed, treatments targeting other limiting factors were insufficient to elicit fish response. Many of the IMW teams identified consistent database management, funding for database management, and coordination of data to be challenging but critically important. IMWs are long-term efforts that require a significant time series of information to perform adequate evaluations of restoration benefits, and therefore data must be managed in a way to survive succession within staff and support statistical analyses well into the future. By reflecting on lessons learned and incorporating an adaptive management framework, IMWs have better aligned restoration and monitoring priorities resulting in more efficient and productive restoration programs.

Introduction

The loss of Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss* is a significant ecological, economic, and societal issue facing the Pacific Northwest region of North America. Multiple factors including habitat loss, hatchery supplementation, hydropower, and overfishing have been identified as contributing to the decline or extirpation of these fish. The listing of many salmon and steelhead populations under the Endangered Species Act (ESA) has resulted in approximately two decades of focused restoration efforts at the cost of several billion dollars (Bernhardt et al. 2005).

The primary focus of salmon habitat restoration efforts has been to increase juvenile rearing habitat, though in some cases adult spawning habitat has been the focus. Restoration efforts are guided by the premise that increases in spawning and rearing habitat will improve juvenile life stage survival, ultimately increasing adult fish returns (National Marine Fisheries Service 2014). However, linking habitat restoration to increased adult recruitment at the population level has been difficult (Roni et al. 2008). Further, effectiveness monitoring, the ability to monitor and detect a response from a restoration action, is not always funded or not funded at appropriate temporal and spatial scales to allow measurement of response. Therefore, monitoring and restoration practitioners often rely on incomplete or anecdotal evidence to infer responses in habitat and fish populations. Additional challenges to identifying successful population level responses (i.e., positive response to restoration) include experimental design, implementation, and analysis and monitoring issues (Roni et al. 2008; Bennett et al. 2016). In response to these challenges, Intensively Monitored Watersheds (IMWs) have been implemented in many regions of the Pacific Northwest as long-term case studies to monitor, track, and report on the trajectory of habitat actions and fish population responses (Figure 1).

Over time, as IMWs were individually implemented across the Pacific Northwest, it became apparent that a more coordinated approach would be beneficial. In 2005, the Pacific Northwest Aquatic Monitoring Partnership (PNAMP) began supporting a forum for regional IMW coordination. By hosting workshops and teleconferences, and developing reports, PNAMP provides an informal structure for IMW practitioners, researchers, and other stakeholders to communicate and learn from each other regarding implementing restoration and effectiveness monitoring. With upcoming policy decisions about IMWs on the horizon, PNAMP was enlisted to improve access to information generated by IMWs, including the development of this report. To gather information for this report, PNAMP distributed a questionnaire (Appendix 1) to IMW scientists that allowed them to point to existing reports that contained the desired information, as well as the opportunity to provide new information not reported elsewhere. The amount and quality of information presented within this report was affected by the ability of IMWs to dedicate staff time to contribute supporting material, especially in cases where they are no longer under contract for such work. The questionnaire was sent to the 18 known IMWs in the Pacific Northwest; two IMWs, Alsea River, OR and Carnation Creek, BC, did not have staff available to respond to the questionnaire. The 16 IMWs that did respond were somewhat uneven in the amount of detail provided for inclusion in this report, this is most apparent in the IMW Synopses section.

IMWs are designed to address key questions in a disciplined scientific manner. The overarching questions of interest for IMWs are:

- *"Does the collective effect of restoration and/or management actions result in improved watershed condition and fish population response? Why or why not?*
- *What are the causes of those responses?"*

Bennett et al. (2016) summarized the scope and status of IMWs used to test the effectiveness of salmon and steelhead habitat restoration. Namely, is there a relation between habitat restoration and fish production. They found that IMWs are the most reliable method to measure population-level fish responses and to assess the efficacy of watershed scale habitat restoration efforts. However, they also reported challenges in implementing and maintaining IMWs, particularly: 1) lack of coordination between researchers, restoration teams, and funders, and 2) inconsistent funding over the course of the IMW for sufficient restoration treatments, long-term monitoring, and data evaluation and publication.

This report summarizes additional findings since the publication of that manuscript, emphasizes that expectations for IMW results must keep in mind that habitat and fish responses to restoration may take several decades, and highlights valuable lessons learned in the implementation of IMWs. Some of the tables presented here will have similar information and formatting to those used by Bennett et al. (2016). In this report, we provide a synthesis for 16 IMWs in British Columbia, California, Idaho, Oregon, and Washington (Table 1). We identify common themes and elements of IMWs and provide short synopses of these elements including background, planning and development, design and methods, response, and lessons learned. Our goal is to compile this information to help natural resource managers and IMW implementation teams gain access to more data and information generated from IMWs and summarize the successes and challenges of restoring Pacific salmon habitat in one document.

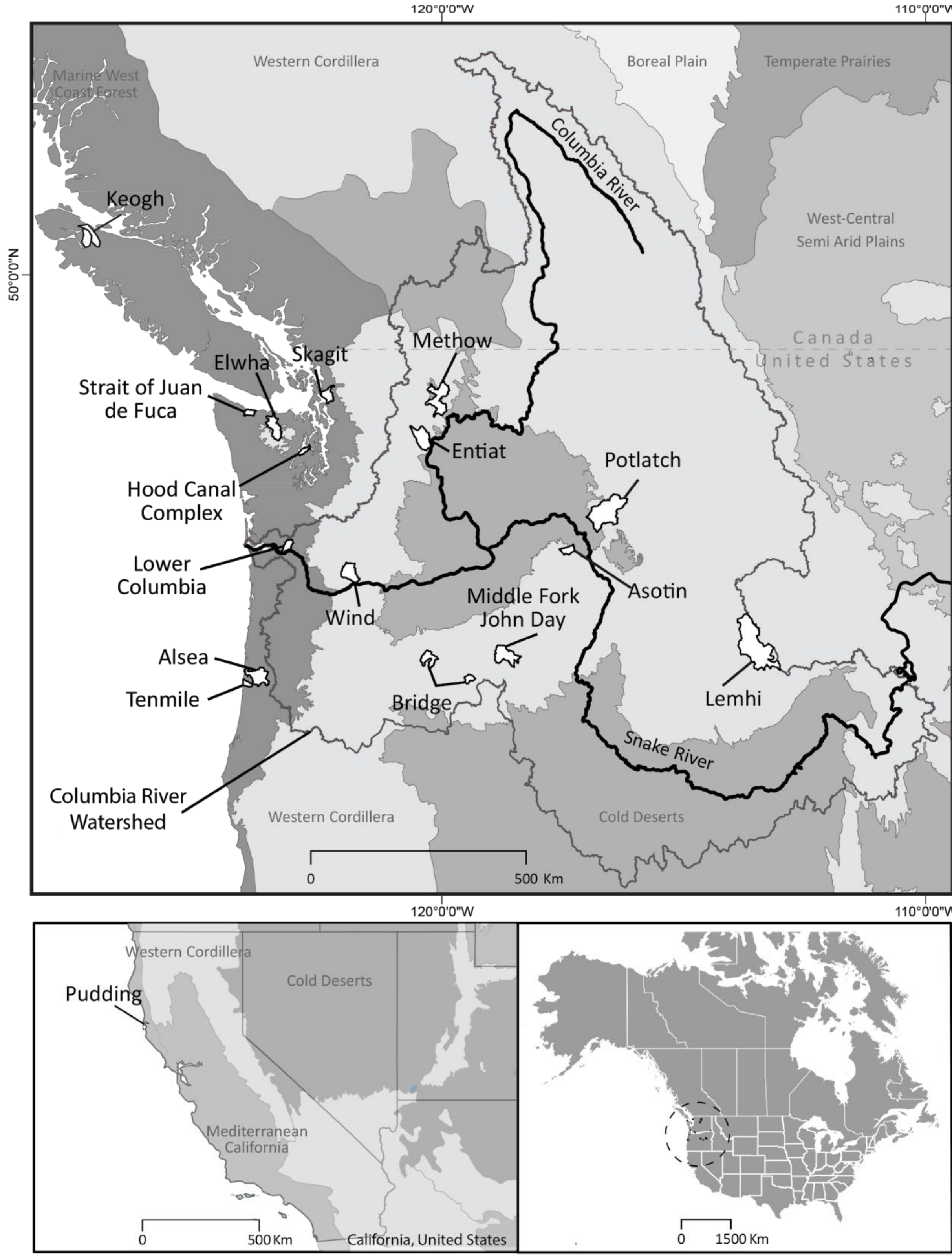

Figure 1. Locations of intensively monitored watersheds across the Pacific Northwest. Reproduced with permission from Bennett et al. 2016.

Table 1. List of names, years, locations, treatments, and fish species monitored for intensively monitored watersheds (IMWs). Adapted from Bennett et al. (2016).

IMW	Monitoring Years	Restoration Year(s)	State or Prov	Basin/ Watersheds	Focal Species	Treatment	Physical Results to Date	Biological Results to Date	Status
Asotin	2008-present	2012-2016	WA	Lower Snake/ Charley, North and South Fork Asotin Creeks	steelhead	LWD	Significant increases in pools, bars, and LWD density	Significant increases in juvenile steelhead density (3.7 - 48%). Survival, growth, and production is being evaluated.	Treatments complete in 2016. Monitoring ongoing through 2024
Bridge	2007-2017	2010	OR	John Day/ Bridge and Murder's Creeks	steelhead	Beaver dams, riparian improvement	Increases in beaver dams, moderation of high water temperature	Increases in juvenile steelhead density (168%), survival (52%), and production (175%)	Phase I treatment and monitoring completed in 2014, Phase II restoration in 2016 with post-treatment monitoring through 2020
Elwha	2000-present	2011-2015	WA	Puget Sound/ Elwha River	Bull Trout, Cutthroat Trout, Chinook, steelhead, Pacific Lamprey	Barrier removal, ELJ	300% increase in available habitat length. Movement of in river sediments and subsequent increase in delta size	Recolonization of many habitats by all anadromous life stages, resumption of anadromous life history (Bull Trout). Changes to the food web for juvenile salmonids	Third year of post-treatment monitoring underway
Entiat	2003-present	2012-present	WA	Upper Columbia/ Entiat River	Chinook, steelhead	ELJ, LWD, boulders, floodplain reconnection	No change in habitat metrics but LWD has increased	Increase in juvenile steelhead survival, decrease in growth, no change in density	Treatments occurred in 2012, 2014 and proposed for 2019

IMW	Monitoring Years	Restoration Year(s)	State or Prov	Basin/ Watersheds	Focal Species	Treatment	Physical Results to Date	Biological Results to Date	Status
Hood Canal	2003-present	2007-present	WA	Puget Sound/ Big Beef, Little Anderson, Seabeck, and Stavis Creeks	Coho, steelhead	LWD, barrier removal, floodplain reconnection	Significant interannual variation in several metrics but generally not attributable to LWD placement	In Little Anderson, a significant increase in Coho smolt abundance after 2002 culvert replacement and non-significant increase in Coho smolt abundance after LWD placement	Posttreatment monitoring ongoing; additional restoration projects proposed but currently unfunded
Keogh	1976-present	1976-present	BC	Keogh River, Waukwaas River	Coho, steelhead	Road abandonment, boulders, LWD, nutrient addition, hatchery augmentation, flow augmentation	Treatment and monitoring are ongoing for current flow augmentation experiment	Treatment and monitoring are ongoing for current flow augmentation experiment	Treatments scheduled to end in 2018 but monitoring will continue
Lemhi	2007	2009-present	ID	Upper Salmon/ Lemhi River, Hayden Creek	Chinook, steelhead, Bull Trout	Barrier removal, flow augmentation, LWD, floodplain reconnection	22% increase in wetted stream area, 19% increase in pool habitat	Increase in juvenile Chinook salmon productivity, Spawning steelhead and rearing Chinook Salmon juveniles present, increase in the distribution of Bull Trout	Treatment and monitoring ongoing

IMW	Monitoring Years	Restoration Year(s)	State or Prov	Basin/ Watersheds	Focal Species	Treatment	Physical Results to Date	Biological Results to Date	Status
Lower Columbia	2001-present	2010-present	WA	Lower Columbia/ Mill, Abernathy, and German Creeks	Coho, Chinook, steelhead	Nutrient enhancement, floodplain reconnection, LWD, barrier removal		Immediate nutrient uptake by invertebrates and fish that did not translate into a population-level fish response	Habitat treatments ongoing. Posttreatment monitoring ongoing
Methow	2009-2018	2012-2014	WA	Upper Columbia/ Methow River	Chinook, steelhead, Bull Trout	ELJ, barrier removal, screens, LWD, floodplain reconnection, riparian improvement	Yet to be determined	Increase in juvenile growth rate and density	Three years of post-treatment monitoring completed. USBR Completion report in Spring 2019
Middle Fork John Day	2004-present	2008	OR	John Day/ Middle Fork John Day River	Chinook, steelhead	Floodplain reconnection, riparian improvement, LWD, barrier removal	Vegetation	High water temperature is limiting fish response	Treatments and post-treatment monitoring ongoing
Potlatch	2005-present	2009-present	ID	Clearwater/ Potlach River	steelhead	Barrier removal, flow augmentation, LWD, riparian improvement	Increased pool density/ wetted habitat and decreased water temps in treatment reaches; increased pool density and canopy cover in treatment tributaries	Expanded spawning distribution; seasonal use of wood structures at LWD projects; trends in increased emigrant age composition and growth	Treatments and monitoring ongoing
Pudding	2006-present	2015	CA	Northern California Coast/ Pudding and Caspar Creeks	Coho, steelhead	LWD	None	Too early to evaluate but higher returns in 2016-2017	Two years of post-treatment data. Monitoring expected thru 2020

IMW	Monitoring Years	Restoration Year(s)	State or Prov	Basin/ Watersheds	Focal Species	Treatment	Physical Results to Date	Biological Results to Date	Status
Skagit Estuary	1992-present	2001-present	WA	Puget Sound/ Skagit River	Chinook	Restoration of tidal wetland inundation, reconnection of tidal channels	Over 600 acres restored, gaining habitat despite erosion losses	Juvenile residence time increased and estuary-wide densities decreased. Size and densities increased locally at restoration sites.	Treatments and post-treatment monitoring ongoing
Strait of Juan de Fuca	1992-present	1996-present	WA	Puget Sound/ Deep Creek, East Twin, and West Twin Rivers	Coho, steelhead, Cutthroat Trout	LWD, barrier removal, road abandonment, riparian improvement	None detected	Small increases in Coho and steelhead adults	Treatments complete except for lower Deep Creek scheduled for 2018. Posttreatment monitoring ongoing
Tenmile	1991-present	1996	OR	Northern Oregon Coast/ Tenmile and Cummins Creeks	Coho, steelhead, Cutthroat Trout	LWD, road abandonment, barrier removal, riparian improvement	Increases in LWD, pool and side channel habitat	Increase in freshwater survival of juvenile Coho and steelhead, increases in juvenile steelhead and Cutthroat Trout	Intensive fish and habitat monitoring through 2001, juvenile out-migrant trapping continues in treatment watershed.
Wind	2000-present	2009	WA	Lower Columbia/ Wind River, Trout and Panther Creeks	steelhead	Barrier removal, ELJ, LWD	None reported	Large increases in adult steelhead, smaller increases in parr and smolts	Post treatment monitoring through 2020

IMW Synopses

Asotin Creek

A short summary of the key elements and results to date for the Asotin Creek IMW are provided in Table 2.

Table 2. Elements and results to date for the Asotin Creek Intensively Monitored Watershed.

Study Tributaries	Charley, North Fork Asotin, and South Fork Asotin Creeks
Years Monitored	Pre-treatment monitoring: 2008-2012 Treatment: 2012-2014, 2016 Post-treatment monitoring: 2012-2024
Focal Species	Snake River summer steelhead (note this is functionally a wild population; hatchery fish are removed at mouth and no supplementation); also designated as a wild steelhead refuge by WDFW
Limiting factors	Lack of pool habitat and cover for fish, lack of spawning habitat, lack of floodplain connectivity with limited refugia during high flows, and reduced large woody debris (LWD).
Restoration Plan	Staircase design with LWD treatments in 2012 (South Fork), 2013 (Charley Creek), 2014 (North Fork), and 2016 (South Fork).
Monitoring Experimental Design	Each creek has one treatment and two control reaches each of which is 4 km long.
Treatment	High density LWD placement (majority of the wood is placed by hand to minimize the disturbance to recovering riparian; cost of implementation order of magnitude lower than heavy machinery)
Magnitude of Treatment	39% of study area, 654 structures (4.7 structures/100 m stream length)
Pre-treatment Data	Stream temperature, discharge, geomorphic diversity, erosion rate, deposition rate, substrate composition, percent pool habitat, and net rate of energy intake
Results to Date	Juvenile density increased by 27% across the three study streams (range 3.7 - 48% in individual streams). Significant increases in the number of pools, bars, and LWD density and increases in juvenile capacity as measured by NREI at some sites.

Background

Asotin Creek is a tributary of the Snake River in southeast Washington. The Asotin Creek watershed is dominated by deep, narrow canyons cut into underlying basalt lithology and surrounded by semi-arid sagebrush steppe and grasslands at lower elevations and open conifer-dominated forests at higher elevations (Omernik 1995). The Asotin watershed is approximately 842 km^2 and the average annual precipitation ranges from 115 cm at higher elevations in the Blue Mountains to less than 30 cm at lower elevations (240 m) along the Snake River. Three study creeks make up the Asotin Creek IMW study area: Charley Creek, North Fork Asotin Creek, and South Fork Asotin Creek.

Beginning in the late 1800's, extensive grazing in the watershed caused terraced hillslopes and high rates of erosion. After World War I, grazing declined while logging and agriculture became the predominant forms of land use. The combined effects of agriculture, forest harvesting, and grazing have contributed to the degradation of stream habitat, especially in the lower stream reaches (Soil Conservation Service 1984). Currently, the primary limiting factors for salmonid production in Asotin Creek are lack of pool habitat and cover for juvenile fish, poor bar development (spawning habitat), lack of floodplain connectivity with limited refugia during high flows, and reduced large woody debris (LWD). Although many of the threats have been removed, degradation persists due to a lack of LWD.

Planning and development

The Asotin Creek IMW was initiated in 2008 and chosen because there was extensive fish and habitat data dating back to the 1980’s, ongoing WDFW monitoring, minimal hatchery influence, moderate seeding levels of steelhead, and public support. The goals of restoration for this IMW are to test the effectiveness of treatments in increasing steelhead productivity (juveniles per spawner) and production (biomass) in Asotin Creek, and to determine the mechanisms leading to increased productivity/production at multiple spatial and temporal scales through intensive monitoring.

Design and methods

The IMW team used a staircase design after a simulation revealed that it would be more powerful than a before-after-control-impact (BACI) design to detect response under high variance assumptions. For the design, each creek had a single treatment and two control reaches. The study consisted of three tributaries in the mid to upper part of the Asotin Creek Watershed: Charley Creek, North Fork Asotin Creek, and South Fork Asotin Creek. The first 12 km of each stream was divided into three 4-km long sections. One of the sections was designated for treatment in each of the three creeks and was restored from 2012-2014. In 2016, the team treated an additional section of the South Fork Asotin Creek, resulting in two treatments and one control section in that tributary.

Results to date

Preliminary results indicated statistically significant increases in overall juvenile steelhead density in treatment compared to control areas. Juvenile steelhead density increased in the treatment compared to the control sections in all three tributaries following restoration. Practitioners report decreases in juvenile growth, and are currently assessing seasonal survival rates, and productivity/production in treatment versus control sites (PNAMP IMW Questionnaire 2017). The IMW team observed some density dependent effects on growth, but there were no density dependent effects on density. The high efficiency of the Asotin Creek monitoring infrastructure of PIT tag arrays, smolt traps and adult weirs allows relatively robust enumeration of smolts and adults (e.g., PIT tag arrays have 70-90% efficiency, smolt trap ~20% efficiency, adult weir ~ 90% efficiency). As such, productivity results have been calculated for 2008-2014 and as age data become available for PIT tagged juveniles, and migrating smolts and adult returns are enumerated, productivity will be established for 2015-2024 monitoring years. Researchers continue to monitor the study areas as treatments were completed in 2016. They report increases in the number of pools and bars, the level of sinuosity, the amount of floodplain connection, and the amount of geomorphic complexity. The IMW team also documented a 30-50% increase in habitat capacity. The IMW team continues to refine indices of geomorphic change, net rate of energy intake, and habitat suitability to better describe the effectiveness of LWD treatments.

Lessons learned

Staircase designs as employed by the Asotin Creek IMW are powerful alternatives to BACI designs because they can account for treatment * year interactions, are more logistically feasible to implement, and allow for multiple streams to be treated (i.e., more stream types). Staircase designs also make implementation more logistically feasible because treatments are spread out over several years. Hand placement of high density LWD can be a viable, cost-effective action that promotes immediate habitat change over large areas without damaging riparian areas. Monitoring fish year-round provides the ability to assess seasonal survival and fish movement that can help confirm assumptions of independence. Data management is a major challenge for IMWs and more resources are needed to help teams manage large volumes of data. Large Woody Debris treatments could be modified to install structures in higher density to promote greater habitat change and buffer against high flows. The speed of treatment could increase by using, or building from, existing features where possible (e.g., old side-channels, tree roots, boulders). The IMW team indicated that resources might be better allocated toward treating larger sections of streams as opposed to over-designing a smaller number of LWD structures. Restoration will be more effective when we understand both the short-term (1-5 years) and long term (5-10 years) fish and habitat responses. Waterways were degraded over a 200-year period and we might expect recovery to occur over a similar time scale.

Bridge Creek

A short summary of the key elements and results to date for the Bridge Creek IMW are provided in Table 3.

Table 3. Elements and results to date for the Bridge Creek Intensively Monitored Watershed.

Study Tributaries	Bridge Creek, Tributary of the Lower John Day River Bear and Gable creeks, Tributaries of Bridge Creek Murderers Creek, Tributary of the South Fork John Day River
Years Monitored	Pre-treatment monitoring: 2007-2009 Treatment: 2010 Post-treatment monitoring: 2010-2017
Focal Species	Middle Columbia steelhead
Limiting factors	Highly incised channel form, low habitat complexity, high stream power, floodplain and groundwater disconnection, high water temperatures
Restoration Plan	Construct beaver dam analogs and then measure response at 4 treatments and 7 control reaches in Bridge Creek, 2 tributary references in Bear and Gable Creeks, and 3 watershed reference reaches in Murder's Creek
Monitoring Experimental Design	Spatially Hierarchical Staircase BACI. Intervention analysis. Treatment and reference reaches were randomly selected. Selection of streams and watersheds was based on existing infrastructure
Treatment	121 beaver dams constructed on the mainstem of Bridge Creek. However, increases in beaver population resulted in treatment like effects in some control reaches.
Magnitude of Treatment	4 km - about 30 % of degraded habitat
Pre-treatment Data	Approximately 3 years of juvenile survival, juvenile growth, juvenile density. Adult returns, water temperature, groundwater elevation, channel aggradation rate, and riparian vegetation extent.
Results to Date	Floodplain reconnection, sediment trapped, increased channel complexity, groundwater connectivity moderates temperature extremes. Increases in juvenile survival, productivity, and density.

Background

The Bridge Creek IMW was conducted on the lower 32 km of Bridge Creek, a tributary to the lower John Day River. The John Day River flows out of the Blue Mountains in north-central Oregon and empties into the Columbia River at river kilometer (rkm) 353. The John Day River is 457 km long and the third longest free-flowing river in the contiguous United States. Steelhead in the John Day River are listed as threatened under the ESA.

Historical records indicate that this semi-arid region of the Columbia Basin contained numerous small channels with riparian forests. These stream channels were small, deep, and meandering across the landscape. These streams and the once numerous beaver *Castor canadensis* dams within them created abundant off-channel habitat with good flow and cool temperatures for much of the year. Due to cattle grazing and agricultural practices, many of these channels are incised, riparian vegetation has diminished, and beaver dams are nearly absent. This has resulted in streams with ephemeral flows and high water temperatures (Pollock et al. 2007).

In this experiment, beaver dam analogs (BDAs) were placed in randomly selected river reaches within Bridge Creek and reference reaches in Bear and Gable creeks. Additionally, a watershed reference reach was selected in Murderers Creek, a tributary to the South Fork of the John Day River. The IMW team hypothesized that placement of BDAs would alter the thermal, hydrologic, geomorphic, and riparian vegetation characteristics of the watershed. These changes would in turn, benefit listed salmonids by creating more suitable steelhead habitat (Bouwes et al. 2016).

Planning and development

This project developed hypotheses at three nested spatial scales: 1) the site-specific treatment, 2) the entire reach where a treatment or treatments occur, and 3) the watershed scale where multiple reaches in Bridge Creek were treated (Pollock et al. 2012). Five variants of BDA treatments were employed varying from new construction to reinforcement of abandoned beaver dams.

Design and methods

The Bridge Creek IMW used a spatially hierarchical BACI design that allowed for contrasts at the stream reach and watershed scales, having treatment, tributary, and a single watershed reference. Selection of the 4 treatments and 7 control reaches was random, while the selection of stream and watershed references were based on existing monitoring infrastructure. Pre-treatment monitoring occurred from 2007-2009. Treatment occurred in 2010, followed by post- treatment monitoring that has been ongoing for seven years.

Juvenile steelhead growth, survival, and density data were collected. The IMW team also measured adult returns. Physical habitat variables measured included stream temperature, groundwater elevation, channel aggradation rate, and riparian vegetation extent.

Results to date

The IMW resulted in statistically significant increases in juvenile steelhead survival (52%), productivity (175%), and density (168%) initially (Bouwes et al. 2016). Data from 2016 indicate reduced juvenile steelhead densities (ISEMP/CHaMP 2017), but the overall response to restoration is still positive. Beaver dams may buffer against high water temperatures during summer by storing greater amounts of surface water and through greater surface and groundwater connectivity (Weber et al. 2017). This experiment used fish production as a broad metric of response to restoration. Here, fish production is the product of density, growth, and survival. Increases in beaver dams and BDA's did not affect upstream spawner migration. However, there have not been significant increases in adult returns yet.

Lessons learned

This project demonstrated how use of BDAs can influence habitat at broad spatial scales and that beavers can positively influence previously degraded salmon habitat (PNAMP IMW Questionnaire 2017).

Elwha River

A short summary of the key elements and results to date for the Elwha River IMW are provided in Table 4.

Table 4. Elements and results to date for the Elwha River Intensively Monitored Watershed.

Study Tributaries	The Elwha and the Quinault Rivers
Years Monitored	Pre-treatment monitoring: 2000-2010 Treatment: 2011-2015 Post-treatment monitoring: 2014-present
Focal Species	Chinook, Coho, Pink, Chum, and Sockeye salmon, steelhead, Bull Trout, Cutthroat Trout, and Pacific Lamprey
Limiting factors	Lack of habitat connectivity (two dams over 30 m and 61 m in height that previously blocked about 90% of the anadromous salmonid habitat in the Elwha Watershed and prohibited significant sediment accretion in the delta)
Restoration Plan	Complete removal of two dams, natural colonization of fish along with limited hatchery planting
Monitoring Experimental Design	BA or BACI depending on metric
Treatment	Complete removal of two dams, LWD placement
Magnitude	About 128 km of salmon habitat opened
Pre-treatment Data	Multiple metrics of fish, habitat, food web, and water quality
Results to Date	Sediment accretion created new habitat and altered the lower river from pool-riffle to a more braided morphology, adults and juveniles quickly colonized newly created habitats above dam removal sites increasing overall returns, Bull Trout resumed anadromous life history, returning adult Chinook salmon and steelhead numbers were below recovery goals but were greater than before the dams were removed.

Background

The Elwha River is an 833 km^2 watershed on the Olympic Peninsula. It flows northward 72 km from the glaciers and snowfields of Olympic National Park and empties into the Strait of Juan de Fuca near Port Angeles, Washington. Elwha Dam (rkm 8), constructed in 1911, and Glines Canyon Dam (rkm 21), constructed in 1927, blocked anadromous fish passage to more than 110 km of salmon habitat in the Elwha River Watershed. The Elwha is one of the few rivers in the Pacific Northwest that harbors all five species of Pacific Salmon. Prior to dam construction, anadromous fish runs were estimated at nearly 400,000. However, after construction only 4,000 returned to the 8 km of river below Elwha Dam. Millions of cubic yards of sediment were also trapped behind the dams, altering the Elwha River Estuary and the near shore ocean environment near the mouth of the Elwha River.

Planning and development

In 1992 Congress enacted the Elwha River Ecosystem and Fisheries Restoration Act. Subsequently, the National Park Service acquired the Elwha and Glines Canyon dams. In 2012 the Elwha Dam was removed and in 2015 the Glines Canyon Dam was removed. The IMW used portions of the Elwha and the Quinault rivers as reference sites. The Elwha River monitoring and adaptive management plan employed the use of hatchery planting and natural recolonization to populate the reopened habitat (Peters et al. 2014). Fish recovery goals were annual returns of 10,000 naturally produced Chinook Salmon and 2,700 naturally produced steelhead. In addition to dam removal, forty constructed log jams were also placed in the Elwha River below rkm 8.

Design and methods

The IMW team measured fish, physical habitat, food web, and water quality metrics. Fish metrics included anadromous fish density, productivity, distribution and diversity. Adult fish were enumerated using SONAR and their spatial distribution was determined with redd surveys. Snorkel surveys and electrofishing were used to enumerate parr. Screw traps were used to enumerate out-migrating smolts. Physical habitat variables measured included percent fines, residual pool depth, proportion of functioning side channels, braiding, and sinuosity. Pebble counts and bulk sediment samples were used to enumerate particle size distribution for the streambed. Large Woody Debris was tagged to gain an understanding of wood inputs and outputs at the watershed scale. Habitat surveys enumerated the amount and quality of off-channel habitats. Aerial photos and remote sensing were used to enumerate the erosion and deposition of sediments throughout the entire watershed. Food web variables measured were benthic invertebrate density, diversity, composition, functional feeding groups, and proportion of aquatic and terrestrial invertebrates in juvenile salmonid diets. Drift and benthic kick net surveys were also conducted. Water quality variables collected included turbidity, suspended sediment, and water chemistry. The control reaches were portions of the Elwha and Quinault rivers (PNAMP IMW Questionnaire 2017).

Results to date

Dam removal resulted in rapid geomorphic changes such as changes in stream channel morphology and development of a riverine/estuarine delta (Foley et al. 2017). Sediment flushed downstream after dam removal and increased the area of the river delta to over 150 ha. The new delta was immediately colonized by ESA-listed juvenile salmonids, Eulachon *Thaleichthys pacificus*, but also non-native American Shad *Alosa sapidissima* (Shaffer et al. 2017). Due to aggradation of sediment previously stored behind the dams, the lower river shifted to finer grained sediments and a 50% increase in the channel braiding index (East et al. 2015). Initially, deposition of sediment altered the benthic community and reduced it by over 90%, resulting in changes to the food web and the diet of juvenile salmonids which transitioned from aquatic dominated to terrestrial dominated food. However, benthic invertebrate densities now are increasing in the lower Elwha. The reestablishment of marine derived nutrients from anadromy allowed riverine birds to migrate smaller distances, become more year-around residents, and exhibit increased clutch sizes. Fish recolonization occurred immediately after dams were removed and resulted in immediate (first generation) changes to life history trajectories in Bull Trout *Salvelinus confluentus*, which resumed an anadromous life history (Quinn et al. 2017). Juvenile salmonids expanded use of habitats beyond adult spawning areas. Current numbers of returning adult Chinook Salmon (3,000 - 4,000 hatchery and wild combined) and steelhead (500 - 1,500 hatchery and wild combined) are below recovery goals for a viable population in the Elwha but are greater than before the dams were removed.

Lessons learned

The IMW team noted the importance of understanding how to quantify the difference between the "signals" (i.e., treatment effects) and the "noise" (i.e., the natural variability). They encourage the use of multiple fields of expertise, multiple ecosystem metrics, multiple tools for response, multiple life stages of fish, and multiple years of biological pre-treatment data. Further, consistent database management, funding for database management, and coordination of data between fields is critical because it reduces the amount of time spent at the back end when analysis is paramount. The IMW team recommends that results are summarized annually so that synthesis can occur after 3 to 5 years and the project can be adaptively managed. They also recommend that a project champion or overseer is identified in order for things to link together and become finalized. Lastly, the IMW team identifies the importance of communicating between partners, colleagues, and collaborators "till it hurts" (PNAMP IMW Questionnaire 2017).

Entiat River

A short summary of the key elements and results to date for the Entiat River IMW are provided in Table 5.

Table 5. Elements and results to date for the Entiat River Intensively Monitored Watershed.

Study Tributaries	The Entiat River Watershed
Years Monitored	Pre-treatment monitoring: 2003- Treatment: 2012, 2014, and proposed for 2019 Post-treatment monitoring: 2012-2017
Focal Species	Chinook Salmon, steelhead
Limiting factors	Low habitat complexity
Restoration Plan	Hierarchical staircase design. Mad River used as a steelhead reference, the Chiwawa, White, and Little Wenatchee used as Chinook references
Monitoring Experimental Design	BACI and LCM for habitat and fish metrics
Treatment	LWD and boulder placement, floodplain connectivity, levy breaching, off-channel habitat creation
Magnitude	Lower 43 km of the Entiat River
Pre-treatment Data	
Results to Date	Improvement in juvenile steelhead survival, decrease in growth rate, and no change in density. No change in the habitat metrics, except the amount of LWD has increased.

Background

The Entiat River is in north central Washington, draining from the east slope of the Cascade Mountains. It enters the Columbia River upstream of Rocky Reach Dam at rkm 777 near the town of Entiat, Washington. The primary tributary of the Entiat is the Mad River. The Entiat and the Mad rivers both have numerous minor tributaries with little additional anadromous habitat. Together these rivers drain a watershed of about 1,237 km^2. The watershed has been prone to wildfire, flooding, and subsequent debris movement. Land use has included channel modification, timber harvesting, agriculture, grazing, splash damming, and hydropower generation. Land use activities have resulted in simplified channels that have reduced the productivity of salmonids within the watershed. Spring Chinook Salmon, steelhead, and Bull Trout found in the Entiat are all listed under the ESA.

Planning and development

In 2010, the Integrated Status and Effectiveness Monitoring Program (ISEMP) and collaborators designated the lower 43 km of the mainstem Entiat River and lower five km of the Mad River as an Intensively Monitored Watershed (IMW). Because these portions of the Entiat River subbasin encompass the majority of anadromous habitat in the subbasin and contain distinct geomorphic sections that are easily broken into different spatial scales, it was well suited for a watershed-scale experiment. ISEMP worked with collaborators to map out how habitat restoration projects could be sited and implemented over a 9-year period and developed a robust monitoring framework to evaluate project effectiveness and facilitate measurement of habitat and fish response at multiple scales.

Project sponsors implemented actions in 2012 and 2014; however, additional actions planned for 2017 were delayed due to changes in land ownership and funding. It is anticipated that restoration efforts will resume in 2018-19 through alternative funding sources, however the associated intensive monitoring programs have been indefinitely postponed following CHaMP/ISEMP IMW habitat monitoring in 2016, and ISEMP fish population monitoring in 2017. Limited fish population monitoring is planned to continue through a smolt trap and spawner escapement studies in 2018.

Design and methods

The Entiat IMW relied on a hybrid hierarchical staircase design to deal with logistical complexities of a watershed scale experiment. Treatments were intended to be implemented over time and space to facilitate evaluation of both year-to-year and year-treatment interactions and determine the mechanisms by which changes to physical habitat improve freshwater productivity, at multiple scales. Control sites varied by fish species, with a complex network of internal and external controls including (external) the Chiwawa, White, and Little Wenatchee Rivers, and (internal) the Mad River and Geomorphic Valley Segment 2 of the Entiat River (PNAMP IMW Questionnaire 2017).

Results to date

Although treatments are ongoing, the IMW team indicates that steelhead exhibited increased survival, decreased growth rate, and no change in density. In contrast, Chinook Salmon exhibited no change in density or survival but a decrease in growth rate. With respect to physical responses, there has been an increase in LWD from restoration measures; however, the absence of larger flood pulses since restoration has done little to modify the existing channel. There has been no increase in the frequency of pools (PNAMP IMW Questionnaire 2017).

Lessons learned

Given the long timeframe of the IMW experiment, critical need for community support, and large number of collaborators, there was an ongoing danger of “IMW fatigue”. Obtaining and competing for funding was challenging (PNAMP IMW Questionnaire 2017). The interplay of politics, logistics, funding, and environment made it impossible to roll out restoration actions on the intended schedule, adding tremendous challenges and complexity to the effectiveness analysis framework. A long-term stall in actions ultimately led to the dismantling of the original experimental design, and indefinite postponement of further monitoring studies.

Hood Canal

A short summary of the key elements and results to date for the Hood Canal IMW are provided in Table 6.

Table 6. Elements and results to date for the Hood Canal Intensively Monitored Watershed.

Study Tributaries	Little Anderson, Seabeck, Big Beef and Stavis Creeks
Years Monitored	Pre-treatment monitoring: 1992-2007[1] Treatment: 2007- ongoing Post-treatment monitoring: 2003 – present
Focal Species	Coho Salmon are the focus, as their abundance is estimated at three distinct life stages. Cutthroat Trout, Chum Salmon, and steelhead are also present in some watershed and/or at some life stages
Limiting factors	Reduced number and complexity of river channels, increased stream power and erosion
Restoration Plan	Remove barriers and constraints to flows of water, sediment, and fish, and restore stream roughness elements (LWD) and processes that will lead to future wood recruitment (riparian restoration and protection).
Monitoring Experimental Design	Multiple BACI. Spatially balanced design. Approximately 20 habitat sites per watershed. Fish data from 10 parr monitoring sites plus spawner surveys throughout known spawning distribution plus smolt traps in each of four watersheds
Treatment	LWD placement, floodplain reconnection, and barrier removal
Magnitude	In Little Anderson Creek, 3.7 km were treated with 495 pieces of LWD in three phases, and a barrier culvert was removed. In Big Beef Creek, 7.5 km were treated with 213 pieces of LWD in three phases, and a dike was removed, reconnecting 4.5 hectares of floodplain wetland habitat. In Seabeck Creek, three culverts were replaced, though two of these were primarily road infrastructure projects. More restoration has been proposed in Little Anderson and Seabeck creeks but is currently unfunded.
Pre-treatment Data	Comprehensive fish and habitat data collection began in 2003
Results to Date	Statistically significant Coho smolt abundance increase in Little Anderson Creek following culvert replacement and non-significant increase in Coho smolt abundance following LWD placement

[1] Smolt abundance is the only fish metric available prior to 2003.

Background

The Hood Canal Complex IMW consists of three treatment watersheds - Little Anderson, Big Beef, and Seabeck creeks. A fourth, Stavis Creek, is used as a reference watershed. All the creeks flow north and enter Hood Canal near Seabeck, Washington. Hood Canal flows into Puget Sound in western Washington State. The watersheds in the IMW are low elevation and flow is primarily dominated by rainfall, which is about 105 cm/year.

Watersheds within the IMW generally suffer from a legacy of industrial logging (beginning in the 1870's) and rural development. This has resulted in a dramatic imbalance in sediment dynamics, with some reaches (frequently but not always those upstream of undersized culverts) serving as severe deposition zones and other reaches deeply incised. Simple single thread, plane-bed channel forms with uniform depth profiles are common throughout the study watersheds. In especially acute deposition zones, stream flow often goes subsurface during the summer, resulting in a series of isolated pools. The study site is generally representative of small streams recovering from intense logging that are currently subject to rural residential human development, a common landscape in western Washington.

Planning and development

The overarching habitat goals of restoration were to: 'First, restore patterns of connectivity for water, sediment, wood, and fish', and 'Subsequently, enhance stream complexity' (Anderson et al. 2015). The planned treatments were barrier removal, floodplain reconnection, and placement of LWD.

Design and methods

The project employs a BACI study design and uses a life cycle monitoring approach to estimate the number of Coho salmon adults, parr, and smolts in all four creeks. However, if the assumption of correlation between treatment and reference was violated, a before and after (BA) approach would then be used. A spatially balanced design was used where approximately 20 habitat sites, 10 Coho salmon parr monitoring sites, spawner surveys, and smolt traps were sampled in each of the four watersheds. A power analysis revealed that monitoring would be able to detect a 30-50% change in Coho Salmon *O. kisutch* smolt production after 12 years with larger responses detectable sooner (Anderson et al. 2015).

The IMW collected both physical habitat and salmon variables. Salmon variables were redd counts, watershed-scale parr abundance via mark-recapture, and watershed-scale smolt abundance. Fish sampling also collects data for egg to parr survival, parr to smolt survival, and size/growth. Additionally, a channel spanning weir in one watershed, Big Beef Creek, provides a precise estimate of total adult abundance, marine survival, and harvest rate, using coded wire tags applied to wild Coho salmon smolts. Intensive physical habitat surveys provide a variety of potential metrics; the variables of initial focus have been width/depth ratio, percent spawning gravel, LWD frequency, and pool frequency.

Results to date

At this point relatively few restoration actions have been completed with sufficient post-treatment time to evaluate the fish and habitat response. The exception is Little Anderson Creek, where a relatively large increase in smolt abundance was detected after a culvert at the creek mouth was replaced. A recent pulse of restoration activity in Big Beef Creek (2015 – 2017: LWD placement, floodplain reconnection) and Little Anderson Creek (2017: LWD placement) offers additional opportunity to evaluate restoration effectiveness in the coming years. Several more, relatively high magnitude projects have been proposed in Little Anderson and Seabeck creeks but are currently unfunded.

Keogh River

A short summary of the key elements and results to date for the Keogh River IMW are provided in Table 7.

Table 7. Elements and results to date for the Keogh River Intensively Monitored Watershed five-year flow augmentation experiment.

Study Tributaries	Keogh and Waukwaas Rivers
Years Monitored	Pre- treatment monitoring: 2011-2013 Treatment: 2014-2018 Post-treatment monitoring: 2014-2018
Focal Species	Winter run steelhead and Coho Salmon. Pink Salmon, Chum Salmon, Cutthroat Trout, and Dolly Varden Trout are also present
Limiting factors	Low summer base flows, high water temperatures
Restoration Plan	Evaluate for 3 years prior to a 5-year flow augmentation experiment
Monitoring Experimental Design	BA with complete enumeration
Treatment	Flow Augmentation over a 5-year period
Magnitude	Vancouver Island, British Columbia
Pre-treatment Data	Three years of stream discharge, water temperature, habitat characteristics, rearing habitat quality, juvenile density, and smolt production data
Results to Date	steelhead smolt production considerably below 1976-1998

Background

The Keogh River population dynamics project has been in operation since 1976. The Keogh River is the longest data series on the Pacific coast that collects accurate trends in abundance and separation of freshwater and marine influences on fish survival and returns of salmonids. Operating over the last 42 years, the large fish fence near the river mouth of the river has provided accurate census of the adult steelhead abundance, as well as full counting of all seaward migrant smolts (steelhead, Coho, Dolly Varden, cutthroat).

Salmonid enumeration studies on the Keogh River have provided trends in fish abundance, information on the effects of environmental change, and information on the functional relationships of factors affecting salmonid life history. Research projects involving enumeration of migrant salmonids have included documentation of recurring patterns of timing and size of salmonid smolts, evaluation of factors affecting their survival in freshwater and the ocean, age at return, oceanic distribution, and description of steelhead egg-to-smolt population dynamics, towards understanding of the steelhead stock-recruitment relationship.

The Keogh River is a third order coastal stream that flows into Queen Charlotte Strait near Port Hardy, British Columbia on the north end of Vancouver Island. It drains an area of 129 km^2 and has a mean discharge of 5.6 m^3/s. Like other watersheds in southern British Columbia, the Keogh is subject to low flow/high water temperature periods during late summer, the severity of which are expected to increase with climate change. During late summer, the quantity and quality of habitat diminishes for juvenile steelhead which rear in the stream prior to migrating seaward. The maintenance of minimum flows during late summer has been used to maintain or enhance fish production. In the Georgia Basin, which includes the Keogh River, steelhead numbers are critically low in many watersheds.

Planning and development

The Keogh River is an active research site to better understand variables that affect winter run steelhead production and life history characteristics. Over the project's duration (which is still ongoing), more than 100 publications have been produced. Currently, a study to evaluate the effects of summer flow augmentation to increase fish production is being investigated. Previously, road abandonment, LWD and boulder placement, and nutrient additions occurred in the Keogh. Previous work estimated density-dependence in the spawner-smolt recruitment relationship in the Keogh and therefore, the effects of flow augmentation can be separated from density-dependent effects. The Keogh has existing infrastructure to store and release water, to monitor temperatures, and to count steelhead juveniles and adults. A before-after experimental design was used to evaluate flow augmentation relative to smolt production and the habitat of fry and smolts. Specifically, the plan was to measure stream discharge, water temperature, habitat characteristics, quality of rearing habitat, juvenile density, and smolt production for three years prior to a five-year period of flow augmentation (British Columbia Conservation Foundation 2014). In December 2015 and June 2016, a resistivity fish counter was used to estimate spawner density in addition to mark-recapture methods. The fish counter was also used to enumerate out-migrant smolts (Harding 2016). The specific IMW objectives were: 1) to study the effects of water releases on steelhead smolt production, adjusted for spawner density, under reference and treatment (flow augmentation) effects using a BA experimental design, and 2), measure and characterize flow, water temperature, juvenile steelhead habitat quality and quantity under summer low flow conditions, measure the density and size of juvenile steelhead, and relate summer rearing habitat to steelhead smolt production (British Columbia Conservation Foundation 2014).

Design and methods

The Keogh River is an active research site and research activities are coordinated with academic partners. In addition to the work above, studies that investigate the impacts of pink salmon abundance, temperature, and flow on winter run steelhead abundance and life history are currently underway.

The Keogh River IMW is currently implementing a planned 5-year flow augmentation project to increase juvenile steelhead summer rearing capacity and smolt production. Pre-treatment data was collected in 2011-2013. Flow augmentation will occur from 2014-2018. After this project is complete, enumeration of steelhead and other salmonids will continue, however, finer spatial information on juvenile steelhead distribution that was collected during the flow augmentation project will cease.

These data calculated probability of habitat use based on depth, velocity, species, and age class. steelhead and Coho Salmon juveniles were counted near the river mouth to measure smolt production. Scales were also taken from a subset of juveniles to determine the age distribution of smolts. Adult escapement was measured during the winter and spring. There is no control watershed used or planned and therefore the project is using a BA approach to evaluate flow augmentation.

Results to date

Treatment is still ongoing and post augmentation monitoring has not yet begun. Pretreatment data suggest that smolt production has declined from what it was in the 1980's. steelhead smolts per female dropped in the three years leading up to flow augmentation from 79.8 in 2011 to 27.1 in 2012, to 24.3 in 2013. steelhead spawner density increased from 2010-2015, but decreased in 2016. Annual smolt production ranged from 2,450 to 3,800 from 2011-2013. In 2016 (n=2,019), it was about half of the average number from 1977-2015. However, during 2015-2016, Coho Salmon smolt density was 91,582- higher than the 1997-2014 average of 67,449. Marine survival has changed over time. In 2013 it was 4.9%, while in 2012 it was 6.0%. From 2009-2013, the average marine survival was 5.6%, while in 2002 and 2005, it was 1.8% and 2.3%, respectively (Harding 2016).

Lessons learned

Earlier work done by the IMW concluded that stocking steelhead is not an effective strategy for recovery of wild steelhead populations in the Keogh River (PNAMP IMW Questionnaire 2017).

Lemhi River

A short summary of the key elements and results to date for the Lemhi River IMW are provided in Table 8.

Table 8. Elements and results to date for the Lemhi River Intensively Monitored Watershed.

Study Tributaries	The Lemhi River Watershed- Big Timber, Bohannon, Canyon, Hawley, Kenney, and Little Springs Creeks. Hayden Creek is a reference
Years Monitored	Pre-treatment monitoring: 2007-2008 Treatment: 2009 - present Post-treatment monitoring: 2011-present
Focal Species	Snake River steelhead, Chinook Salmon, and Bull Trout
Limiting factors	Lack of habitat connectivity, reduced spawning and rearing habitat, reduced flows in the Lemhi River mainstem, thermal constraints, low habitat complexity
Restoration Plan	Increase mainstem flow, reconnect tributary spawning and rearing habitat, reconnect floodplain and side channel habitat, LWD placement.
Monitoring Experimental Design	BA and BACI designs. Juvenile density estimates at the sub-basin, tributary, and reach scales. Juvenile distribution and survival.
Treatment	Barrier removal, flow augmentation, LWD, floodplain reconnection
Magnitude	36 km of spawning and rearing habitat reconnected
Pre-treatment Data	Productivity comparison: 5 years pre-treatment, tributary standing stock: up to 8 years depending on tributary
Results to Date	22% increase in wetted stream area, 19% increase in pool habitat. Increase in juvenile Chinook Salmon productivity. Rearing Chinook Salmon juveniles and spawning steelhead present in re-connected reaches. Re-establish fluvial Bull Trout life history following reconnection.

Background

The Lemhi River is a major tributary to the Salmon River in east-central Idaho. It is a low-gradient, 4^{th} order system with a drainage basin of about 3,290 km^2. It originates near Leadore, Idaho, and flows in a northwesterly direction for 90 km until it enters the Salmon River near Salmon, Idaho. Spring creeks and ground-water inputs influence the hydrology of the Lemhi River as does input from snowmelt dominated tributaries. The Lemhi River historically had many beaver dam complexes and an extensive riparian area consisting of willows and cottonwoods. The Lemhi River basin was historically one of the most important spawning areas for migratory salmonids in the upper Salmon River basin. Three ESA-listed salmonids, Chinook Salmon, steelhead, and Bull Trout, are the focal species of restoration.

Currently, loss of connectivity prevents anadromous and resident/fluvial salmonids from accessing historically important spawning and rearing habitat in the tributaries. Chinook Salmon production is currently limited to the upper mainstem Lemhi River and Hayden Creek. Juvenile salmonids rearing in the Lemhi River are unable to seek thermal refuge in the tributaries when mainstem temperatures increase or use additional rearing habitats year-round as densities in natal reaches increase. Irrigation has also reduced the high-volume flows necessary for maintaining the complexity of stream channels, removing fine sediments, and providing loose gravels for spawning. Diversion dams, barriers, loss of habitat from agricultural and highway development, and loss of riparian vegetation further impact the production of salmonids in the Lemhi Basin.

Planning and development

The Lemhi IMW priority was to reconnect tributaries to the mainstem Lemhi River by implementing flow agreements and removing barriers. Treatments in the mainstem Lemhi River included channel re-meandering, floodplain reconnection, side channel construction, and LWD placement. The IMW team measured the distributions of adult Chinook Salmon, steelhead, and resident/fluvial salmonids in the Lemhi River, Hayden Creek, and candidate tributaries for reconnection, 2) estimated the productivity of Chinook Salmon and steelhead, and 3) estimated parr standing stock and emigrant abundance. The quantitative measures established for successful restoration were a 7% increase in freshwater productivity of Chinook Salmon and a 3% increase in productivity of steelhead (Uthe et al. 2017).

Design and methods

The objectives of the study were to: 1) develop a watershed model that evaluates productivity and carrying capacity by life-cycle stage as a function of habitat availability and quality, and then simulate expected life-stage specific benefits from increased habitat availability or quality, 2) empirically measure reach-specific juvenile productivity, survival, and condition to determine whether tributary reconnection provided benefits to fish, and 3), use movement and distribution data to identify if anadromous and resident fish are utilizing newly available habitat (Uthe et al. 2017).

Researchers used a spatially nested sampling framework structured to the basin, tributary, and reach scales beginning in 2007 (Uthe et al. 2017). This structure allowed the IMW team to examine the results of various treatments and their effects and examine life stage-specific outcomes on juvenile and adult salmonids (i.e., growth and survival). Hayden Creek was used as a reference for comparison with treatment reaches of the mainstem Lemhi River upstream and downstream of Hayden Creek. Since 2009, 36 km of spawning and rearing habitat from three tributaries has been reconnected to the mainstem Lemhi River. A minimum flow agreement was established to provide sufficient water in the lower Lemhi River for fish passage during the summer. Water conservation measures have been implemented to increase rearing habitat in selected reaches and tributaries.

Results to date

Restoration actions had measurable effects on fish and habitat. Overall, restoration resulted in a 22% increase in wetted stream area and a 19% increase in pool habitat compared to pre-treatment conditions (ISEMP and CHaMP 2017b). The IMW team reports an increase in juvenile Chinook Salmon productivity (PNAMP IMW Questionnaire 2017). Juvenile Chinook Salmon were documented in treatment tributaries (with one exception) for the first time since the mid- to early 2000's. Juveniles were found in streams following barrier removal projects. When juvenile Chinook Salmon had access to summer rearing areas in priority tributaries in the upper Lemhi River, more age-1 smolts were produced per redd compared to before restoration. Juvenile Chinook Salmon expanded their distribution upstream within reconnected tributaries. Adult steelhead began using reconnected tributaries as spawning habitat and increased the upstream extent of spawning after barrier removal. Bull Trout were moving between habitats in reconnected tributaries suggesting an increase in their life history expression with increased access to stream habitat (Uthe et al. 2017).

Lessons learned

A critical component of the Lemhi River IMW was successful communication between monitoring and restoration personnel and between research collaborators within the monitoring program. This was extremely important from an adaptive management standpoint because restoration and sampling plans were altered based on monitoring results. The majority of habitat actions were implemented on private land, therefore, restoration practitioners and monitoring staff needed to account for the additional timeline necessary to gain support and trust from landowners. The Lemhi River IMW has the largest drainage area of all the IMWs. Therefore, more time is needed to implement enough projects to elicit a watershed-scale response compared to IMWs in smaller watersheds (PNAMP IMW Questionnaire 2017).

Lower Columbia

A short summary of the key elements and results to date for the Lower Columbia IMW are provided in Table 9.

Table 9. Elements and results to date for the Lower Columbia Intensively Monitored Watershed.

Study Tributaries	Abernathy, Germany, and Mill Creeks, direct tributaries of the Lower Columbia River
Years Monitored	Pre- treatment monitoring: 2001-2012 Nutrient enhancement treatment: 2011-2015 Nutrient enhancement monitoring: 2011-2015 Habitat treatments: 2012-2020 Post-treatment monitoring: 2021-2033
Focal Species	Coho Salmon, Chinook Salmon, and steelhead
Limiting factors	Channel stability, habitat diversity, habitat quality, sediment load, water temperature, and flow
Restoration Plan	1. Nutrient enhancement in the form of salmon carcass analogs in fall (Germany Creek) and spring (Abernathy Creek) 2. Increase connectivity of off-channel and instream habitats 3. Increase complexity of the instream habitat 4. Improve fish passage in select tributaries
Monitoring Experimental Design	BACI
Treatment	Nutrient enhancement (addition of salmon carcass analogs), LWD placement, floodplain reconnection, barrier removal
Magnitude	2.4 km of stream length, 0.14 km^2 of riparian habitat, and 3 nutrient treatments in Germany Creek. 8.0 km of stream length, 0.04 km^2 of riparian habitat, and 3 nutrient treatments in Abernathy Creek.
Pre-treatment Data	Fish – estimated annually as parr (e.g., densities, body size, abundance), outmigrants (e.g., abundance, body size, migration timing), and spawners (e.g., abundance, spawn timing, body size and age) Habitat – measured annually in index reaches selected using spatially balanced design. Water quality/quantity – measured on daily basis near mouth of each creek (e.g., flow, temperature, turbidity, etc.)
Results to Date	Nutrient enhancement – immediate nutrient uptake response from invertebrates and fish (not periphyton). Increased growth of juvenile Coho salmon in response to spring but not fall treatment. This was not sustained over time and did not result in a population-level response of outmigrants the next year. Habitat treatments - TBD

Background

The lower Columbia River IMW 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 due to their relatively small watershed size and the availability of baseline smolt data. The drainage area of the watersheds ranges from 59 km^2 to 75 km^2. Run-off in the creeks is dominated by rain with peak winter flows between November and March and low summer flows in August and September. Snow accumulation in the headwaters results in rain-on-snow freshets that are of substantial magnitude in some years. Present habitat conditions are influenced by the legacy of past timber harvest practices. The primary limiting factors in the Lower Columbia IMW are channel stability, habitat diversity, habitat quality, sediment load, water temperature, and flow.

Planning and development

Two types of restoration activities have been or are being implemented in Abernathy and Germany creeks. A watershed-scale nutrient enhancement project was completed in Germany Creek (fall treatment) in 2013 and Abernathy Creek (spring treatment) in 2015. Reach-scale physical habitat projects have been implemented and more are planned. Mill Creek is a reference watershed.

Design and methods

The Lower Columbia IMW study tests the general hypothesis that increasing the complexity and connectivity of the stream network will cause an increase in the freshwater productivity (i.e., smolt output) of salmon and steelhead. In Germany Creek, 2.4 km of stream length and 0.14 km^2 of riparian habitat were treated and there were fall nutrient treatments in three successive years. In Abernathy Creek, 8.0 km of stream length and 0.04 km^2 of riparian habitat were treated and there were spring nutrient treatments in three successive years (PNAMP IMW Questionnaire 2017).

Results to date

Key findings associated with the floodplain reconnection, instream wood, and fish passage treatments are awaiting the completion of planned restoration treatments. There was an immediate ecosystem response to the salmon carcass analog treatment in that analogs were taken up by invertebrates and fish, but not periphyton. An immediate growth response for juvenile Coho Salmon was observed in the spring but not the fall treatment. The growth response was not sustained through the Coho Salmon smolt outmigration. There was no effect of the nutrient treatments on the number or size of outmigrating Coho Salmon smolts (PNAMP IMW Questionnaire 2017).

Lessons learned

Recent analysis by the Lower Columbia IMW team focused on analysis and interpretation of the habitat data. The pretreatment data has shown that commonly-used habitat metrics are highly variable among locations in a given year and among years across streams and that the among-year variability follows similar patterns among the three streams. The overall effect of inter-annual variability on habitat metrics was that detecting a response at any single restoration project has been difficult for the two projects that currently have post-treatment monitoring. Over time, watershed-wide variability may mask the changes seen at specific restoration sites. Correlation in habitat metrics among the three streams is the basis of the BACI design. The correlations in watershed conditions should improve the proponent's ability to detect watershed level responses in fish populations. (PNAMP IMW Questionnaire 2017).

Methow River

A short summary of the key elements and results to date for the Methow River IMW are provided in Table 10.

Table 10. Elements and results to date for the Methow River Intensively Monitored Watershed.

Study Tributaries	Methow River (rkm 66-80) and Beaver Creek, a tributary of the Methow River
Years Monitored	Pre-treatment monitoring: 2009-2012 Treatment: 2012-2014 Post-treatment monitoring: 2015-2018
Focal Species	Upper Columbia Spring Chinook and Upper Columbia steelhead. Bull Trout are also present
Limiting factors	Habitat fragmentation, reduced flows, nonnative species, riparian condition, sedimentation, increased mortality from mechanical injury
Restoration Plan	Protect and restore access, flow, and habitat complexity for UCR Spring Chinook Salmon and steelhead
Monitoring Experimental Design	BACI
Treatment	*Methow River*: 1 instream flow project, 3 fish screens, 4 fish passage structures, 19 stream and floodplain enhancements, 4 riparian rehabilitation projects, and 50 land acquisitions and easements *Beaver Creek*: 4 instream flow projects, 1 fish screen, 8 fish passage projects, 4 stream and floodplain enhancements, 2 riparian rehabilitation projects, and 2 land acquisitions
Magnitude	Treatment occurred in approximately 8% of the Methow River and 22% of Beaver Creek
Pre-treatment Data	Five years of habitat, fish, and prey data
Results to Date	Higher densities and growth of juveniles in side channels

Background

The Methow River flows south and east out of the Cascade Mountains in North Central Washington joining the Columbia River at rkm 843. The Methow River Watershed, which also includes the Twisp and Chewuch rivers, has ESA-listed populations of Upper Columbia Spring Chinook Salmon and Upper Columbia River Summer steelhead. The Methow also has anadromous populations of summer Chinook Salmon, Coho Salmon, and Pacific Lamprey *Entosphenus tridentatus*, and resident salmonids including Mountain Whitefish *Prosopium williamsoni*, Westslope Cutthroat Trout *O. clarkii*, Bull Trout, and nonnative Brook Trout *S. fontinalis* (Benjamin and Bellmore 2016). Anadromous fish runs in the Methow River have been depressed owing to dams, water diversions, overfishing, nonnative species, and habitat degradation (Bellmore et al. 2013).

Planning and development

The project goals were to restore access, instream flow, and habitat complexity for spring Chinook Salmon and steelhead. The primary purpose of the Methow River IMW was to measure the response of ESA-listed anadromous fishes to restoration by the US Bureau of Reclamation occurring from 2012-2014 (Connolly 2009).

Design and methods

The IMW team used a BACI approach. Three times a year, dependent variables were sampled. These variables consisted of physical habitat attributes, fish metrics, and food web indicators. Habitat variables included channel dimensions and water temperature. Fish density was estimated from electrofishing and snorkeling. Food web variables included benthic invertebrates, terrestrial invertebrates, and gut contents of juvenile salmonids. Gut contents were gathered during the handling of PIT-tagged fish.

Results to date

Side channels contained higher densities of rearing steelhead and Chinook Salmon compared to mainstem habitat and provided refuge from piscivores. A side-channel site at Whitefish Island had significant increases in juvenile salmonids. Increasing hydrologic connectivity between off channel habitat and the mainstem increased use by target species, particularly for seasonally disconnected side channels where fish previously had only a limited time to access the habitat. Juvenile salmonids exhibited high growth but low survival in disconnected side channels. Food web analysis in the middle Methow showed that the structure of food webs, including species compositions and the types and strengths of predator-prey interactions, varied among habitat patches, presumably influenced by the type of habitat (e.g. mainstem versus side channel) and the degree of hydrologic connectivity. In the middle Methow mainstem and side channel sites, the available prey base can support a greater density of rearing juvenile salmonids than was present at those sites, suggesting that the carrying capacity for juvenile rearing had not been reached (PNAMP IMW Questionnaire 2017).

Lessons learned

Detecting ecological response is difficult: restoration actions occur over a wide range of locations, intensities, sizes, and time frames, so the variation in treatments was high and makes it challenging to develop robust study designs or to make suitable comparisons. Fish may move in and out of the watershed throughout the study period, while the number of juveniles and their timing of entry into the study area is also dependent on variable environmental conditions (e.g. streamflow, water temperature, sediment load), which will affect how many juveniles encounter and utilize locations of habitat enhancement in any given year. In addition, large areas of the watershed need to be improved to detect fish responses. Roni et al. (2008) reported that more than 20% of a watershed would need to be improved to measure a *population/watershed scale* response to enhancement. Some actions such as riparian revegetation improvements and the many conservation easements are difficult to assess benefits to habitat. The measurement of halting of "continued degradation" from human-caused impacts such as livestock grazing and land development is especially challenging to evaluate. Riparian vegetative changes are occurring and mostly documented via photopoints at this time.

Fish Passage

The IMW team found that recolonization following barrier removal occurred slowly and was strongly influenced by out-of-basin factors (Weigel et al. 2013). Some immediate benefits occurred with adult steelhead moving the following year to spawn, but density and population-scale changes are difficult to distinguish. The population increase from barrier removal in Beaver Creek depended on factors limiting fish production before treatment, and how well passage improvements addressed those limiting factors. Limiting factors of the target population should be determined before performing barrier removal to scale expectations of recolonization rates, and to pair the barrier removal with habitat enhancement or other actions as appropriate (PNAMP IMW Questionnaire 2017). In this case, some passage above barriers was occurring prior to treatments, resident O. mykiss are present above barriers and high-water events re-created some passage issues, clouding the evaluations.

Floodplain and side channel habitat enhancement

Strategies that provide high side channel habitat diversity, such as a combination of perennial flow through, alcove, seasonally connected channels with annual floodplain access, complex cover and pool habitat are expected to be the most effective at increasing production of multiple target species and improving resilience over time. Diverse habitat patches within the floodplain landscape are valuable because they host very different local food webs that are used extensively by juvenile Chinook Salmon and steelhead. Side channel enhancement projects that have sufficiently provided deep pools with large wood have been shown to improve habitat suitability and carrying capacity of the habitat, especially for side channels that are seasonally disconnected. Side channel enhancement projects that maximize hyporheic and groundwater connectivity are likely to have high benefits. Hyporheic upwelling moderates surface water temperatures and can increase fish production. Placing side channels in areas likely to receive upwelling, such as the inside of a meander bend, or constructing groundwater collection galleries, have both been used successfully to increase groundwater connectivity (PNAMP IMW Questionnaire 2017).

Channel complexity

Studies in the mainstem and side-channels of the Methow River showed target fish densities are positively associated with deep pools with large wood and overhead cover. Channel reconstruction and large wood enhancement in a small stream can increase spawning densities, total fish production, and the degree of consumption of invertebrate food resources. Enhancement may also decrease the relative consumption of food resources by non-target species such as Brook Trout. Large wood configured to promote local scour and bed movement has been shown to increase benthic invertebrate food available to drift-feeding ESA-listed juvenile salmonids (PNAMP IMW Questionnaire 2017).

Food web interactions

The analysis showed that when you scale up to the larger channel/floodplain system, high spatial complexity produces weak trophic interactions, which promotes biodiversity and stability of food webs that are important for sustaining fish populations (PNAMP IMW Questionnaire 2017).

Aquatic Trophic Model (ATP)

The development of the ATP model by U.S. Geological Survey for the Methow River demonstrates the ability to use select habitat variables to describe stream and trophic conditions for salmonids and what changes can be predicted as these variables change (Benjamin and Bellmore 2016). The web-based version of the ATP model can be found at : https://exchange.iseesystems.com/public/ryan-bellmore/atp/index.html#page1

Middle Fork John Day River

A short summary of the key elements and results to date for the Middle Fork John Day River IMW are provided in Table 11.

Table 11. Elements and results to date for the Middle Fork John Day River Intensively Monitored Watershed.

Study Tributaries	Middle Fork of the John Day River, Camp and Murderers Creeks
Years Monitored	Pre- treatment monitoring: 2004-2017 Treatment: 2008-2017 Post-treatment monitoring: ongoing
Focal Species	Chinook Salmon, Summer steelhead
Limiting factors	Water temperature, degraded floodplain, altered hydrology, channel structure, sediment routing
Restoration Plan	Implemented over 100 restoration projects since 2008
Monitoring Experimental Design	BA, BACI, GRTS
Treatment	Channel restoration, floodplain reconnection, riparian fencing, LWD placement, log weir removal
Magnitude	Expanded habitat by 48 river km, 4.8 km of channel realignment, revegetated over 2 km^2
Pre-treatment Data	Four plus years of salmonid abundance and productivity
Results to Date	No response detected in juvenile fish metrics at the watershed scale, increase in adult steelhead abundance

Background

The Middle Fork John Day River is a tributary of the John Day River located in Northeastern Oregon. It originates in the Blue Mountains of the Malheur National Forest and flows west for 121 km and joins the North Fork John Day River about 29 km north of the town of Monument, Oregon. The Middle Fork John Day River drains 2,087 km^2 with elevations ranging from 671 m near the mouth to 2,500 m in the headwaters. The watershed receives about 50 cm of precipitation each year. The hydrograph has shifted from historic times, with peak flows greater than in the past and late season flows more diminished, likely due to reduced rates of soil infiltration, reduced capacity for ground water/riparian storage, and diminished in-channel storage in beaver ponds. Further it is believed that the hydrologic regime changes are due to increasing air temperatures and its impact on snowfall and snowmelt. The focal species of the IMW are Mid-Columbia Summer steelhead (ESA-threatened) and Spring Chinook Salmon, neither of which is influenced by in-basin hatchery introductions. Bull Trout and Pacific Lamprey are also present.

Planning and development

The goals of the Middle Fork John Day River IMW were to: 1) evaluate the overall benefit of restoration actions to summer steelhead and spring Chinook Salmon in the upper part of the river and

2) understand how specific restoration actions impact instream habitat, temperature, and salmonid metrics at the watershed, tributary, and reach scales. The team implemented approximately one hundred projects including fish passage, channel reconfiguration, instream habitat improvement, flow increases, upland management, and riparian fencing and planting.

Design and methods

The objectives were to evaluate the effectiveness of the combined restoration actions on anadromous salmonid populations and to understand how specific types of actions impact habitat and fish performance metrics at multiple spatial scales. Researchers used a nested hierarchical framework. The framework included a whole watershed-scale evaluation of restoration actions and a nested experiment within the larger framework that targeted specific actions ranging from the watershed to individual project scale.

The priority of the IMW was increasing productivity of steelhead and Chinook Salmon populations. The team compared the number of smolts/adult spawner in the Middle Fork to the South Fork John Day River for steelhead, and the North Fork John Day River and Upper Mainstem John Day River for Chinook Salmon. Practitioners used a BACI design and measured adult and juvenile salmonid density, distribution, smolts-per-spawner, and survival. The nested experiment, referred to as the Camp Creek and Granite Boulder Creek Experiment, was a BACI design where the effect of treatments on fish in the Camp Creek watershed was evaluated against the control Granite Boulder Creek. Later, to take advantage of a long-term data set, the reference watershed was changed to Murderer's Creek in the South Fork John Day River. Researchers collected adult and juvenile salmonid density, distribution, smolts-per-spawner, and survival from 2008 to 2017.

The team also measured temperature and groundwater at multiple spatial scales and used a model simulation to predict effects of riparian planting on stream temperature. The effects of riparian habitat restoration (fencing and planting) were monitored at the reach scale to better understand the impact of wild ungulate grazing on riparian areas. Researchers monitored physical in-stream habitat at multiple spatial scales to monitor the effects of channel reconfiguration, instream habitat enhancement, floodplain reconnection, and riparian fencing and planting using two different sampling protocols. Researchers monitored the effects of restoration at multiple spatial scales on macroinvertebrates to gain insight on the food base and community dynamics. Researchers also implemented an economic study, to examine the effects of watershed restoration on the county.

Other significant efforts for the IMW included the development of a life cycle model for steelhead that simulated two differing restoration scenarios using habitat data from habitat and fish data from the Middle Fork John Day River. In one scenario, modelers simulated enhanced rearing capacity and survival for juveniles by providing cooler summer temperatures. In the second scenario, modelers simulated an increase the population's juvenile carrying capacity by increasing the structural/hydraulic complexity of select reaches (via large wood and structural additions). These simulations demonstrated a practical approach for upscaling reach-level mechanistic models to inform population-level assessments and will inform large-scale restoration prioritization and strategies for future IMWs.

Results to date

Freshwater productivity, measured as smolts per spawner, has not increased since the inception of the IMW. Similarly, adult spawners and smolt density did not increase significantly when compared to reference watersheds. Results also suggest that although freshwater habitat improved, water temperature was not significantly altered. The results from the life-cycle modeling suggest that temperature is limiting the production of juvenile steelhead in the Middle Fork John Day River. The team concluded that without mitigation of high stream temperatures, treatments targeting quantity and quality of instream habitat were insufficient to elicit fish responses. Elevated stream temperature remains the most significant limiting factor for steelhead and Chinook Salmon populations, overriding the benefits from instream habitat improvements (Middle Fork IMW Working Group 2017).

Groundwater inputs did not significantly decrease Middle Fork John Day River stream temperatures but did affect tributary temperatures. The primary cooling mechanism of the Middle Fork John Day River occurred at the confluence of the mainstem and its tributaries, where tributaries supplied cooler, groundwater rich water into the main channel. Since surface water surface area is a key metric for change in stream temperature, planned restoration scenarios can be simulated to predict the impact on stream temperature by comparing pre- to post-restoration stream surface area. Overall habitat index, LWD frequency, and the percent of undercut banks in Camp Creek and the Middle Fork John Day River increased significantly (Middle Fork IMW Working Group 2017).

Removal of livestock increased vegetation, particularly *Carex nudata,* within the active channel with influences on channel morphology and habitat. Channels did not significantly narrow and deepen or become more sinuous in response to restoration as hypothesized. Pool depth increased significantly in some locations. Both project reaches and control reaches experienced a significant decrease in the percentage of embedded gravels and were not greatly influenced by a major flood in 2011. In the absence of grazing by domestic livestock, browsing pressure from deer and elk is limiting the restoration of native riparian forests in the absence of adequate fencing (Middle Fork IMW Working Group 2017).

Lessons learned

River restoration is a long-term investment. Restoration actions aimed at improving watershed function, such as riparian restoration and instream habitat improvement, may take decades to develop fully and produce detectable improvements in salmonid productivity. During the planning process, anticipated response times might also influence monitoring design and timelines. Life cycle modeling can help predict magnitudes and timing of fisheries response variables from restoration and help to prioritize the restoration actions that maximize effects on fish populations. Given the limited time for habitat recovery from active restoration, and the lag time of population-scale fish responses, fish populations will take longer to respond to treatments in the Middle Fork John Day River (Middle Fork IMW Working Group 2017).

The Middle Fork John Day River IMW team emphasized that communication among all parties during planning was important, and that consistency and annual reviews could improve communication. The use of a life cycle model was recommended to better understand the magnitude of a response to a given habitat project. Other IMWs might benefit from developing or applying existing life cycle models as new restoration approaches or projects are developed (Middle Fork IMW Working Group 2017).

Potlatch River

A short summary of the key elements and results to date for the Potlatch River IMW are provided in Table 12.

Table 12. Elements and results to date for the Potlatch River Intensively Monitored Watershed.

Study Tributaries	Potlatch River Basin; Big Bear Creek (BBC) and East Fork Potlatch River (EFPR) watersheds.
Years Monitored	Pre-treatment monitoring: BBC 2005 and EFPR 2008; Treatment: BBC 2013-present and EFPR 2009-present; Post-treatment monitoring: ongoing for both watersheds
Focal Species	Snake River steelhead
Limiting factors	BBC: low summer base flows and tributary blockages. EFPR: lack of pool habitat and cover for fish, and degraded riparian conditions
Restoration Plan	BBC: Remove barriers and supplement flows. EFPR: place LWD and restore riparian zone.
Monitoring Experimental Design	Hierarchical scaled design (BA, BACI) at the watershed, tributary, and reach scale; adaptive management.
Treatment	BBC: Barrier removals and flow supplementation. EFPR: LWD placement and riparian restoration.
Magnitude	BBC: 10 barriers removed (~ 10 km of restored spawning and rearing habitat); 16 km treated with flow supplementation, including 8 km of restored rearing habitat (temporary project). EFPR: 218 LWD structures placed within 4.0 km, >11,200 shrubs and trees planted, and >5,000 m of fencing installed.
Pre-treatment Data	Production and productivity at watershed scale and juvenile density, growth, and survival and habitat conditions at the tributary and reach levels.
Results to Date	Expansion of spawning distribution; seasonal use of structures by juvenile steelhead; increased wetted habitat and pool density and improved water quality; increasing trends in habitat conditions (pool density and canopy cover) and age composition and growth of EFPR emigrants

Background

The Potlatch River is in northern Idaho and enters the lower Clearwater River 20 km east of Lewiston, Idaho. The basin is comprised of two distinct parts with notable differences in stream morphology, hydrology, and land use. The lower watershed is characterized by steep basaltic canyons rimmed by cropland. The primary limiting factors are low summer base flows and tributary blockages. In contrast, the upper watershed is characterized by timbered hills and meadow terrain. The primary limiting factors in the upper watershed are a lack of pools and instream cover and degraded riparian conditions.

Planning and development

Priorities differ between the two parts of the watershed. In the lower watershed, the primary restoration strategies are to expand rearing habitat by removing barriers and to increase base-flow conditions by supplementing summer stream flows. In the upper watershed, the primary strategies are to improve riparian function and to increase instream habitat complexity by re-meandering stream channels, installing log structures, planting riparian areas, and fencing out cattle. Initial efforts were conducted opportunistically with willing landowners throughout the basin. Since the implementation of the IMW, restoration has been focused in two index watersheds: Big Bear Creek in the lower watershed and East Fork Potlatch River in the upper watershed.

Monitoring began in 2005 in Big Bear Creek and expanded to East Fork Potlatch River in 2008 upon implementation of the IMW. Early efforts focused on intensive monitoring of steelhead production and productivity at the watershed-scale and juvenile density and distribution at the tributary-level (Bowersox and Biggs 2012). In 2013, monitoring expanded to include juvenile density, survival, and growth to better identify responses (Bennett et al. 2016).

Restoration work included barrier removals, LWD/riparian treatments, and flow supplementation. In Big Bear Creek, 10 barriers have been removed to open >10 km of potential spawning and rearing habitat. Temporary flow supplementation treated >16 km during low summer flows and created 8 km of additional wetted habitat. Riparian treatments (re-meandering, fencing and planting), LWD placement, and road improvements were conducted in the East Fork Potlatch River watershed. Approximately 4 km were treated with LWD (218 wood structures), >11,200 shrubs and trees were planted, and >5,000 m of fencing was installed, mostly in tributary streams.

Design and methods

The Potlatch River IMW study used a hierarchical study design with three levels of monitoring (index watershed, tributary, and reach scales) to evaluate fish and habitat responses to habitat restoration. The broadest monitoring used a BA design to measure the total responses in the two index watersheds. Tributary-scale monitoring used a BACI design to isolate responses by restoration type. Reach-scale monitoring was conducted to isolate responses by restoration type and for specific guidance to the restoration program.

In addition to empirical data, researchers used a life-cycle model to examine potential watershed-scale responses in juvenile steelhead production to the planned restoration projects in each index watershed. In Big Bear Creek, three planned barrier removal and flow supplementation projects have the potential to restore access to 30-40 km of additional rearing habitat, nearly doubling the amount of rearing habitat currently available. Modeling indicated a potential 90% increase in juvenile production. In the East Fork Potlatch River, planned LWD treatments will treat 15 km of stream over the next 5 years. Results suggest that if the LWD projects increased rearing densities closer to the excellent habitat rating of 20 per 100 m^2 (Petrosky and Holubetz 1988), then smolt production could increase by 40%.

Results to date

Currently, about 25% of planned treatments have been completed. Although treatments have not generated a detectable population-level productivity response (emigrants/spawner), responses at finer scales indicate the potential for future changes in the study populations. Researchers documented expanded spawning distribution following barrier removals, fall/winter use of LWD structures by juvenile steelhead, increased wetted habitat and improved water quality conditions following flow supplementation, and improved pool density and canopy cover in the East Fork Potlatch River. Further, shifts in East Fork Potlatch River emigrant age composition and length-at-age suggest an initial response. Life-cycle models indicate that planned restoration projects could substantially increase smolt production within the index watersheds (Uthe et al. 2017).

Lessons learned

Funding, personnel, and private-land limitations have impacted the pace of habitat restoration implementation within the Potlatch River IMW. Restoration projects in the index watersheds are not yet to a magnitude sufficient for a detectable population-level response. However, preliminary results demonstrated the value of the restoration approaches implemented. Adaptive management has better aligned restoration with monitoring priorities in the IMW and led to a more efficient and productive restoration program (Uthe et al. 2017).

Pudding Creek

A short summary of the key elements and results to date for the Pudding Creek IMW are provided in Table 13.

Table 13. Elements and results to date for the Pudding Creek Intensively Monitored Watershed.

Study Tributaries	Pudding and Caspar Creeks. Both drain directly into the Pacific Ocean near Fort Bragg in Northern California.
Years Monitored	Pre-treatment monitoring: 2006 - 2014 Treatment: June - August 2015 Post-treatment monitoring: 2016 - 2020
Focal Species	Central California Coast Coho Salmon. North-Central Coast steelhead are also present.
Limiting factors	Low habitat complexity, high flows with little refugia
Restoration Plan	Determine if the addition of large wood to coastal California streams can be used to increase smolt production. In addition to life-cycle monitoring on both streams, this study incorporates the monitoring of seasonal physical stream habitat attributes and seasonal juvenile density, growth, and survival.
Monitoring Experimental Design	Paired watershed BACI with Caspar Creek as the reference watershed. Paired T-tests, ANOVA, ANCOVA, Generalized Linear Modeling
Treatment	Installation of LWD (n=438)
Magnitude	Treated 12.1 km, eighty percent of Pudding Creek, with large wood
Pre-treatment Data	Three years of pre-treatment data
Results to Date	Limited post-treatment monitoring thus far but 2016-2017 exhibited higher than average adult returns

Background

Pudding and Caspar creeks are located on the northern California coast. Both creeks flow directly into the Pacific Ocean near Fort Bragg, California. The watersheds of the creeks are only about 50 km^2, but they are important Coastal Coho Salmon streams. Central California Coast Coho Salmon are listed under the ESA and limited by overwinter survival. Pudding and Caspar creeks have been logged extensively and the removal of LWD within the creeks has reduced channel complexity and refugia for young Coho Salmon rearing and overwintering in the streams before migrating to the Pacific Ocean. To increase the amount and complexity of rearing and overwintering habitat for juvenile Coho Salmon, LWD was installed in 80% of Pudding Creek. Caspar Creek, a similar watershed about 8 km south, was used as an untreated reference.

Planning and development

Previous research suggested that to double Coho Salmon smolt production, at least 80% of the stream needed treatment. Therefore, the project took the approach of trying to treat 80% of the stream by placing 438 pieces (1,366 m^3) of LWD. Large Woody Debris was measured and tagged with unique identification numbers.

Design and methods

The IMW used a repeated measures whole watershed BACI design with the control watershed being Caspar Creek. The project goal was to treat 80% of the available anadromous salmonid habitat by installing LWD to increase both the quantity and quality of summer and winter habitat relative to the reference stream. The metrics measured for biological response were over winter and over summer survival, production, and growth of juvenile steelhead and Coho Salmon. The five physical response variables were total habitat by volume, slow water habitat area, the ratio of slow to fast water habitat, habitat diversity, and average residual pool depth.

Results and lessons learned

Posttreatment monitoring began in 2016 and therefore examination of response is limited. Adult returns were higher than average in 2016-2017. To date, there has been no measurable habitat response (PNAMP IMW Questionnaire 2017).

Skagit Estuary

A short summary of the key elements and results to date for the Skagit Estuary IMW are provided in Table 14.

Table 14. Elements and results to date for the Skagit Estuary Intensively Monitored Watershed.

Study Tributaries	North and South Forks of the Skagit River.
Years Monitored	Pre-treatment monitoring: 1992-present Treatment: 2001-present Post-treatment monitoring: ongoing in many sites
Focal Species	Skagit River Chinook Salmon- six wild stocks
Limiting factors	lack of habitat connectivity, reduced rearing habitat
Restoration Plan	Ongoing restoration of tidal habitat in the South Fork of the Skagit River with the North Fork being an unrestored control.
Monitoring Experimental Design	BACI to test for estuary restoration on population effects with North Fork used as a reference. BA with covariates used to test for the effects of estuary restoration upon post-estuarine life stages.
Treatment	Dike removals, setbacks, and breaches; tidal muting devices, fill removal
Magnitude	Skagit River Estuary
Pre-treatment Data	Average juvenile Chinook Salmon size, change in size during rearing, rearing density over the season, timing of residence, changes in timing, marine survival, and frequencies of life history types
Results to Date	Restoration increased cohort residence time of juvenile Chinook salmon in estuary habitats and decreased densities system-wide as salmon were able to spread out over more habitat. Effectiveness monitoring studies demonstrated that restoration resulted in local increases in density.

Background

The Skagit River flows westward and drains into Skagit Bay in the northern part of Puget Sound. Near Mt. Vernon, Washington, the river turns south before splitting into two forks (North and South Forks of the Skagit) that create Fir Island and then empty into Skagit Bay. Skagit Bay is bounded by Whidbey Island to the west, Camano Island to the South, and Fir Island and the mainland to the east. The Skagit River watershed is the largest watershed entering Puget Sound, draining an area of approximately 8,030 km2, including inputs from the Baker, Cascade, Sauk, and Suiattle rivers. The river maintains wild anadromous populations of all five Pacific salmon, steelhead, cutthroat trout, and ESA-listed bull trout. Peak flows result from rain on snow events from November to February and then snowmelt from May to June (Zimmerman et al. 2015).

Like other watersheds in the Pacific northwest, the entire basin has been subject to extensive logging and other resource extraction. However, this IMW focuses on projects reversing over a century of modifications in the estuary that have reduced habitat for juvenile ESA-listed Chinook salmon. Much of the Skagit tidal delta was subject to diking, dredging, and filling *starting* around the 1860's, and about

75% of the tidal delta *is now* disconnected from freshwater and tidal inundation. Nearly 25% of the intertidal shoreline in Skagit Bay is now armored to protect existing farmland and infrastructure from erosion.

Planning and development

Although salmon are imperiled the Skagit River was chosen as an IMW to relate estuary habitat restoration to juvenile Chinook salmon population responses. More than other Pacific salmon, juvenile Chinook salmon utilize estuary as habitat during their outmigration. The Skagit River is home to six wild Chinook salmon stocks, all of which contribute juveniles that use the estuary. The six stocks express five juvenile life histories varying in freshwater and estuarine residence – yearling migrants, parr migrants, tidal delta fry, fry migrants rearing in nonnatal estuaries, and fry migrants rearing in marine waters. While the first two life histories do not exhibit extensive estuary residence, the latter three are hypothesized to be limited by the amount of rearing habitat in the estuary (Greene and Beechie 2004, Beamer et al. 2005). Estuary restoration is one of several recovery goals in the watershed, and the recovery plan lists a long-term goal of 60% increase in estuarine rearing capacity (Beamer et al. 2005, Greene et al. 2015). Thus far, estuary restoration has achieved 20% of that goal.

Design and methods

Treatments occurred on the South Fork Skagit River and the reference sites were on the North Fork Skagit River. To determine juvenile response to treatments, the IMW team used general linear models and mixed effects models with covariates (when BA study designs are used). Variables measured were average juvenile Chinook Salmon size, change in size during rearing, rearing density over the season, timing of residence, changes in timing, marine survival, and frequencies of life history types.

Results to date

Restoration increased capacity by allowing juvenile Chinook Salmon to spread out in restored estuary habitat. Restoration allows for a longer rearing period in estuary and nearshore habitats. While smolt to adult return rate demonstrates a strong density-dependent relationship, restoration to date has been insufficient to greatly change these rates. Modeling suggests that recent low spawner numbers have resulted in poor conditions to test for density-dependent responses. Greater amounts of estuary restoration in the context of higher spawner numbers should result in observable changes in smolt-adult returns rates (Beamer et al. 2005). To date, there has been little relation between increased capacities on marine survival; however, the comparisons have weak statistical power, but overall improvements are positive (PNAMP IMW Questionnaire 2017).

Lessons learned

It is difficult to plan restoration in a research context; the limited opportunities for estuary restoration often dictate where restoration can be completed. In addition, in the context of a larger recovery plan for Chinook salmon, estuary restoration competes for funding with other recovery actions, so it is impossible to commit all resources to addressing the research questions of the IMW. Data management and analysis are two major activities for IMWs that are not often considered in budgets. Large scale estuary restoration takes a lot of time and concerted effort. Most funding for restoration does not include much funding for long-term implementation and effectiveness monitoring. Dike removal/setbacks and breaches result in the largest changes in rearing density. IMWs need concerted effort and long-term resources to evaluate success. Long-term funding requires independent efforts by project managers (PNAMP IMW Questionnaire 2017).

Strait of Juan de Fuca

A short summary of the key elements and results to date for the Strait of Juan de Fuca IMW are provided in Table 15.

Table 15. Elements and results to date for the Strait of Juan de Fuca Intensively Monitored Watershed.

Study Tributaries	Deep Creek, East Twin River, and West Twin River
Years Monitored	1) Deep Creek Treatments: 1996-2018 2) Deep Creek Monitoring: 1992-present 3) East Twin River Treatment: 2000-2011 4) East Twin River Monitoring: 2002-present 5) West Twin River Monitoring: 2004-present
Focal Species	Coho Salmon, steelhead, and Cutthroat Trout
Limiting factors	Simplified channels with high stream power
Restoration Plan	The goals of restoration were to: 1) increase the amount of in-stream wood, 2) increase overwintering habitat, 3), reduce the frequency of anthropogenic influenced landslides, and 4), restore riparian forest. The IMW treated approximately one third of the anadromous habitat in Deep Creek and the East Twin River. The West Twin was used as a control watershed because it was similar in size, hydrology and geomorphology to the East Twin River and Deep Creek
Monitoring Experimental Design	Varies with scale and metric. Could view watershed scale as CI while some habitat measures are BACI
Treatment	Addition of LWD, fish passage, off-channel development, riparian tree planting, culvert replacement, and road abandonment
Magnitude	Treated approximately 1/3 of the anadromous habitat in Deep Creek and East Twin Rivers. No treatments were conducted in West Twin River (reference watershed)
Pre-treatment Data	Varied by metric and watershed
Results to Date	Juvenile Coho expressed multiple life histories and emigration timing but could not directly link to restoration. Small increases in Coho Salmon and steelhead adults in East Twin River relative to West Twin River. Small increases in Coho Salmon adults in Deep Creek relative to West Twin River.

Background

The East Twin River, West Twin River, and Deep Creek flow into the Strait of Juan de Fuca on the north side of the Olympic Peninsula, Washington. The watersheds of each creek are less than 50 km^2. The region receives about 190 cm of rain per year, which occurs from October to May. The region has a history of logging, wildfire, removal of LWD, and road construction which have led to an increased frequency of landslides. This creates the potential for mass-wasting events and the inability of the streams to store sediments. Over time, creeks have developed simplified channels with high stream power (Hall et al. 2016).

Planning and development

The goals of restoration were to: 1) increase the amount of in-stream wood, 2) increase overwintering habitat, 3), reduce the frequency of anthropogenic influenced landslides, and 4), restore riparian forest. Although a reference was established, the ability to relate restoration to watershed effects was hampered because periods of treatment and response were not well defined. Also, the statistical design was not well defined. Statistical techniques were largely for comparison of individual metrics. Generally, the habitat sampling did not reference for inter-annual effects.

Design and methods

The IMW treated approximately one third of the anadromous habitat in Deep Creek and the East Twin River. The West Twin River was used as a control watershed because it was similar in size, hydrology and geomorphology to the East Twin River and Deep Creek. The IMW measured: 1) juvenile Coho Salmon and steelhead overwinter survival, migrant production, and growth, 2) smolt to adult return rates for Coho Salmon and steelhead, 3) peak flow magnitudes and duration, and 4), habitat quality metrics.

The IMW team conducted annual juvenile PIT-tag surveys and continuous monitoring using passive arrays at river mouths. PIT-tagging of juvenile out migrants and detection of returning PIT-tagged adults was also conducted. Smolt trap and PIT-tags were used to estimate outmigrant production and estimates of adult returns were estimated from spawner surveys. DOE maintained discharge monitoring sites near the river mouths and continuous water level sensors were installed at the PIT-antenna arrays in the treatment watershed. Habitat surveys that enumerate wood jams, LWD, pools and riffles and document river depths and bankfull widths, canopy closure, pool area, pool forming features, riffle area, gradient and side channel length were implemented in each system.

Results to date

Over the last 18 years, the LEKT has developed and implemented two watershed-scale restoration plans in East Twin River and Deep Creek that has focused on increasing salmonid habitat quality, habitat quantity, and restoring watershed processes. In addition, the SJF IMW team had the vision of utilizing one watershed, West Twin River, as a control watershed to see how their actions fared in the restored basins relative to an unrestored basin. The effort included over 20 large-scale restoration projects during that period. The majority of projects included placed logs and log structures, barrier removal, road decommissioning, and floodplain reconnection. The question we posed at the onset of the SJF IMW was do these restoration actions, over time, lead to a watershed-scale response in habitat conditions and salmonid populations over time?

We found that out of all the indicator metrics we used (returning adults, smolt production, smolts per spawner, late summer parr densities, and survival) to monitor change in salmonid populations survival showed the most notable and obvious change from 2009 to 2014. Specifically, Deep Creek juvenile Coho salmon survival increased from less than 0.5 to over 1.25 times the West

Twin River survival, indicating that the difference in survival was negative in 2009 and positive by 2016. This is important because a change in survival can have positive changes to overall salmonid productivity, when coupled with other factors such as juvenile density and growth (Bouwes et al. 2016). In addition, changes to survival can lead to long-term changes in the contribution of specific habitats to overall Coho salmon productivity (Ogston et al. 2015). There was also an indication that smolt increased as a function of spawners in Deep Creek. However, we did not see this translate in other indicators related to relative smolts or smolts per spawner for Coho salmon.

Another major conclusion associated with our 18-year study is the diversity of life history types for Coho salmon and steelhead we have documented. Both Coho salmon and steelhead show multiple life history types that result in differences in survivorship and contribution to the overall returning adult population for each species and watershed. This identification and quantification of life history type has implications for what we may see or not see with respect to a watershed-scale restoration effect on salmonid populations.

Specifically, we hypothesize that a positive trend in the proportion of yearling Coho salmon or O. mykiss migrants over time is important for population recovery in these systems. We have indirect evidence for this in Deep Creek, which has undergone numerous restoration treatments and has maintained a higher proportion of yearling O. mykiss migrants as compared to both East Twin and West Twin Rivers. Continued monitoring will be required to pair the Deep Creek trends with adult return trends given that we do not yet have complete adult returns from the most recent juvenile cohorts. However, if the trend of increasing yearling proportions for O. mykiss in Deep Creek does continue, this pattern would differ from that which has been observed in East Twin River that has also received restoration treatments.

We are seeing a general increase in the proportion of yearling Coho salmon migrants over time in all three systems since 2010. The increasing trend was not paired with an increase in adult Coho salmon escapement given that adult escapement has either remained relatively flat or declined slightly since 2005 due to other factors, including a large-scale debris flow in East Twin River. Nevertheless, potentially increasing fish size through restoration actions, coupled with larger fish that are more likely to remain in the stream and become yearling migrants, could lead to potentially higher return rates for adults.

Lessons learned

Managing large quantities of data can be difficult without proper support; building a PIT- tag database was instrumental in making data entry and analysis much more efficient. Habitat surveys conducted within each system of an IMW in the same year may provide better trends detection as compared to staggered monitoring across years and systems given the potential influence of interannual variations in stream flow. Juvenile steelhead exhibited variation in age and seasonal outmigration, and the number of years spent in the ocean. However, unlike Coho Salmon, earlier migrating steelhead did not contribute to adult returns (Ehinger et al. 2016). Wood jam volumes and/or piece counts should be collected in addition to counts of wood jams to monitor changes in woody debris within a system (PNAMP IMW Questionnaire 2017).

Monitoring fish migrations with PIT-tag antennas can provide a more complete picture of life history diversity, migration timings, and out-migrant productivity compared to traditional spring smolt trap monitoring. The IMW demonstrated that large numbers of fish move downstream during periods not typically covered by spring smolt traps. It is important to keep up with PIT-tag and communications technology as recent advances represent a vast improvement over the original gear. Improved tag detection and reduced down time during fish migration windows were keys to the success of this project. NOAA developed an Oracle Application Express (APEX) application for housing PIT-tag and habitat data from IMW collaborators. The database provides an easy-to-use, web-based interface and allows for customized reports and data queries. Strait of Juan de Fuca collaborators can access the entire database and the general public can access NOAA's IMW data (PNAMP IMW Questionnaire 2017).

In summary, we have been able to identify trends associated with salmon populations in the IMW that can be, in part, attributable to changes in habitat condition from restorative actions. However, these signals are not consistent over the entire suite of indicators, nor are they consistent over the entire time period of the actions. There is still the potential for a response that is happening to both habitat and fish population response that will take years to decades to play out in terms of an overall watershed-scale response. Specifically, the indirect effects of the restoration actions resulting from changes in habitat forming processes will likely require decades to take full effect. Therefore, much of the restoration response may be still to come.

Tenmile Creek

A short summary of the key elements and results to date for the Tenmile Creek IMW are provided in Table 16.

Table 16. Elements and results to date for the Tenmile Intensively Monitored Watershed.

Study Tributaries	Tenmile Creek is the treatment and Cummins Creek is the reference watershed. Both are direct ocean tributaries on the central Oregon coast
Years Monitored	Pre-treatment monitoring: 1991-1996 Treatment: 1996 (planned LWD placement and also deposited from a large storm event) Post-treatment monitoring: 1996-2001, out-migrant trapping through 2012 in Tenmile and Cummins Creeks, limited out-migrant trapping in Tenmile Creek now - ongoing
Focal Species	Oregon Coast Coho Salmon, Oregon Coast steelhead, and Cutthroat Trout
Limiting factors	Lack of pool and side channel habitat, lack of spawning habitat
Restoration Plan	Addition of large amounts of LWD in summer of 1996, both from planned restoration and unplanned from a large storm event the same year
Monitoring Experimental Design	BACI design – this design was compromised because the reference watershed did not track the treatment watershed. As a result, the data were analyzed separately for each watershed.
Treatment	LWD Placement. Other concurrent actions included road decommissions, culvert removals, and riparian tree plantings
Magnitude	About one-third of the watershed was treated
Pre-treatment Data	Population size, smolt density, and freshwater survival of juvenile steelhead, Coastal Cutthroat Trout, and Coho Salmon for five years pre- treatment (1991-1996)
Results to Date	The density of juvenile Coho Salmon and steelhead did not increase significantly but survival did. The production of steelhead and Cutthroat Trout increased significantly.

Background

Both Tenmile Creek and a control watershed, Cummins Creek, are direct ocean tributaries on the central coast of Oregon, but neither has an estuary. The two creeks are 8 km apart and located just south of Yachats, Oregon. The Tenmile Creek watershed encompasses over 60 km^2 and has two primary tributaries, the South Fork Tenmile Creek and Wildcat Creek. Precipitation in the area is about 200 cm annually and both creeks experience a maritime climate dominated by rainfall with wet winters and dry summers (Johnson et al. 2005). Homesteading, logging, and road construction have compromised fish habitat in the watershed.

Planning and development

To characterize fish habitat and distribution, three contiguous reaches were established in Tenmile Creek and a fourth in Wildcat and South Fork Tenmile creeks combined. Three contiguous reaches were established in the reference watershed, Cummins Creek. Watershed restoration began in the summer of 1996 as a cooperative agreement between the US Forest Service and local landowners.

Design and methods

For LWD placement from restoration, 88 trees were placed in the upper half of Reach 2, 133 trees were placed throughout Reach 3, and 20 trees were placed in the lower portion of Reach 4. The metrics measured were: physical habitat during summer and winter, population density of steelhead, Coho Salmon, and Cutthroat Trout. The IMW team estimated population size, smolt density, and freshwater survival of steelhead, Coastal Cutthroat Trout, and Coho Salmon juveniles for five years prior to treatment (1991-1996) and then for five years after treatment with LWD (1996-2001). Prior to the completion of LWD placement, a large storm event deposited a significant amount of wood into the watershed, effectively doubling the amount of restoration.

Results to date

Wood addition in the treatment watershed resulted in an increase in pool and side channel habitats that are important rearing areas for juvenile salmon and steelhead. Localized gravel deposition was observed at wood jams, but no reach level changes were detected in substrate composition in either the treatment or control streams (PNAMP IMW Questionnaire 2017).

The density of juvenile Coho Salmon and steelhead did not increase significantly; however, freshwater survival did increase between the pre- and post-treatment periods in the treatment watershed compared to the control watershed. There was no significant difference in the number of outmigrating Coho Salmon in the treatment or control reaches between pre- and post-treatment periods. steelhead smolts and Cutthroat Trout outmigrants did increase significantly in both the treatment and control watersheds (PNAMP IMW Questionnaire 2017).

Lessons learned

Long term, sustained monitoring is needed to identify a response because external confounding factors such as a large storm event or low spawner density (i.e. the reference stream) unrelated to restoration can occur. Monitoring at full seeding across multiple life stages in addition to spawner density could provide further context (PNAMP IMW Questionnaire 2017).

Wind River

A short summary of the key elements and results to date for the Wind River IMW are provided in Table 17.

Table 17. Elements and results to date for the Wind River Intensively Monitored Watershed.

Study Tributaries	The Wind River Watershed
Years Monitored	Pre-treatment monitoring: 2000-2009 Treatment: 2009 Post-treatment monitoring: 2010-2020
Focal Species	steelhead
Limiting factors	Lack of habitat connectivity, low habitat complexity
Restoration Plan	Examine the effects of dam removal on steelhead abundance and production in the Wind River
Monitoring Experimental Design	A BACI is used for density and a BA is used for productivity and capacity
Treatment	Barrier removal (Hemlock Dam) primarily, but also culvert removal, Engineered Log Jams (ELJ) and LWD placement, road decommissioning
Magnitude	Treatment primarily in Trout Creek which improved access to 22 km of fish habitat
Pre-treatment Data	Some data from 1992-2000 but primarily 10 years (2000-2009) leading up to Hemlock dam removal
Results to Date	Large increases in steelhead adult returns and smaller increases in smolt abundance in Trout Creek (treatment) vs Wind River (control)

Background

The Wind River watershed drains about 582 km^2 in the Cascade Mountains of southwest Washington. The climate is temperate and precipitation totals about 280 cm annually, most of which occurs between November and March. The river flows into the Columbia River at rkm 245 just above Bonneville Dam. The watershed has historically been subject to riparian logging, road and culvert construction, splash damming, and overharvest of wild steelhead through the mid 1980's. Summer steelhead subsequently declined and are now listed as threatened under the ESA. Columbia River mainstem hydropower development also has an impact in the migration corridor. In 2009, the removal of Hemlock Dam on lower Trout Creek, a major tributary, presented an opportunity to experimentally test the effects of restoration on steelhead abundance, survival, and capacity relative to a reference site.

Planning and development

Various restoration activities have occurred in the Wind River watershed for over 30 years, but the Hemlock Dam removal presented an opportunity to experimentally test the effects of restoration on steelhead production. For the experiment, Trout Creek was the treatment and the mainstem Wind River was the reference. Minimal restoration has occurred in the reference site.

Design and methods

The primary dependent variables measured were adult, smolt, and parr abundance of steelhead. Adult returns were measured with a fish ladder trap prior to dam removal in Trout Creek and then estimated using mark-resight methodology after removal. A similar mark-resight methodology was used to monitor adult steelhead throughout the remainder of the Wind River. Smolt and parr abundance were measured via a rotary screw trap coupled with capture efficiency estimates. Spawner-recruit relationships have also been estimated for smolts using smolt trap abundance data, and scales to determine age and assign recruits to parental brood years.

Results to date

The project resulted in large increases in steelhead adults and smolt abundance in Trout Creek (treatment) relative to the Wind River (reference). Adult returns increased from 77 spawners pre-treatment to 208 spawners in 2017. The proportion of spawners above the dam site increased from 10-20%. Smolt density increased 29% in Trout Creek (treatment site), while in the Wind River (reference site) it decreased 7.4% (PNAMP IMW Questionnaire 2017).

Lessons learned

The IMW team indicated that a study design leveraging existing long-term datasets, as opposed to development of new monitoring methods and randomized site selection, at the time of project conception, greatly increased statistical power and the overall success of the project. Coordinating effectiveness monitoring and restoration activities among multiple partners and funding sources throughout the life of the IMW has been a challenge (PNAMP IMW Questionnaire 2017).

Summary and Conclusions

Of the 16 IMWs studied, only seven have completed their planned restoration, and in some cases, initial results have only recently become available (Table 1). Although treatments in some IMWs began as early as 1996 (Strait of Juan de Fuca), only the Tenmile IMW has had a post-treatment period that exceeds a salmon's generation time. Results to date show positive juvenile fish response in most IMWs, however more time is needed before IMWs can fully evaluate the impacts of restoration on salmon and other fish populations.

The most common treatment applied by IMWs is the addition of wood in the form of large woody debris (LWD), engineered log jams (ELJ), or beaver dam analogs (BDA). Of the 16 IMWs summarized here, 14 IMWs placed LWD or ELJ's and one placed BDA's, ten instituted barrier removals/fish passage improvements, seven IMWs addressed estuary or floodplain connectivity, and six implemented riparian improvements. Flow augmentation, road decommissioning, boulder placement, and nutrient enhancement were also employed in a small number of IMWs (Table 1). Most, but not all IMWs, incorporated several treatments. For example, the Wind River IMW team removed a barrier on one of its main tributaries, Trout Creek, but also placed LWD and ELJ's, decommissioned roads, and removed culverts.

Twelve IMWs reported positive responses in juvenile salmonid metrics (survival, density, production, growth) (Table 18). Increases in juvenile metrics were associated with instream habitat modification such as wood additions (LWD, ELJ's, BDA) and floodplain reconnections. While juveniles may benefit immediately from changes to habitat quality in freshwater, because the post-treatment time period for most IMWs considered in this report is shorter than the generation cycles of the salmon it will be three to five years or longer before impacts to adult returns can be expected. However adult returns have increased in three IMWs where dams or barriers were removed.

Habitat responses to restoration often take time, and biological responses to those changes take even longer. It is reasonable to expect that watershed restoration experiments, such as IMWs, are likely to take multiple salmonid generations for widespread positive population responses to occur. The authors of this report concur with Bennett et al. (2016) assertions that the degraded state of watersheds occurred over a period of more than a century, and the time frame necessary to make habitat improvements will, in some cases, take many decades to ultimately result in watershed and fish population scale detectable results. However, many short-term positive responses in both habitat and fish have been found. While further monitoring will be necessary to fully gauge fish population responses to restoration actions, most IMWs report positive short-term responses that suggest more significant successes will build from those already measured.

Table 18. Metrics of fish response to restoration to date for individual IMWs. This table represents a simplification of fish response and is intended to convey generalities; readers should consult the individual IMW synopses for details. In the table '↑' indicates increases to date, '↓ ' indicates decreases

to date, '↔' indicates no change to date, 'NEY' indicated not evaluated yet, and blank cells indicates not reported. Increases and decreases do not necessarily represent statistically significant differences.

Metric / IMW	Adult returns	Adult marine survival	Redd numbers	Juvenile density	Juvenile survival	Juvenile growth	Juvenile production	Juvenile residence time	Life history diversity
Asotin	NEY		NEY	↑	NEY	↓	NEY	NEY	NEY
Bridge				↑	↑		↑		
Elwha	↑		↑						↑
Entiat				↔	↑	↓			
Hood Canal							↑		
Keogh		↓					↓		
Lemhi							↑		
Lower Columbia						↑			
Methow				↑	↑	↑	NEY	NEY	
Middle Fork John Day			↑	↔	↔	↔	↔		
Potlach				↑					
Pudding									
Skagit	NEY	↔	NEY	↑	NEY	NEY	↑	↑	↔
Strait of Juan de Fuca	↑	↑	↔	↑	↑	↑	↑		↑
Tenmile	NEY	NEY	NEY	↔	↑	NEY	↑	NEY	NEY
Wind	↑			↑			↑		

Bennett et al. (2016) separates IMWs into two main types: those that are more opportunistic vs those that are built from the ground up. Opportunistic restoration takes advantage of existing monitoring or restoration that is underway, while 'ground up' projects are pre-planned with all treatments pre-conceived before the onset of monitoring. Restoration that involves multiple treatments (e.g. culvert replacement, LWD, road abandonment) makes it difficult to gage the success of any one type of action. If there is a positive response in a metric, it cannot be directly attributed to a single action but must be attributed to all actions collectively. However, as the Elwha IMW team points out, it is important to separate treatment effect from natural variability. Some IMWs had treatment effects beyond what was planned. In Bridge Creek, placement of BDA's ultimately led to more beavers (and beaver habitat) that led to more beaver dams and extended treatment effects spatially and temporally. Similarly, in Tenmile Creek, large flow events increased the treatment magnitude by depositing large amounts of LWD in addition to that placed during restoration that same year.

The 16 IMWs included in this summary reported lessons learned related to most aspects of an IMW: experimental design, restoration design and implementation, monitoring design and implementation, data management and analysis, communication and collaboration, adaptive management, and funding. Because individual IMWs often face a unique set of challenges it is not surprising that the lessons learned reported in the synopses are often specific to an IMW; however, there were some commonalities. One frequently reported lesson learned was the importance of adequate deliberation and documentation of the time and geographic scale over which restoration must occur to ultimately result in both habitat and fish measures of success. Another lesson learned reported by multiple IMWs was the importance of identifying and addressing the highest priority limiting factor(s). If the primary limiting factor wasn't effectively addressed, treatments targeting other limiting factors were insufficient to elicit fish response. Regular communication between IMW implementation team members was also commonly identified as essential to ensure that implementation of both restoration and monitoring is proceeding as planned and any necessary adjustments are made on a timely basis. Overwhelmingly, practitioners identify the need for broad and regular communication between team members and between different IMW teams. Many of the IMW teams identified consistent database management, funding for database management, and coordination of data to be challenging but critically important. IMWs are long-term efforts that require a significant time series of information to perform adequate evaluations of restoration benefits, and therefore data must be managed in a way to survive succession within staff and support statistical analyses well into the future. Data management needs to be part of the monitoring plan and requires funding and maintenance for the duration of the study and often well beyond the period of restoration. By reflecting on lessons learned and incorporating an adaptive management framework, IMWs have better aligned restoration and monitoring priorities resulting in more efficient and productive restoration programs.

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Appendix 1 – PNAMP IMW Questionnaire

Background
The region collectively has invested a significant amount of time, expertise, and money in the implementation of Intensively Monitored Watersheds (IMWs). Many of the IMWs have reached or exceeded a 10-year mark of study and analysis. In the near future, key policy conversations will occur and decisions will be made about the current network of IMWs.

PNAMP is coordinating the development of several communication products to help inform these discussions and decisions. Although they are being written/compiled by a handful of people, the products rely heavily on information that will be provided by IMW practitioners via this questionnaire. Please provide your responses to the questions below so that you can be part of and help shape these important policy conversations and decisions.

Directions
Insert answers into the questionnaire and save as a Word document. Email your responses to Amy Puls (apuls@usgs.gov) and cc Craig Haskell (chaskell@usgs.gov) and Tracy Hillman (tracy.hillman@bioanalysts.net).

Step 1. By **November 15th**, point us to information that is already documented.

- If the answers to the questions below are already in writing in an existing report or document, please point us to that information.
- Answers should consist of links or citations to existing documents and the page number where the answer is found.
- You can also copy and paste the answer into the questionnaire, but we'd still like the link or citation and page number for where the information was copied from.
- If citations are provided instead of links, please attach the cited documents to the email along with the questionnaire.

Step 2. By **December 20th**, provide answers that aren't already documented.

- If the answer to a question below is not already documented, we'd like you to do your best to write out the answer.
- If you're not able to answer a question, we'd like to know what you would need to be able to answer it - more time, more information, more resources, etc.

If you have any questions about this process or how the information will be used, please email Amy Puls (apuls@usgs.gov) and cc Craig Haskell (chaskell@usgs.gov) and Tracy Hillman (tracy.hillman@bioanalysts.net).

Please provide responses to the following:

Basic Information

1. IMW name:
2. Name(s) of who to contact if we have questions about responses to questionnaire:
3. Link to IMW website (if applicable):

4. Link/citation to Implementation Plan (if applicable):
5. Links/citations to protocols and method documentation (if applicable):
6. Link/citation to most recent annual report (if applicable):
7. Links/citations to any other documents you think are relevant to this effort (if applicable):

Context

8. What are the target populations (or subpopulations) of interest?
9. What is the geographic boundary of the IMW?
10. What factors or threats are contributing to current conditions (e.g., road density, upland activities, etc.)?
11. What habitat action(s) (treatments) were implemented to improve existing conditions?
12. What was the extent of the treatments (e.g., percent of degraded habitat treated)?
13. What are the goals and objectives of the habitat action(s)?
14. What hypotheses are tested?
15. What is the age or stage of the IMW and restoration implementation (e.g., only have pretreatment data, have pretreatment data and only one year of post-treatment data, etc.)?

Statistical Design (for Watershed, Reach, and Project Scales)

16. What statistical design was used (e.g., BA, BACI, etc.)?
17. How were control/reference areas selected?
18. Are treatment and control areas independent (i.e., are control areas unaffected by habitat actions?)?
19. What changes have been made to the study design and why?
20. What statistical techniques were used, or will be used to analyze the data?

Sampling Design (for Watershed, Reach, and Project Scales)

21. How many sampling units were measured and how were they selected (e.g., random, stratified, systematic, etc.)?
22. Did the selection of sampling sites change over time and if so what changes were made?
23. Was "practical significance" (e.g., environmental or biological effects of the action) defined for the study and if so how was it defined?
24. For important outcomes, what is the desired precision on the estimates?
25. What Type I and II error rates were selected?

Measurements

26. What important dependent variables were measured?
27. How were those variables measured?
28. What was the sampling frequency for field measurements?

Results

29. How will the results inform future management decisions?
30. Over the life of the IMW, what are the key findings?
31. Over the life of the IMW, what are the lessons learned that can help practitioners improve future planning, monitoring, and restoration efforts? Suggested categories for lessons learned include, but are not limited to:

- Experimental Design
- Monitoring Plan and Data Management
- Restoration Implementation
- Restoration Effectiveness
    - habitat change
    - fish response
- General Logistics/ Information Transfer