Evaluation of Intensively Monitored Watershed Projects

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LIST OF ACRONYMS AND ABBREVIATIONS

BA	Before-After study design
BACI	Before-After Control-Impact study design
BACIP	Before-After Control-Impact Paired study design
BDA	Beaver dam analog
BiOp	Biological Opinion
CHaMP	Columbia Habitat Monitoring Program
ELJ	Engineered log jam
EMAP	Environmental Monitoring and Assessment Program
FCRPS	Federal Columbia River Power System
GRTS	Generalized random tessellation stratified sample
ha	Hectare
IMW	Intensively Monitored Watershed
ISEMP	Integrated Status and Effectiveness Monitoring Program
km	Kilometer
LWD	Large woody debris
MBACI	Multiple Before-After Control-Impact study design
MBACI(P)	Multiple Before-After Control-Impact Paired study design
NOAA	National Oceanic and Atmospheric Administration
PNAMP	Pacific Northwest Aquatic Monitoring Partnership

1 Introduction

Each year, tens of millions of dollars are spent on efforts to improve or enhance stream habitat in the Pacific Northwest (Bernhardt et al. 2005). Most of the investments in stream enhancement are driven by the listing of salmon and trout under the Endangered Species Act, with the assumption that stream enhancement will improve the viability of listed species (Katz et al. 2007; Roni et al. 2002). However, there is little evidence that stream enhancement work has benefited populations of listed species. There is evidence that stream enhancement has resulted in benefits as small spatial scales (e.g., project or reach scales; see Hillman et al. 2016) but benefits at the population or watershed scale are rare. This is largely because conducting monitoring at the population or watershed scale requires robust large-scale monitoring and implementation designs; long-term monitoring, coordination, and funding commitments; and large and extensive treatments (Roni et al. 2015; Bennett et al. 2016; Hillman et al. 2016).

Regardless of the difficulty in conducting monitoring at large spatial scales, there are several such programs that have been implemented within the Pacific Northwest (Bennett et al. 2016; Hillman et al. 2016). These programs are referred to as “Intensively Monitored Watersheds” or “IMWs.” An IMW is defined as a large-scale experiment with a well-developed, long-term monitoring program to determine population/watershed-scale fish and habitat responses to enhancement actions (Bennett et al. 2016). In general, the goals of IMWs are to assess the effectiveness of enhancement actions at increasing salmonid productivity and ultimately extrapolate the results to other populations/watersheds where intensive monitoring is not possible (Bilby et al. 2005; McDonald et al. 2007; Bennett et al. 2016). The purpose of this report is to conduct an independent evaluation of the IMWs that have been implemented within the Pacific Northwest. Specifically, we were asked to respond to the following eight key questions:

1. Are the IMWs covering a representative range of habitat improvement strategies and environmental conditions?
2. Are the IMWs asking the most appropriate and relevant questions?
3. Are the IMWs in watersheds with high potential for learning?
4. What are we, in general, learning from IMWs?
5. Are all the IMWs still needed to answer the primary questions in the region? If so, for what purposes and for what period of time?
6. Are there IMWs that have reached a logical conclusion or for other reasons should be ramped down or ended?
7. Are there additional IMWs that should be brought online?
8. Are any of the IMWs unlikely to meet their intended objectives within the implied 10-year timeline, and, if so, what is constraining them?

In this report, we first describe briefly each of the IMWs implemented in the Pacific Northwest. This includes a summary of the goals and objectives of the programs, statistical and sampling designs, indicators and metrics, and recent results. We then use this information to respond to the eight key questions. Finally, we offer our conclusions and recommendations for improving IMWs.

2 Overview of Intensively Monitored Watersheds

In this section, we provide an overview of 17 IMWs within the Pacific Northwest. Although several enhancement actions are being evaluated within the IMWs, the most common actions are instream placement of large wood, reconnection/improved access to tributary and floodplain habitat, and barrier removal (Table 1). Riparian enhancements are occurring within most of the IMWs, but their effects are not yet being evaluated directly for increasing fish productivity because of the time needed for trees to grow. At least nine IMWs have been implemented within the Columbia River basin (Reeves et al. 1997; Bennett et al. 2016). These projects are located in the Asotin, Bridge, Entiat, Fish Creek, Lemhi, Lower Columbia, Middle Fork John Day, Potlatch, and Wind River watersheds (Figure 1). An additional eight IMWs occur outside the Columbia River basin. Those are located in the Alsea, Elwha, Hood Canal Complex, Keogh, Pudding, Skagit, Strait of Juan de Fuca, and Tenmile watersheds (Figure 1).

Table 1. Summary of intensively monitored watersheds (IMWs) within the Pacific Northwest (table from Bennett et al. (2016) and Hillman et al. (2016) with modifications). LWD = large woody debris, ELJ = engineered log jam, and BDA = beaver dam analogs. Fish Creek data are from Reeves et al. (1997).

IMW NAME	YEAR STARTED		ECOREGION	BASIN/ WATERSHEDS	FOCAL SPECIES	ENHANCEMENT TESTED	MAGNITUDE OF TREATMENT
	MONITOR	ENHANCE					
Alsea	1988	1990 in Nestucca 1991 in Alsea	Coast Range	Northern Oregon Coast/ Alsea and Nestucca	Coho, steelhead, cutthroat	LWD, floodplain reconnection	52 pools, 21 alcoves
Asotin	2008	2012	Columbia Plateau	Lower Snake/ Charley, North Fork and South Fork Asotin creeks	Steelhead	LWD	654 wood structures in 12 km
Bridge	2007	2010	Blue Mountains	John Day/ Bridge Creek	Steelhead	Beaver dams (BDAs)	121 beaver dam analog structures in 4 km
Elwha	2000	2011	Strait of Georgia/ Puget Lowland	Puget Sound/ Elwha River	Bull trout, salmon, steelhead	Barrier removal, ELJ	Access to 110 km
Entiat	2003	2012	North Cascades	Upper Columbia/ Entiat	Chinook, steelhead	ELJ, LWD, boulders, floodplain reconnection	35 ELJ structures, 1.9 km reconnected side channels

IMW NAME	YEAR STARTED		ECOREGION	BASIN/ WATERSHEDS	FOCAL SPECIES	ENHANCEMENT TESTED	MAGNITUDE OF TREATMENT
	MONITOR	ENHANCE					
Fish Creek	1982	1986	Central Cascades	Clackamas/ Willamette	Coho, steelhead, Chinook	LWD, boulders, floodplain reconnection, riparian improvement	500 LWD structures and two off-channel ponds
Hood Canal Complex	2003	2007	Strait of Georgia/ Puget Lowland	Puget Sound/ Little Anderson, Big Beef, Seabeck, Stavis creeks	Coho, steelhead	LWD, barrier removal, floodplain reconnection	Wood placement >200 pieces in 4 km, 2 bridges and 6 culverts replaced
Keogh	1976	1997 for habitat structures and nutrients 2014 for flow augmentation	Coast Range	Keogh River, Waukwaas River	Coho, steelhead	Road decommissioning, boulders, LWD, nutrient addition, flow augmentation	Nutrients added to mainstem and several tributaries, 500 instream structures, 7 off-channel ponds, extensive road stabilization and deactivation
Lemhi	2007	2009	Middle Rockies	Upper Salmon/ Lemhi River	Chinook, steelhead, bull trout	Barrier removal, flow augmentation, LWD, floodplain reconnection	Reconnected 275 km of tributary habitat
Lower Columbia	2001	2011	Coast Range	Lower Columbia/ Mill, Abernathy, and German creeks	Chinook, coho, steelhead	Nutrient addition, floodplain reconnection, LWD, barrier removal	Treated 10.4 km of stream and 0.18 km^2 of riparian habitat
Middle Fork John Day	2004	2008	Blue Mountains	John Day/ Middle Fork John Day River	Chinook, steelhead	ELJ, floodplain reconnection, LWD, flow augmentation, riparian improvement	200 ELJ, 600 pieces of LWD in 12 km, 13 km reconnected side channels, and 2 km^2 or riparian vegetation

IMW NAME	YEAR STARTED		ECOREGION	BASIN/ WATERSHEDS	FOCAL SPECIES	ENHANCEMENT TESTED	MAGNITUDE OF TREATMENT
	MONITOR	ENHANCE					
Potlatch	2005	2009 in East Fork Potlatch River 2013 in Big Bear Creek	Columbia Plateau	Clearwater/ Potlatch River	Steelhead	Barrier removal, flow increase, LWD, riparian improvement	10 km new access, improved flow, 218 wood structures, planted 11,200 shrubs and trees, and 5 km of fencing
Pudding	2006	2015	Coast Range	Northern California Coast/ Pudding Creek, Caspar and Noyo rivers	Coho, steelhead	LWD	438 pieces LWD in 12.1 km
Skagit	1992	2001	Strait of Georgia/ Puget Lowland	Puget Sound/ Skagit River	Chinook	Estuary reconnection	Reconnected 540 hectares of estuary
Strait of Juan de Fuca	1992	2000 for East Twin River 1996 for Deep Creek	Coast Range	Puget Sound/ East Twin River, West Twin River, and Deep Creek	Coho, steelhead, cutthroat	LWD, floodplain reconnection, riparian improvement, barrier removal	273 in-channel structures (1997-2004)
Tenmile	1991	1996	Coast Range	Northern Oregon Coast/ Tenmile, Cummins, Mill creeks	Coho, steelhead, cutthroat	LWD	Wood placement, 241 conifers in 11 km
Wind	2000	2009	Cascades	Lower Columbia/ Wind River, Trout and Panther creeks	Steelhead	Barrier removal, LWD	Removal of dam improved access to 22 km of habitat

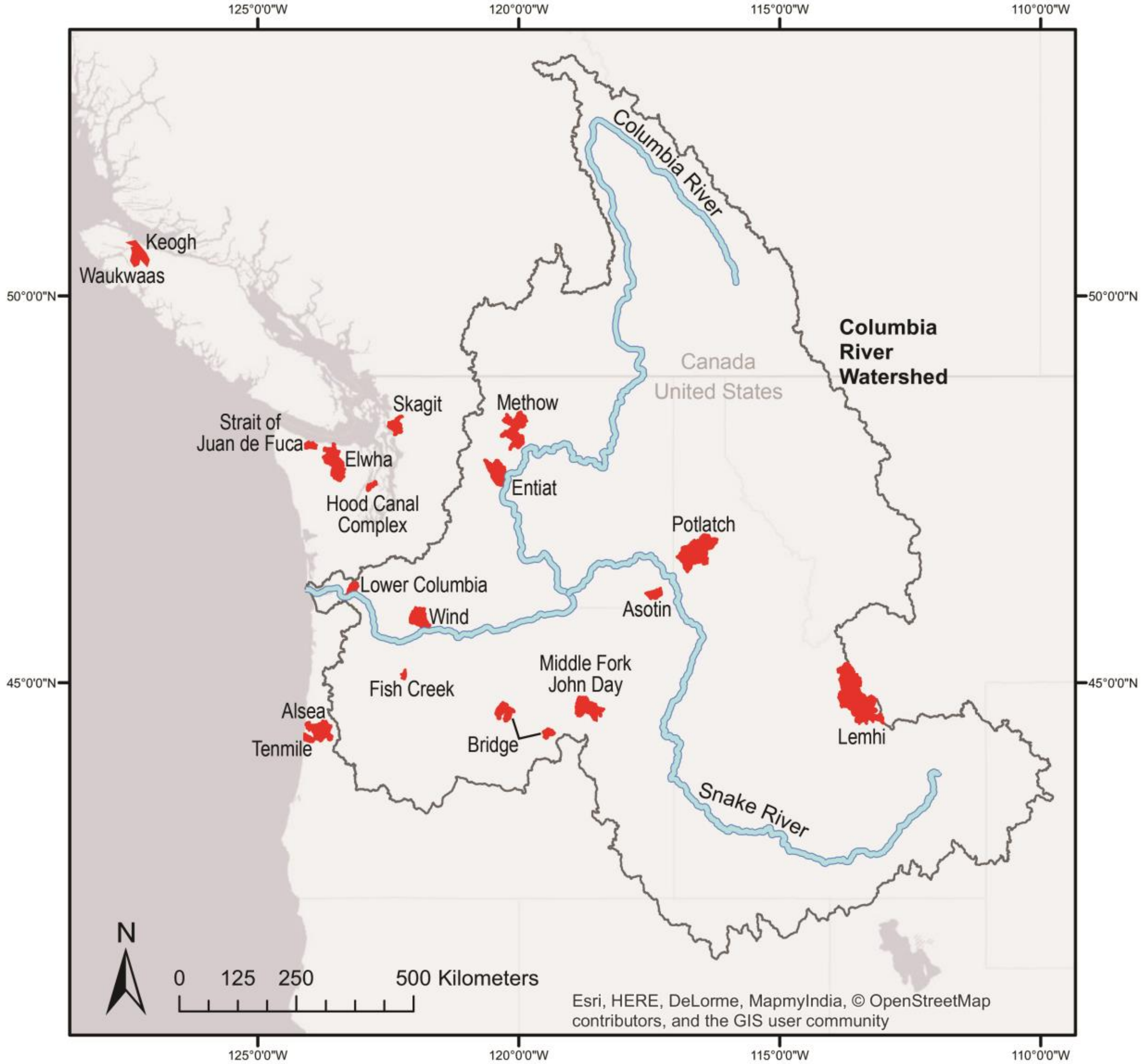

Figure 1. Locations of IMWs within the Pacific Northwest (figure from Bennett et al. (2016) with modifications).

In order to compile the most recent information on each IMW, we worked with the Pacific Northwest Aquatic Monitoring Partnership (PNAMP) to develop an IMW questionnaire (see Appendix 1). The questionnaire asked for basic and specific information about each IMW. The questionnaire was sent to primary investigators of each IMW. Investigators provided responses[1] to the questions and PNAMP compiled those responses in a draft report titled, “Key Findings and Lessons Learned from Pacific Northwest Intensively Monitored Watersheds.” The information provided below is based largely on the information contained in the PNAMP draft report and responses to the questionnaire.

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[1] Responses varied from general to very detailed. Thus, the quality of information provided is not equal among the IMWs. This is reflected in our summaries of each IMW.

It is important to note that most enhancement actions have not been implemented long enough to have been fully evaluated. Some IMWs are several years away from any definitive conclusions regarding enhancement effectiveness (e.g., Lower Columbia, Middle Fork John Day, and Pudding). In addition, as noted above, the coverage of each IMW below is not even. This is because the same amount and quality of information is not available for all IMWs.

2.1 Alsea IMW

The Alsea IMW is one of the earliest IMWs focused on enhancement and is one of the most successful IMWs to date (Solazzi et al. 2000). For this IMW, investigators conducted extensive work before enhancement to determine that overwinter habitat was limiting coho salmon, steelhead, and cutthroat trout within coastal streams. To determine if habitat enhancement actions increased the quality and quantity of winter habitat, and thus increased the abundance of downstream migrating salmonids, they set up a Before-After-Control-Impact (BACI) design where similar size streams located mostly on public lands were paired and evaluated over an eight-year period. One pair, Moon Creek (control; 13.2 km^2) and East Creek (treatment; 17.5 km^2), were in the Nestucca Basin and the other pair, East Fork Lobster Creek (control; 14.2 km^2) and Upper Lobster Creek (treatment; 12.4 km^2), were in the Alsea Basin, Oregon. Winter enhancement actions included construction of alcoves and wood and instream structures designed specifically to increase pool area and overwinter habitat. They created 23 dam pools and eight alcoves along 3.2 km in Upper Lobster Creek and 29 dam pools and 13 alcoves along 2.4 km in East Creek. Constructed pools averaged 160 m^2 in surface area compared with an average of about 50 m^2 for natural pools. The investigators used the Hankin and Reeves (1988) methodology to evaluate changes in summer and winter habitat in the paired streams before and after enhancement. They also estimated summer fish populations using a combination of snorkeling and electrofishing surveys and used modified incline-plane traps to estimate the number of downstream-migration coho salmon, steelhead, and cutthroat trout in each stream during spring. For each habitat or fish population parameter, they calculated the ratio of treatment to reference each year, estimated the mean log ratios for the pretreatment and post-treatment periods, and used a t-test to compare the means.

The investigators found that the enhancement actions significantly increased winter habitat and coho and steelhead abundance and survival within each of the treatment streams (East and Upper Lobster creeks). Winter rearing habitat increased by 700-1,300% in the two treatment streams compared to control streams. Coho and steelhead smolt production and survival increased by 200-800% in treatment streams relative to control streams.

This project was successful because enhancement actions targeted the factors limiting salmonids in the coastal streams and the design was sufficient to detect treatment effects. The inclusion of control streams was critical to the design of the study in order to detect a signal from the enhancement action due to interannual variation. If only before-after data were available, the researchers would have concluded that summer populations did not differ between the pre- and post-treatment periods. However, because summer populations in the control streams decreased post-treatment, the relationship between populations in treatment streams and control streams changed significantly.

2.2 Asotin Creek IMW

The Asotin Creek IMW is one of a few unique projects that evaluates a single enhancement action, implementation of LWD, at a watershed scale. The goal of the project is to use "active" adaptive management[2] to test the effectiveness of adding LWD to increase habitat complexity and increase steelhead production (Bouwes et al. 2016a).

Asotin Creek is a tributary of the Snake River in southeast Washington. The watershed covers 842 km^2 and has been affected by agricultural practices, forest harvesting, and grazing. The combined effect of these land-use actions has degraded stream habitat, especially in the lower reaches of the watershed. Important factors limiting salmonid production in the watershed include a lack of pool habitat and cover, lack of spawning habitat, lack of floodplain connectivity with limited refugia during high flows, and reduced large woody debris. The goal of this IMW is to examine the effectiveness of large wood additions in increasing steelhead productivity and production. The program also includes the use of grazing exclosure fencing and riparian plantings to promote the passive recovery of the riparian corridor. Importantly, Asotin Creek supports a mostly wild steelhead population as no steelhead supplementation occurs in the watershed and adult hatchery steelhead straying into the Asotin Basin are removed at the mouth of Asotin Creek.

In this study, researchers added LWD to 4-km-long treatment sections within each of three tributaries to Asotin Creek. Enhancement included the implementation of about 135-208 LWD structures within each treatment section. These structures were hand built to reduce costs and minimize disturbance to riparian vegetation. Following a staircase experimental design, one tributary was treated per year from 2012 to 2014, resulting in a total of 12 km of LWD treatment. An additional treatment was added to one stream in 2016. In total, 654 structures were installed resulting in 39% of the study area being treated (4.7 structures/100 m stream length). Fish and habitat conditions within these three treatment sections were compared to one to two 4-km-long control sections within each of the three tributaries. The researchers monitored a variety of fish, habitat, and biophysical factors (discharge, temperature, and water quality) across several spatial scales (at the LWD structure, site, treatment section, and watershed scales). They used mark-recapture techniques to monitor juvenile steelhead abundance, growth, movement, survival, and production at the site, treatment section, and watershed scale during all four seasons, and adult and smolt migrations at the watershed scale. Habitat conditions were evaluated using CHaMP protocols.

Although the project is incomplete (post-treatment monitoring is still occurring), current results are showing significant improvements in habitat complexity. The project has increased the frequency of LWD by 185% in treatment sections compared to control sections. The structures are creating hydraulic and geomorphic responses as hypothesized, and the researchers are finding a greater diversity of geomorphic features in treatment sections after enhancement compared to control sections (i.e., increase in total number of geomorphic features and increases in different types of features such as multiple pool and bar types). In addition, preliminary results indicate a significant increase in juvenile steelhead densities in treatment areas compared to control areas. In contrast, juvenile steelhead growth has decreased, likely because of density-dependence effects. The remainder of the study is focused on estimating seasonal survival rates, changes in productivity, production, and other life-history characteristics of steelhead, and identify the causal mechanisms of observed change.

According to Bouwes et al. (2016a), this IMW is successful because they implemented the IMW within an adaptive management framework. In short, the adaptive management framework includes a planning phase, doing phase, and an evaluation and learning phase, which allowed adjustments if necessary. Importantly, during the planning phase, the researchers and their partners used existing watershed assessments and literature reviews to identify problems within Asotin Creek. They followed up with their

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[2] Active adaptive management implements actions with the goal to maximize learning or reduce uncertainties that will inform future management actions (Sabine et al. 2004; Bouwes et al. 2016a).

own field studies to corroborate previous assessments and developed conceptual models for several aspects of stream dynamics and steelhead population life history. Given that enhancement actions in the 1990s addressed sediment inputs and riparian protection and enhancement, the researchers could focus on implementing LWD structures that would increase velocity refugia, pool habitat, geomorphic diversity, bar development, and floodplain connection without the worry that sediment recruitment would bury or displace their structures. Results from the planning phase were used to develop an enhancement strategy that would be large enough to "kick" the system out of its degraded state and put it on a trajectory where passive recovery and natural recruitment of LWD would increase both habitat complexity and steelhead production. That said, this study needs to compare responses in Asotin Creek with a reference or control watershed.

2.3 Bridge Creek IMW

Like the Asotin Creek IMW, the Bridge Creek IMW evaluates a single enhancement action at a watershed scale. In this case, researchers developed a watershed-scale experiment to test whether constructing beaver dam analogs (BDAs) to encourage natural beaver dam development could aggrade Bridge Creek (Bouwes et al. 2016b; ISEMP/CHaMP 2015; ISEMP/CHaMP 2016).

Bridge Creek is a tributary to the John Day River in Oregon. The watershed covers 692 km^2 and has been affected heavily by agricultural practices and grazing. As a result, Bridge Creek is a deeply incised stream with riparian vegetation limited to a narrow band along the stream. The stream lacks habitat complexity and has poor habitat quality. The goal of this IMW is to use BDAs to improve habitat quantity and quality and increase juvenile steelhead density, growth, survival, and production. The researchers are testing the hypothesis that BDAs and beavers will aggrade the channel and therefore alter hydrologic, thermal, geomorphic, and vegetation characteristics, which in turn will improve habitat conditions for steelhead.

The researchers saturated four reaches on Bridge Creek with BDAs, thereby providing resident beavers stable platforms that would encourage establishment of multi-dam complexes. Treatments were implemented in a spatially hierarchical staircase BACI design where the researchers established four of each treatment, control, and reference reaches within Bridge Creek. They also selected one control reach in each of two tributaries to Bridge Creek, and three reaches in a control watershed, Murderers Creek. In total, the researchers treated about 30% of the degraded habitat in Bridge Creek. Monitoring occurred three years before treatment (2007-2009) and seven years after treatment (2010-2017). The stream was treated in 2010. The researchers used extensive mark-recapture techniques to estimate juvenile steelhead abundance, growth, and survival. They used CHaMP protocols to examine changes in habitat conditions.

In 2013, following treatment, researchers counted 236 beaver dams in Bridge Creek. About half (n = 115) of these were made by beavers; the others (n = 121) were functioning BDAs. The combination of natural beaver dams and dams built on BDAs represents an eight-fold increase over the 2005-2008 pre-manipulation average. Treatment reaches experienced raised water levels and deeper pools, lower water temperatures, the creation of large upstream dam pools and downstream plunge pools, a 228% increase in inundation area, increased thermal refugia, and a 1,216% increase in side channel area. The beaver complexes also created greater variability in water depths, channel widths, and temperatures indicating an increase in habitat complexity. These changes in habitat conditions translated into changes in fish density, density-dependent decreases in growth, and increases in juvenile survival. Four years following treatment, juvenile production (product of density, growth, and survival) increased in Bridge Creek by

175% relative to the control (Murderers Creek). The treatments had no negative effects on upstream or downstream migration of juvenile or adult steelhead.

Results from this study demonstrate that BDAs and beavers are successful in aggrading incised channels, resulting in greater habitat complexity and improved steelhead abundance and survival. Importantly, the BDA approach is cost-effective and requires little or no long-term maintenance.

2.4 Elwha IMW

The Elwha IMW is focused on monitoring the largest dam removal project to date in the Northwest. The Elwha River basin is located on the Olympic Peninsula, Washington, and drains into the Strait of Juan de Fuca. It covers an area of 833 km^2. Elwha Dam (rkm 8), constructed in 1911, and Glines Canyon Dam (rkm 22), constructed in 1927, blocked anadromous fish passage to more than 110 km of habitat in the watershed. The Elwha and Glines Canyon dams were removed in 2012 and 2015, respectively. Before dam removal, only the lower 8 kilometers of the watershed were accessible to anadromous fish.

Researchers use a BA or BACI monitoring design, depending on which variables are measured. The study incorporates portions of the Elwha and Quinault rivers as reference areas. In addition to dam removal, treatments also included the placement of 40 log jams in the lower 8 km of the river. Pre-treatment data were collected during 2000-2010; post-treatment data collection began in 2014 and will continue into the future. The goal of the study is to evaluate changes in habitat conditions and the recolonization of anadromous fish.

The investigators collect fish, physical habitat, food web, and water quality data. Fish sampling includes estimating fish density, productivity, distribution, and diversity using SONAR, redd surveys, snorkel and electrofishing surveys, and screw traps. Habitat measurements include estimating percent fines, substrate composition, sediment recruitment, residual pool depth, proportion of functioning side channels, braiding, sinuosity, and wood transport. Food webs are constructed from collecting benthic invertebrate density, diversity, composition, functional feeding groups, and proportion of aquatic and terrestrial invertebrates in juvenile salmonid diets. Turbidity, suspended sediment, and water chemistry are measured to assess changes in water quality.

Dam removal resulted in rapid changes in stream channel morphology and development of a riverine/estuary delta. Several studies documented the massive amounts of sediment and changes in habitat following the removal of Elwha River dams (e.g., Magirl et al. 2014; East et al. 2015; Foley et al. 2017; Shaffer et al. 2017). For example, East et al. (2015) reported that 10.5 million tons of sediment were released from the two former reservoirs, resulting in widespread bed aggradation of 1 m or more, changed the river from pool-riffle to braided morphology, and decreased the slope of the lowermost river. Initially, deposition of sediment altered the benthic community and reduced it by over 90%, resulting in changes to the food web and diets of juvenile salmonids, which transitioned from aquatic dominated to terrestrial dominated food. However, benthic invertebrate densities now are increasing in the lower Elwha. Salmonids are rapidly recolonizing newly accessible habitat, and this has resulted in immediate (first generation) changes to life-history trajectories in bull trout, which have resumed an anadromous life history. Returning numbers of Chinook salmon and steelhead have increased since the removal of the dams; however, their numbers remain below recovery goals. Juvenile salmonids have expanded their use of habitats beyond adult spawning areas.

This study is demonstrating that dam removal has large benefits to anadromous fish, even if there are short-term negative effects from sediment mobilization. The rigorous design and intensive sampling scheme used by the researchers allows them to effectively detect treatment effects from a background of large natural variability.

2.5 Entiat River IMW

The Entiat IMW focuses on enhancing habitat complexity and off-channel connectivity within the Entiat River. The Entiat River is located in northcentral Washington and flows into the Columbia River just upstream from Rocky Reach Dam. The Entiat River basin covers an area of 1,207 km^2 and stream conditions have been affected by agricultural practices, timber harvest, splash damming, roads, channelization, and residential communities.

Researchers and stakeholders determined that reduced instream complexity was the primary concern limiting Chinook salmon and steelhead production in the lower 42 km of the Entiat River, downstream from the boundary with the U.S. Forest Service (ISEMP/CHaMP 2015; ISEMP/CHaMP 2016). Current land uses (e.g., agriculture, roads, and resident communities) restrict enhancement options in this portion of the Entiat River; therefore, an engineered approach is used to increase complexity, including adding rocks and large wood to the river, and reconnecting the floodplain by breaching levees where possible. Similar to the Bridge Creek IMW, researchers in the Entiat IMW are using a hierarchical-staircase design to guide where and when enhancement actions are implemented to support comparisons between treatment and control reaches. Two of four planned rounds of habitat actions have been implemented so far (one round every 2-3 years), affecting about 14% of the targeted stretch of river. Researchers are testing the hypothesis that increasing instream complexity will result in increases in density, growth rates, survival, and productivity of juvenile salmonids. Intensive fish (mark-recapture studies) and habitat (CHaMP) monitoring occurs within treatment and control segments.

To date, habitat monitoring has shown a significant increase in the volume of wood in the Entiat River. No other habitat or geomorphic metrics have yet responded to the two pulses of treatments. At this time, researchers have found a significant increase in survival of steelhead but not for Chinook. In addition, fish are responding to the treatments on a seasonal basis at a fine scale. For example, higher densities of juvenile Chinook and steelhead use off-channel habitats compared to main channel locations within the Entiat River. Juvenile salmonid densities within off-channel locations were highest during the summer months and gradually declined through the fall and winter. Off-channel habitats located in the upper watershed produced more yearling spring Chinook smolts than those in the lower watershed. Similarly, estimates of seasonal survival for juvenile Chinook and steelhead were higher for locations in the upper watershed and more juvenile salmonids used habitats located higher in the watershed for over-winter rearing than in the lower watershed. Additionally, adult steelhead have been observed spawning within the enhanced side channels.

During 2009-2013, Polivka et al. (2015) conducted a detailed evaluation of habitat occupancy by juvenile Chinook and steelhead at some of the enhancement structures in the Entiat River. They found that both species were more abundant in improved pools than in natural pools in early summer, but this difference was mostly absent by September. Based on their extensive sampling, they concluded that the increase in juvenile Chinook abundance in improved pools was related to an increase in habitat capacity and not because of a redistribution of fish from natural habitat in the same segment.

Although monitoring data so far have not demonstrated substantial improvements in habitat or fish populations, it is important to note that the Entiat River has not experienced the high flows needed to affect channel morphology as hypothesized. Furthermore, the original enhancement plan is only 50% complete. Changes to the scope and timeline of the original IMW design (ISEMP 2015) also produced projects of smaller scale and scope, likely making it more difficult to detect a watershed-scale response to enhancement. Whether the enhancement plan can be implemented as originally designed is questionable. There are landowner and funding constraints that currently limit the success of the implementation and monitoring plan. In addition, during the implementation of the IMW, the Entiat National Fish Hatchery switched production from spring Chinook to summer Chinook. The IMW was not designed to address this major change in the basin. The Entiat IMW showcases the many challenges of implementing enhancement actions under a structured monitoring design.

2.6 Fish Creek IMW

Fish Creek, like the Alsea, is one of the earliest IMWs and employed a simple BA monitoring design (Reeves et al. 1997). The Fish Creek Watershed lies in north-central Oregon on the west slope of the Cascade Mountain Range and drains into the upper Clackamas River. The watershed is 21 km long and covers 171 km^2. The watershed supported coho salmon, steelhead, and few Chinook salmon. At the time the IMW was implemented, over 41% of the basin had been subjected to timber harvest and associated activities, including salvage logging within the riparian area, 225 km of roads (1.3 km/km^2), frequent debris flows and landslides, and intensive channel debris clearing. Thus, the focus of habitat enhancement in Fish Creek was to increase the amount and complexity of pool habitat for summer and winter rearing and the amount of spawning habitat, and to rehabilitate riparian vegetation to increase shading and decrease water temperatures. Several enhancement techniques were evaluated during the first three years of the program. Based on this work, the researchers decided to treat areas in the lower and middle portions of Fish Creek intensively during 1986-1988. This included the addition of 500 log and boulder combinations along the streambanks and construction of off-channel ponds. In most years, the ponds were stocked with hatchery coho fry.

Habitat and fish data were collected for seven years before enhancement actions (1982-1988) and seven years following enhancement (1989-1995). Habitat and fish data were collected in 1996 following major floods in November 1995 and February 1996 (the 1996 flood was considered to be a 100-year event). Data collection focused on quantifying the amount of habitat available to anadromous salmonids in late summer, estimating the number of juvenile anadromous salmonids in late summer, and estimating the number of smolts leaving in the spring. Sampling methods changed over time. Two approaches were used to assess habitat: (1) measuring area and volume of habitat units in five representative reaches and extrapolating those results to the rest of the watershed accessible to anadromous salmonids (1982-1984) and (2) beginning in 1985, estimating total habitat available to anadromous salmonids using the procedures of Hankin and Reeves (1988). During 1982-1984, researchers used electrofishing and snorkel surveys to estimate total numbers of juvenile anadromous salmonids within individual habitat types at eight different locations. Beginning in 1985, researchers employed the methods of Hankin and Reeves (1988) to estimate juvenile anadromous salmonid numbers. Numbers of smolts migrating from Fish Creek were estimated from 1985-1988 using a modified Humphrey trap. A revolving helix-screw trap was used to estimate numbers of smolts beginning in 1989. Numbers of smolts leaving the off-channel ponds were assessed using a rotating-drum screen located at the outlets of the ponds.

Despite intensive monitoring of habitat, parr, and smolts, significant changes in fish numbers were not detected after enhancement. There were rapid increases in pool habitat following placement of instream structures; pools constituted 39% of the total habitat area in 1995 compared with 11% in 1982. No significant increases in coho or steelhead parr or smolts were detected and Chinook were only present during initial years of study and their response to enhancement could not be examined. Floods in the winter of 1995/1996 damaged or destroyed more than 50% of the instream structures with 49% of the structures exported entirely out of the watershed. Steelhead smolt production decreased 83.5% from the post-enhancement period average and coho smolts decreased 5%. Road failures and other broader watershed-scale factors and processes following enhancement limited the success of the program. This program highlighted the need for (1) addressing watershed-scale processes, (2) a control watershed, and (3) not relying solely on statistical significance to determine fish response to enhancement.

2.7 Hood Canal Complex IMW

The Hood Canal IMW complex consists of four streams: Big Beef, Seabeck, Little Anderson, and Stavis creeks, which are small watersheds located on the Kitsap Peninsula in western Washington. These small streams all flow into Hood Canal, which flows into Puget Sound. These tributaries have suffered from timber harvest and rural development, resulting in homogenous, single-thread, plane-bed channels with deep incisions in some locations and extensive fine-sediment deposition in other areas. In some deposition areas, the stream goes subsurface during the summer, creating a series of isolated pools. A lack of habitat complexity and off-channel connectivity currently limits salmonid productivity within the watersheds. The enhancement plan is to restore patterns of connectivity for water, sediment, wood, and fish, and then increase habitat complexity.

The monitoring approach, which was initiated in 2003, is a BACI study design with Big Beef, Seabeck, and Little Anderson creeks serving as treatment streams and Stavis Creek serving as a control stream. Pre-treatment data were collected from 2003-2007; although, coho smolt data have been collected since 1992. Enhancement actions began in 2007 and will continue into the future. Enhancement activities completed so far include replacement of a blocking culvert with a fish passable structure and addition of 495 pieces of LWD within 3.7 km of Little Anderson Creek, removal of a dike (opened 4.5 hectares of floodplain habitat) and addition of 213 pieces of LWD within 7.5 km of Big Beef Creek, and replacement of three culverts with fish passable structures in Seabeck Creek. Post-treatment sampling is ongoing.

Investigators use a life-cycle monitoring approach to estimate the number of coho salmon adults, parr, and smolts in the four streams. Using a spatially balanced sampling design, investigators collect data within 20 habitat sites and 10 coho parr sites. They also conduct spawner surveys and operate smolt traps within each of the four watersheds. From these data, they estimate total number of redds, watershed-scale parr abundance (using mark-recapture techniques), and watershed-scale smolt abundance. These data are then used to estimate egg to parr survival, parr to smolt survival, and growth. Within Big Beef Creek, investigators use a weir to estimate total adult abundance, marine survival, and harvest rates (based on wild coho smolts tagged with coded wire tags). Within habitat sites, investigators collect a variety of habitat metrics that are used to estimate width-depth ratios, percent spawning gravel, LWD frequency, and pool frequency.

At this time, few enhancement actions have been completed with sufficient post-treatment time to evaluate fish and habitat responses. However, investigators did find a relatively large increase in coho smolt abundance following the replacement of a culvert near the mouth of Little Anderson Creek. The recent pulse of enhancement actions within Big Beef and Little Anderson creeks should provide a detectible treatment response.

Although this study is still in its infancy, it suggests that restoring connectivity may be an important enhancement action for increasing coho smolt abundance. However, low escapement and high harvest rates have raised concerns about whether these streams are at or near full seeding, and whether a full response to enhancement can be detected (Bennett et al. 2016). Reach-scale monitoring of LWD placement projects indicates increases in pool frequency and depth, but enhancement has not yet occurred at a scale needed to produce watershed or population-level changes in coho parr, smolts, or adults. Several high-magnitude enhancement projects are proposed for Little Anderson and Seabeck creeks, but these projects are currently not funded.

2.8 Keogh IMW

The Keogh River IMW is one of the most intensively monitored watersheds in the Pacific Northwest with 42 years of population tend data. The collection of population data since 1976 has allowed researchers to evaluate freshwater and marine influences on fish survival and abundance. This includes evaluation of road abandonment, LWD and boulder placements, nutrient additions, and, most recently, summer flow augmentation on fish production.

The Keogh River is a coastal river that flows into Queen Charlotte Strait on the northeast side of Vancouver Island, British Columbia. It drains an area of 129 km^2 and is subject to low flows and high water temperatures during late summer. Thus, the quantity and quality of salmonid habitat diminishes, especially for steelhead, during late summer. Like many coastal watersheds, the Keogh River watershed has been extensively logged. Because the Keogh River has been and remains an active area for research (over 100 papers have been published on studies conducted in the Keogh River), we focus on studies that evaluated effects of instream structures and nutrient enhancement, and the current stream-flow augmentation study.

In the 1990s, investigators examined the effects of instream structures (LWD and boulder structures) and nutrient enrichment on steelhead and coho growth and survival in the Keogh (treatment) and Waukwaas (control) rivers. This was one of the longest and most detailed studies on effects of nutrient enrichment on salmonid production and several studies have reported on fish responses to these treatments, including McCubbing and Ward (1997; 2000), Slaney et al. (1994; 2003), and Ward et al. (2003). From 1997-2000, investigators placed 475 habitat structures within 10 km of the Keogh River, completed several off-channel ponds and side channels, and treated 36.5 km of the river and 11 km of key tributaries with inorganic nutrients. A BACI design was used to assess if the treatments increased juvenile steelhead and coho abundance, size, smolt yield, and productivity (smolts/spawner). Juvenile abundance was estimated with mark-recapture electrofishing and seine-netting techniques in summer and fall, while smolt yield was estimated with a counting fence and rotary screw traps.

Researchers found that juvenile steelhead and coho abundance, size, and smolt yield, and smolts per spawner increased following addition of nutrients and instream structure placement. For example, steelhead smolt production increased 62% over pre-fertilization years; although, there was no increase in average smolt size because mean smolt age was reduced by about one year. Response of coho salmon was less pronounced with only a 21% increase in smolt production. A corresponding increase in adult steelhead returns was not observed, which was thought to be due to poor marine survival and high harvest levels (Ward 2000). This work demonstrates that large-scale habitat restoration and nutrient enhancement can increase smolt production, but it may not result in increased adult returns because of factors limiting fish survival in the ocean. In addition, it is not clear which action (adding instream structures or adding nutrients) had the greatest effect on increased smolt production.

Investigators are currently evaluating the effects of summer flow augmentation on fish production in the Keogh River. Previous work revealed density dependence in the steelhead spawner-smolt relationship, and by increasing summer flow conditions, researchers believe they will be able to increase steelhead smolt production. The Keogh River has the infrastructure to store and release water, which will allow for a more controlled experiment. The study uses a before-after design with three years of pre-treatment data collection (2011-2013) and five years of treatment (flow augmentation) data collection (2014-2018). Investigators measure stream discharge, water temperatures, habitat characteristics, quality of rearing habitat, juvenile density, and smolt production. It is too early to know the effects of flow augmentation on steelhead smolt production in the Keogh River; however, steelhead smolt production during the pre-treatment period was lower than the production measured in the 1980s.

2.9 Lemhi River IMW

The Lemhi IMW is one of the largest IMWs in the northwest with a watershed area of 3,290 km^2. The Lemhi River flows into the Salmon River in east-central Idaho. Land uses such as agriculture, irrigation diversions, timber harvest, and roads have reduced and degraded habitat conditions in the Lemhi River basin. Historically important spawning and rearing tributaries have been disconnected, stream flows have been significantly reduced, and water temperatures have increased because of land-use activities in the basin. As a result, Chinook salmon production is confined to the upper mainstream Lemhi River and Hayden Creek.

Stakeholders and researchers determined that insufficient instream flows, loss of access to historically important tributary habitat, and mainstem habitat simplification were the primary factors limiting Chinook and steelhead productivity in the Lemhi River basin (ISEMP/CHaMP 2015; ISEMP/CHaMP 2016). Researchers developed a plan to remove or reduce fish migration barriers, maintain or enhance riparian conditions, decrease fine sediment and temperatures, increase tributary connections, and improve habitat quality (i.e., provide quality substrate, increase off-channel habitat, and increase pool frequency). In sum, 22 types of habitat enhancement actions are being implemented to address ecological concerns in high-priority watersheds. To date, tributary reconnections have been achieved through replacing tributary diversions with mainstem diversions, enabling the reconnection of tributaries, reducing total water withdrawals through flow agreements, and allowing cooler tributary water to enter the mainstem Lemhi River. In addition, enhancement actions have addressed tributary passage impediments and improved habitat conditions within tributaries, providing access to relatively intact public lands. Several mainstem habitat enhancement actions were identified to improve habitat complexity and provide access to off-channel habitat.

Researchers implemented BA and BACI designs to assess treatment effects. Pre-treatment sampling occurred from 2007-2008, installation of treatments began in 2009 and will continue into the future, while post-treatment sampling began in 2011 and is ongoing. In this study, Hayden Creek serves as a reference watershed. Fish monitoring includes a generalized random tessellation stratified (GRTS) sampling approach, a spatially continuous sampling approach, smolt trapping, PIT-tag interrogation, and decomposition of adult Chinook and steelhead escapements at Lower Granite Dam. Habitat monitoring uses the CHaMP protocol within the same GRTS sample frame as the fish monitoring effort. This level of monitoring provides a description of life-stage specific responses to individual habitat actions and to accumulated effects of multiple actions at the population scale.

The reconnection of tributaries to the Lemhi River has nearly doubled the length of stream available to Chinook and steelhead, resulting in a 22% increase in stream area and a 19% increase in pool area (ISEMP/CHaMP 2016). Minimum instream flow agreements have addressed seasonal mainstem and Hayden Creek passage impediments, and reduced temperatures in the upper mainstem Lemhi River. Adult steelhead have moved into each of the five reconnected tributaries and these tributaries are producing anadromous juveniles. The distribution of Chinook spawning shifted following treatments, with an increasingly greater fraction of adult Chinook spawning in Hayden Creek. Researchers documented the presence of adult Chinook in two of the five reconnected tributaries and juvenile Chinook in all reconnected tributaries. Little Springs Creek appears to be an important temperature refuge for Chinook rearing. Providing access to important tributaries in the upper Lemhi resulted in more age-1 smolts per redd compared to pre-treatment conditions. Overall, enhancement work in the Lemhi River basin has increased the summer rearing capacity for parr by 62%. Survival information and modeling results indicate that juvenile Chinook rearing habitat, particularly winter habitat, is currently limiting in the lower Lemhi River. As a result, enhancement efforts have shifted to improve habitat in the lower Lemhi.

This study demonstrates the complexities of implementing an IMW within a large watershed. In this case, because most actions were implemented on private lands with several different landowners, an extensive amount of time was needed to gain support and trust from landowners. This project also required excellent communication and coordination among several entities, including monitoring and restoration personnel, landowners, regulators, and funding entities. In addition, because of the size of the watershed, a large treatment effect is needed to demonstrate fish and habitat benefits. The researchers noted that by implementing the study within an adaptive management framework, they were able to make changes in the implementation plan based on monitoring results.

2.10 Lower Columbia River IMW

The Lower Columbia River IMW began in 2001 and consists of three small streams; Mill, Abernathy, and Germany creeks. These adjacent streams flow into the lower Columbia River near the town of Longview, Washington. The area of the watersheds ranges from 59 to 75 km^2. Timber harvest has affected the habitat conditions within these streams. As a result, habitat diversity and quality, channel stability, sediment load, water temperatures, and stream flows limit salmonid production within the streams.

The monitoring approach is a BACI study design with Abernathy and Germany creeks serving as treatment streams and Mill Creek serving as a reference stream. The restoration plan includes nutrient enhancement (fall treatment in Germany Creek and spring treatment in Abernathy Creek), improving off-channel connectivity, increasing habitat complexity, and improving fish passage in tributaries. Investigators collected pre-treatment data from 2001-2012. They treated streams with nutrients (carcass analogs) from 2011-2015 and monitored the effects of those treatments during the same time period. In addition, during 2012-2020, they will address habitat conditions by adding LWD to the channels, reconnecting floodplains, and providing fish passage in tributary streams. So far, they have treated 2.4 km of stream and 0.14 km^2 of riparian habitat in Germany Creek and 8.0 km of stream and 0.04 km^2 of riparian habitat in Abernathy Creek. Post-treatment monitoring will occur from 2021-2033.

Investigators assess fish populations and habitat responses to the treatments within the three streams. For coho salmon, Chinook salmon, and steelhead, they estimate annually the abundance, density, and size of parr; abundance, size, and timing of outmigrants; and abundance, size, age, and timing of spawners within the streams. Habitat conditions are measured annually within index reaches selected from a spatially balanced design and water quality and quantity are measured daily near the mouths of each stream.

At this time, it is too early to assess the effects of floodplain reconnection, instream wood, and fish passage treatments. The streams are currently being treated and will continue to be treated until 2020. However, investigators have evaluated the effects of nutrient enhancement. Based on three years of fall treatments in Germany Creek and three years of spring treatments in Abernathy Creeks, researchers found immediate responses in invertebrates and fish, but not periphyton. They documented increased growth rates in coho salmon from spring treatments but not fall treatments. They found that nutrient enhancement was not sustained over time and did not result in more outmigrants the following year. Thus, nutrient enhancement did not result in a population-level response.

This study demonstrates that nutrient enhancement may not be the best approach for restoring depressed salmonid populations. Even though there was an immediate growth response in coho from spring treatments, there was no population-level response, which is consistent with several other nutrient enhancement studies (see reviews by Collins et al. 2015 and Hillman et al. 2016). Importantly, as far as we know, nutrient limitation was not identified as a limiting factor in Abernathy and Germany creeks. Thus, one may not expect a response to nutrient enhancement.

Based on analysis of pre-treatment data, this study also demonstrates that large spatial and temporal variability in stream habitat conditions will make it difficult to assess the effectiveness of enhancement actions such as instream structures, fish passage actions, and off-channel reconnection projects.

2.11 Middle Fork John Day IMW

The Middle Fork John Day IMW is a large-scale project designed to assess the effects of multiple treatments at different spatial scales. The Middle Fork John Day River is a tributary of the John Day River in northeastern Oregon. The Middle Fork drains an area of 2,087 km^2. Land-use activities (e.g., mining, grazing, and timber harvest) have reduced habitat complexity, channel stability, riparian structure and function, floodplain condition and connectivity, sediment routing, stream flows, and temperature regimes. Compared to historical conditions, peak flows are higher and late-season flows are lower than in the past. The goals of this IMW are to evaluate the benefits of enhancement actions on steelhead and spring Chinook in the upper part of the river and to determine how specific enhancement actions affect habitat, water temperatures, and salmonids at the watershed, tributary, and reach scales.

This IMW is relatively complex, incorporating BA and BACI designs within a nested hierarchical framework. The framework includes a whole watershed-scale evaluation of enhancement actions and nested experiments within the larger framework that target specific actions ranging from watershed to individual project scales. The restoration plan includes the implementation of a wide variety of actions including fish passage, channel reconfiguration, instream habitat improvement, flow increases, upland management, and riparian fencing and plantings. To date, the program has implemented about 100 projects including channel restoration, floodplain reconnection, riparian fencing, LWD placement, and log weir removal. In sum, this work has added 48 km of habitat, 4.6 km of channel realignment, and 2 km^2 of riparian vegetation. Investigators collected pre-treatment data from 2004-2017. Treatments were added during 2008-2017. Post-treatment monitoring began in 2008 and is ongoing.

Researchers measure fish and habitat responses to treatments at multiple spatial scales. At a large spatial scale, researchers compare steelhead productivity data (smolts/spawner) in the Middle Fork (treatment) to the South Fork John Day River (control) and Chinook productivity in the Middle Fork (treatment) to the North Fork John Day and upper mainstem John Day rivers (controls). They measure density, distribution, productivity, and survival for both juveniles and adults. Nested within this larger experiment is the Camp Creek (treatment) and Granite Boulder Creek (control) study, which evaluates enhancement actions at a smaller watershed scale. Because of a longer-term data set, researchers replaced Granite Boulder Creek with Murderers Creek, a small watershed within the South Fork John Day River. Habitat conditions, including temperature, groundwater, riparian habitat, and physical habitat, are measured at multiple scales. In addition, researchers use a model to predict effects of riparian planting on stream temperatures. They also developed a life-cycle model to assess the effects of different enhancement scenarios on steelhead performance. Simulations from the life-cycle model are used to upscale reach-level mechanistic models to inform population-level assessments and to prioritize enhancement actions.

The implementation of about 100 enhancement projects in the Middle Fork John Day has not significantly increased productivity, smolt density, or adult spawners when compared to control watersheds. Although habitat conditions did improve, high water temperatures continue to be the primary factor limiting population performance. Groundwater inputs did improve temperature regimes in tributaries, but those actions did not significantly decrease temperatures in the Middle Fork. Researchers also found that livestock removal increased riparian vegetation and caused changes in channel morphology and habitat, but the changes were not significant. Grazing pressure from deer and elk continues to limit the enhancement of riparian forests.

An important outcome from this ongoing study is that without addressing high water temperatures, treatments targeting instream habitat quality and quantity are insufficient to elicit fish responses. According to their life-cycle modeling work, high water temperature is the primary factor limiting steelhead and Chinook salmon production in the Middle Fork and overrides any possible benefits from improving instream habitat. Importantly, life-cycle modeling has proven effective in identifying limiting factors and prioritizing enhancement actions. Researchers in the John Day recommend the use of life-cycle modeling in other IMWs.

2.12 Potlatch River IMW

The Potlatch River IMW is designed to assess the effects of multiple treatments at different spatial scales. The Potlatch River is located in northern Idaho and enters the lower Clearwater River east of Lewiston, Idaho. It covers an area of 1,538 km^2. The watershed consists of two distinct regions based on differences in stream morphology, hydrology, and land use. The lower portion of the watershed is characterized by steep-basalt canyons rimmed by croplands. Here, the primary factors limiting salmonid production are low summer flows and tributary blockages. In contrast, the upper portion of the watershed is characterized by timbered hills and meadow terrain. The primary factors limiting salmonid production in the upper watershed are a lack of pools and instream cover and degraded riparian conditions.

This IMW, much like the Middle Fork John Day IMW, uses BA and BACI designs within a nested hierarchical framework (Bowersox and Biggs 2012; Heekin 2013). Researchers use BA monitoring to assess treatment effects at the watershed scale and BACI monitoring to assess treatment effects at the tributary scale. Reach-scale monitoring is used to tease out treatment effects by enhancement type. Because of the two distinct regions within the watershed, researchers developed an enhancement plan specific to each region. In the lower watershed, the enhancement strategy is to expand rearing habitat by removing fish passage barriers and increase base-flow conditions. In the upper watershed, the strategy is to improve riparian habitat and increase instream habitat complexity by re-meandering channels, installing log structures, planting riparian areas, and fencing out livestock. Currently, researchers are focusing enhancement efforts in Big Bear Creek in the lower watershed and in East Fork Potlatch River in the upper watershed. In Big Bear Creek, the program has removed ten fish passage barriers, which opened about 10 km of spawning and rearing habitat, and increased base flows within 16 km of channel. In East Fork Potlatch River, the program has installed 218 LWD structures, planted more than 11,200 shrubs and trees, and installed more than 5 km of fencing. Investigators collected pre-treatment data from 2005-2013 in Big Bear Creek and 2008-2009 in East Fork Potlatch River. Treatments began in 2013 in Big Bear Creek and 2009 in East Fork Potlatch River. Treatments in both streams are ongoing. Post-treatment monitoring began when streams were treated and is ongoing.

Monitoring began in 2005 in Big Bear Creek and in 2008 in East Fork Potlatch River. Early monitoring efforts focused on measuring steelhead production and productivity at the watershed scale and juvenile density and distribution at the tributary scale. In 2013, researchers expanded monitoring to include measurement of juvenile survival and growth. In addition, researchers use a life-cycle model to examine potential watershed-scale responses in juvenile steelhead to planned enhancement actions.

To date, researchers have completed about 25% of the planned treatments. Although treatments implemented so far have not generated a measurable increase in steelhead productivity (emigrants per spawner) at the watershed scale, responses detected at the tributary and reach scales indicate the treatments are working and will likely effect change at the watershed scale in the future. Investigators documented an increase in steelhead spawning distribution following barrier removal, juvenile steelhead use of LWD structures during summer and winter, increased stream habitat and water quality with increased base flows, and improved pool frequency and canopy cover. They also documented a shift in the age structure and length at age of emigrants.

This IMW demonstrates the importance of treating a large percentage of the degraded habitat conditions within a watershed. Although researchers were able to demonstrate positive treatment effects at the tributary and reach scales, the treatments were not large enough to generate a detectable response at the watershed scale. Life-cycle modeling work suggests that the addition of proposed enhancement actions could increase juvenile steelhead production 40-90%. Funding, personnel, and land-owner constraints have limited the pace of habitat enhancement; however, incorporating a rigorous adaptive management plan has better aligned enhancement with monitoring results and produced a more efficient enhancement program.

2.13 Pudding Creek IMW

The Pudding Creek IMW is located in northern California and is designed to assess the effects of LWD enhancements on coho salmon and steelhead. Pudding Creek and its paired control stream, Casper Creek, each cover about 50 km^2 and flow into the Pacific Ocean near Fort Bragg. These streams have experienced extensive timber harvest resulting in reduced habitat complexity. Previous research has demonstrated that a lack of habitat complexity is limiting juvenile coho and steelhead production in the streams. The goal of this project is to treat about 80% of Pudding Creek with LWD.

The monitoring approach is a BACI study design with Pudding Creek serving as the treatment stream and Casper Creek serving as the control stream. The restoration plan is to increase summer and winter rearing habitat by treating 80% of Pudding Creek with 438 pieces of LWD (1,366 m^3 of wood in 12.1 km of stream). Investigators collected pre-treatment data from 2006-2014. They treated Pudding Creek with LWD in 2015. Post-treatment monitoring began in 2016 and will go through 2020. As part of the IMW, they measure survival, production, and growth of juvenile coho salmon and steelhead and measure total habitat by volume, slow-water habitat area, ratio of slow to fast water habitat, habitat diversity, and average residual pool depth.

Although the investigators reported higher than average adult returns following treatment, it is too early to determine if the LWD treatments increased the survival, production, and growth of coho and steelhead in Pudding Creek.

2.14 Skagit River Estuary IMW

The Skagit River Estuary IMW is a large monitoring program designed to assess the effects of estuary enhancement actions on different life histories of juvenile Chinook salmon. Before draining into Skagit Bay in the northern part of Puget Sound, the river splits into the North and South Forks of the Skagit River. The Skagit River basin is about 8,030 km^2 and is the largest watershed entering Puget Sound. The Skagit River basin has been subject to extensive agricultural activities, timber harvest, and other resource extractions. The estuary has experienced diking, dredging, and filling with about 75% of the tidal delta disconnected from freshwater and tidal inundation. About 25% of the intertidal shoreline in Skagit Bay is armored to protect farmland and infrastructure from erosion. Because available rearing habitat within the estuary currently limits the production of at least three different life histories of juvenile Chinook salmon that rear in the estuary for varying periods of time (Greene and Beechie 2004; Beamer et al. 2005), the goal of the estuary enhancement project is to increase estuary rearing capacity by 60%.

This IMW incorporates BA and BACI designs with treatments added to the South Fork Skagit River and the North Fork Skagit River serving as the control. The restoration plan includes dike removal, breaching, and setbacks; installation of muted tidal regulators; and fill removal. To date, about 20% of the 60% enhancement goal has been achieved. Investigators collected pre-treatment data from 1992-present. Treatments began in 2001 and are ongoing. Post-treatment monitoring began in 2001 and is ongoing. Researchers measure juvenile Chinook size, growth, density, residence time, changes in timing, marine survival, and the number of different life-history types using the estuary.

The implementation of enhancement actions has increased the capacity of juvenile Chinook salmon in the estuary. Investigators have documented longer rearing periods in the estuary and near-shore habitats and higher densities of juvenile Chinook. At this time, enhancement actions have not been sufficient enough to increase smolt-adult return rates. Modeling suggests that recent low spawner numbers are making it difficult to evaluate density dependence. Thus, additional enhancement actions combined with higher spawning escapements are needed to test for increases in smolt-adult return rates. In addition, the increased capacity within the estuary has not yet translated into higher marine survival; although, there is little statistical power to evaluate survival benefits. The investigators report that improvements in marine survival are positive.

This study demonstrates the difficulty of planning enhancement work within the context of a research plan. That is, limited opportunities for estuary enhancement work often dictate where actions can be implemented. In addition, funding is often limiting, and estuary enhancement projects compete with other recovery actions for limited funds. That said, this study is showing that dike removal/setbacks and breaches increases the density of juvenile Chinook salmon in the estuary.

2.15 Strait of Juan de Fuca IMW

The Strait of Juan de Fuca IMW was initiated to test the watershed-scale response of steelhead and coho salmon to watershed enhancement (Bilby et al. 2005; Roni et al. 2015). The "Straits" IMW includes two treatment watersheds (East Twin River and Deep Creek) and one control watershed (West Twin River), which are located on the Olympic Peninsula in Washington State, draining northerly into the Strait of Juan de Fuca. Each watershed drains an area less than 50 km^2. The watersheds are primarily on commercial forest land and decades of forestry (timber harvest, road building, etc.) have resulted in loss of instream wood, pool habitat, and delivery of fine and coarse sediment from forest roads. These land-use activities have increased the frequency of landslides and the potential for mass-wasting, which has simplified the stream channels. The goal of the enhancement program is to increase in-stream wood, increase overwinter habitat, reduce the occurrence of landslides, and restore riparian habitat. This is accomplished by adding LWD to the channel, removing roads and culverts, creating off-channel habitat, and planting riparian vegetation.

Although the study suffered from not being well defined originally, the program currently uses a control-impact design to assess watershed-scale effects and a BACI design to assess changes in habitat conditions. The program has currently treated about 30% of anadromous habitat in both East Twin River and Deep Creek. East Twin River was treated between 2000-2011, while Deep Creek was treated between 1996-2018. West Twin River remains untreated. Investigators collected pre-treatment data from 1992-1996 in Deep Creek. Limited pre-treatment data were collected in East Twin River. Post-treatment monitoring began in 2002 in East Twin River and in 1996 in Deep Creek. Post-treatment monitoring is ongoing in both watersheds. Monitoring in West Twin River (control) began in 2004 and is ongoing.

Investigators measure habitat quality, flow conditions, and coho and steelhead survival, growth, and production within each watershed. Monitoring of physical habitat and coho and steelhead parr densities began in 2004 using the Environmental Protection Agency’s Environmental Monitoring and Assessment Program (EMAP) site-selection and sampling protocols. Smolt and adult monitoring predates the IMW program, and began as early as 1998 in some watersheds, while stream flow, temperature, and water quality monitoring began in 2004. Habitat surveys record numbers of wood jams, pieces of LWD, pools, and riffles and measure depths and bankfull widths, canopy closure, pool area, pool forming features, riffle area, gradient, and side channel lengths. Stream flows measured near the mouths of the watersheds are used to calculate peak flow magnitude and duration. Mark-recapture surveys (using PIT tags) and smolt traps are used to estimate juvenile coho and steelhead growth, production, and overwinter survival. These data, combined with spawning surveys, are used to estimate smolt to adult return rates for coho and steelhead.

The addition of over 20 large-scale enhancement projects in the treatment watersheds has resulted in increased juvenile survival and life-history diversity. Juvenile coho survival in Deep Creek increased from less than 0.5 to over 1.25 times the survival of juvenile coho in the West Twin River (control). Data also suggest that coho productivity (smolts per spawner) increased in Deep Creek. In addition, researchers are documenting an increase in the proportion of yearling steelhead migrants in Deep Creek compared to West Twin River. There has also been an increase in the proportion of yearling coho migrants, but this increase is occurring in both treatment and control watersheds.

This study highlights the need for collecting pre-project data and regular coordination of monitoring and enhancement activities, which have been challenging because of the variety of organizations involved in data collection. The study also demonstrates the importance of having support and funding to manage large quantities of data. In addition, investigators are finding that analyses of trends improve when habitat sampling occurs each year within the treatment and control watersheds; analyses are more difficult when monitoring is staggered across years. Also, because fish within these watersheds migrate throughout the year, investigators found that monitoring migrations with PIT-tag arrays provides a more complete picture of life-history diversity, migration timing, and out-migration productivity compared to traditional spring smolt trapping. Finally, because restoration of watershed processes can take years to decades to reach their intended goals (e.g., riparian and upland enhancement actions), monitoring programs need to be long term in order to track both habitat and fish population responses at the watershed scale.

2.16 Tenmile IMW

The Tenmile Creek IMW was initiated in 1991 and completed in 2001 and was designed to assess the effects of increasing large wood on summer population size, smolt abundance, and freshwater survival of steelhead, coho salmon, and cutthroat trout (Johnson et al. 2005). The study consisted of one treatment (Tenmile Creek) and one reference (Cummins Creek) watershed. Both streams enter the Pacific Ocean on the central Oregon coast. Tenmile Creek covers an area of about 61 km^2, while Cummins Creek is smaller covering an area of 25 km^2. Tenmile Creek has experienced timber harvest and other land uses, while Cummins Creek is designated as a wilderness area. A lack of pools, side channels, and spawning habitat limit fish production in Tenmile Creek.

Researchers implemented a BACI monitoring design; however, they found that the pairing of the treatment and reference streams was not appropriate because the reference stream did not track well with the treatment stream. Therefore, they compared data before and after treatment separately for each stream. Treatment included the addition of 241 large conifer trees to 11 km of the stream channel. These trees were placed predominantly within the upper half of the Tenmile Creek watershed. During the same year the stream was treated, a large storm caused additional wood to enter Tenmile Creek. Wood from the storm was primarily confined to the lower portion of the watershed and the amount of wood added from the storm was similar to the amount added manually. The storm also recruited large wood to Cummins Creek. Pre-treatment data were collected from 1991-1995 but not consistently for all measured parameters. Tenmile Creek was treated in October 1996. The flood, which recruited wood to the channels, occurred in February 1996. Post-treatment data were collected from 1997-2001 but not consistently for all measured parameters.

The investigators collected both habitat and population data before and after treatment within the two streams. They used the Hankin and Reeves (1988) methodology to estimate the amount of available summer and winter habitat for fish in the two streams. They used snorkel and electrofishing (mark-recapture and removal-depletion) techniques to estimate the number of fish during summer. They also used rotating screw traps to estimate the number of emigrants from the two streams. They collected scales from juvenile steelhead to estimate their ages.

The addition of large wood to Tenmile Creek increased the number of key pieces of wood to levels observed in the reference stream. The wood additions increased the percentage of surface area of pool habitat and pool depth, and increased winter side-channel habitat. Steelhead smolt abundance, steelhead freshwater survival, and coho freshwater survival increased following the input of large wood. However, steelhead age-0+ summer populations and steelhead smolt populations also increased in the reference stream; although, steelhead freshwater survival did not (Johnson et al. 2005). Thus, it was not clear if the fish response observed in the treatment stream was a result of enhancement or natural variation.

This study highlights some of the challenges of using a BACI design at a watershed scale. In this case, the reference watershed did not track the treatment watershed well and therefore did not serve as an adequate reference. In a paired BACI design, it is important that the parameters of interest track each other in the treatment and reference watersheds. One way to address the lack of tracking between paired watersheds is to use more than one reference watershed (known as multiple BACI or MBACI designs). Such designs, however, require significantly more resources and funding to complete. The researchers also noted that inadequate numbers of adult spawners to fully seed available habitat confounded the study. In this case, juvenile steelhead densities increased in the reference watershed as a result of increasing spawning escapements. Finally, this study demonstrates the difficulties in maintaining continuity in funding, personnel, and methods. Unforeseen changes in land-use activities, changes in fishing regulations, or large effects from floods or droughts can affect treatment and reference watershed disproportionately.

2.17 Wind River IMW

The Wind River IMW is designed to assess the effects of dam removal and other enhancement actions on steelhead abundance, capacity, and survival. The Wind River, located in southwest Washington, covers an area of 582 km^2 and drains into the Columbia River just upstream from Bonneville Dam. The watershed has experienced timber harvest, road and culvert construction, and splash damming. As a result, fish passage, reduced abundance of instream woody debris, sedimentation and scour, and reduced channel stability and habitat complexity limit steelhead and Chinook production in the Wind River basin (Coffin 2014; Buehrens and Cochran 2015). To address these issues, a collaborative enhancement and monitoring program was initiated in the 1990s.

Researchers implemented BACI and BA study designs to assess steelhead responses to the removal of Hemlock Dam, which improved access to 22 km of habitat in Trout Creek. In this study, Trout Creek is the treatment stream and the mainstem Wind River serves as the reference stream. In addition to removal of Hemlock Dam on Trout Creek, other enhancement actions included road decommissioning, addition of woody debris and engineered log jams, removal of invasive plant species, riparian enhancement, improved fish passage at road crossings, and the removal of Martha Creek Dam in 2012. However, this IMW focuses on assessing the effects of Hemlock Dam removal on steelhead abundance and survival. Little enhancement work has occurred in the reference stream. Pre-treatment data were collected from 2000-2009, Hemlock Dam was removed in 2009, and post-treatment monitoring began in 2016 and will go through 2020.

The investigators estimated steelhead adult, parr, and smolt abundance in both the treatment and reference streams. Before dam removal, adult abundance in Trout Creek was estimated using a fish-ladder trap. After dam removal, adult abundance was estimated using mark-resight techniques. Mark-resight techniques were used to estimate adult abundance within the reference stream. Investigators used rotary screw traps to estimate parr and smolt abundance. They also collected scales from juvenile steelhead to estimate their ages. These data were used to help develop spawner-recruit (smolt) relationships.

The removal of Hemlock Dam resulted in large increases in juvenile and adult steelhead abundance in Trout Creek compared to the reference stream. Adult steelhead returns increased from 77 spawners before dam removal to 208 spawners following dam removal. Steelhead smolt abundance increased 29% in Trout Creek following dam removal. In contrast, steelhead smolt abundance decreased 7.4% in the reference area during the same time period.

This study demonstrates the importance of leveraging existing, long-term, population data to increase statistical power and the success of the project. It also highlights the challenges of coordinating enhancement and monitoring activities among multiple partners and funding entities throughout the life of the project.

2.18 Summary

Although IMW projects are in varying stages of completeness, many are demonstrating habitat and fish responses. The most immediate responses have resulted from removing barriers (e.g., Lemhi, Potlatch, Wind, and Elwha IMWs). These projects have increased spawning distributions of salmon and steelhead and increased juvenile life-history diversity. Projects that improved floodplain and side-channel connectivity have also shown significant benefits. Instream placement of large wood has, in general, increased habitat diversity by increasing pools and side channels, which has resulted in an increase in juvenile fish density and survival, and in some cases reduced fish growth. At this time, enhanced stream flows and nutrient enhancement have not been fully evaluated.

Factors that continue to make implementing IMWs challenging are controlling other management activities (e.g., harvest, hatcheries, etc.), low spawning escapements, coordination of enhancement activities and monitoring across multiple organizations, the size of the watershed, natural and anthropogenic disturbances, and funding (Roni et al. 2015). Finally, as noted by Chapman (1996), Reeves et al. (1997), and others, maintaining control streams or watersheds is an important element of IMWs. Finding control streams or watershed is difficult and there is no guarantee that controls will remain suitable throughout the life of the project (e.g., Johnson et al. 2005). Excellent coordination among the various entities and stakeholders is needed to help maintain suitable control streams.

In the next section we respond to the eight key questions.

3 Responses to Key Questions

In an effort to answer the eight key questions, we reviewed each of the 17 IMWs implemented in the Pacific Northwest (see Section 2). These IMWs evaluate a wide variety of enhancement actions including barrier removal, instream structures, off-channel/floodplain habitat, riparian improvement, flow augmentation, nutrient enhancement, and reconnecting estuary habitat. What follows are responses to the key questions based on our evaluation of the 17 IMWs.

3.1 Are the IMWs covering a representative range of habitat improvement strategies and environmental conditions?

The current array of IMWs in the Pacific Northwest is evaluating all the major categories of enhancement actions (Table 2). Nearly all the IMWs include instream structures, while fewer include sediment reduction or nutrient enhancement actions. Several IMWs also evaluate fish passage and off channel/floodplain habitat actions. Flow augmentation and riparian improvements are also being evaluated by a handful of IMWs. Although riparian improvements are not noted as primary enhancement actions under most IMWs, we believe riparian actions are occurring at small scales within most IMWs because of permit requirements.

Although all major categories of enhancement actions are included in the existing IMWs, not all action types (subcategories) under each major category are being evaluated (Table 2). For example, nearly all IMWs are evaluating instream structures; however, most of the structures evaluated include the addition of LWD, boulders, ELJs, or beaver enhancement structures, or combinations of these. We are unaware of any IMWs that are evaluating the addition of spawning gravels. This does not necessarily mean that the watersheds being evaluated are not spawning-habitat limited. It may mean that practitioners are using instream structures (e.g., LWD, ELJs, boulders, and beavers) to help retain and sort spawning gravels (e.g., Asotin, Bridge, Fish, and Tenmile IMWs) or removing barriers to provide access to spawning habitat (e.g., Elwha and Lemhi IMWs). Another action that does not appear to be included in the existing IMWs is invasive species control (category under riparian improvement); although, the Wind IMW includes it as an enhancement action but does not appear to evaluate its effects directly. We assume that where riparian actions occur, practitioners are addressing invasive plant species, even though the action is not the primary focus of the project. Actions such as entrainment (category under fish passage) and agricultural practices (category under sediment reduction) are less well represented in the IMWs. The Lemhi IMW included actions to address entrainment. Indeed, the installation of NOAA-compliant screens in the Lemhi River basin is estimated to reduce Chinook smolt mortality from 71.1% to 1.9% (Walters et al. 2012). Regarding agricultural practices, the Middle Fork John Day IMW includes upland management, which appears to address agricultural practices.

Table 2. Habitat enhancement categories and subcategories, and the IMWs that examine each category.

PROJECT CATEGORY	SUBCATEGORY	IMW
Fish Passage	Barrier Removal Entrainment	Elwha Hood Canal Lemhi Lower Columbia Potlatch Strait of Juan de Fuca Wind
Instream Structures	Large wood and boulder placement Engineered Logjams Gravel addition Beaver enhancement structures	Alsea Asotin Bridge Elwha Entiat Fish Creek Hood Canal Keogh Lemhi Lower Columbia Middle Fk John Day Potlatch Pudding Strait of Juan de Fuca Tenmile Wind
Off-Channel/Floodplain Habitat	Reconnection Levee Removal/Setback Side Channel and Pond Construction/Creation Channel Enhancement/Re-meandering	Alsea Entiat Fish Creek Hood Canal Lemhi Lower Columbia Middle Fk John Day Skagit (estuary) Strait of Juan de Fuca
Riparian Improvement	Riparian Plantings and Silviculture Treatment Riparian Fencing and Grazing Invasive Species Control	Fish Creek Middle Fk John Day Potlatch Strait of Juan de Fuca Wind
Sediment Reduction	Road Agricultural practices	Keogh Middle Fk John Day Wind
Flow Augmentation	Water release or improvement Irrigation improvement	Keogh Lemhi Middle Fk John Day Potlatch
Nutrient Enhancement	Salmon carcasses or carcass analogs Organic or inorganic nutrient addition	Keogh Lower Columbia

Importantly, enhancement projects are designed to address specific limiting factors within a watershed. Thus, depending on what factor or factors limit salmonid abundance, distribution, and survival within a given watershed, a single action or multiple actions may be implemented. In some cases, a given enhancement action may address more than one limiting factor. For example, riparian enhancement may be used to address several different limiting factors. In many cases, enhancement actions are implemented to improve natural processes (e.g., improve stream flows, sediment dynamics, and floodplain connectivity) and therefore generally address more than one limiting factor. Thus, it is not surprising that all categories of enhancement types are not equally evaluated across the suite of IMWs.

IMWs are distributed across most of the ecoregions within the Pacific Northwest and therefore cover most of the climatic conditions within the region (Figure 2). The Coast Range includes the most IMWs (Alsea, Keogh, Lower Columbia, Pudding, Strait of Juan de Fuca, and Tenmile IMWs). The Cascades and Strait of Georgia/Puget Lowland ecoregions each include three IMWs. The Entiat, Fish Creek, and Wind IMWs are located in the Cascades, while the Elwha, Hood Canal Complex, and Skagit IMWs are located in the Strait of Georgia/Puget Lowland ecoregion. Asotin and Potlatch IMWs are in the Columbia Plateau ecoregion (the upper portion of the Potlatch IMW extends into the Northern Rockies ecoregion), while the Bridge and Middle Fork John Day IMWs are in the Blue Mountains ecoregion. The Lemhi IMW is the only one in the Middle Rockies ecoregion. No IMWs occur in the Okanogan ecoregion. Importantly, the RME Workgroup under the FCRPS BiOp purposely selected locations for several IMWs so that at least one IMW would fall within each of the major ecoregions within the Columbia River basin.

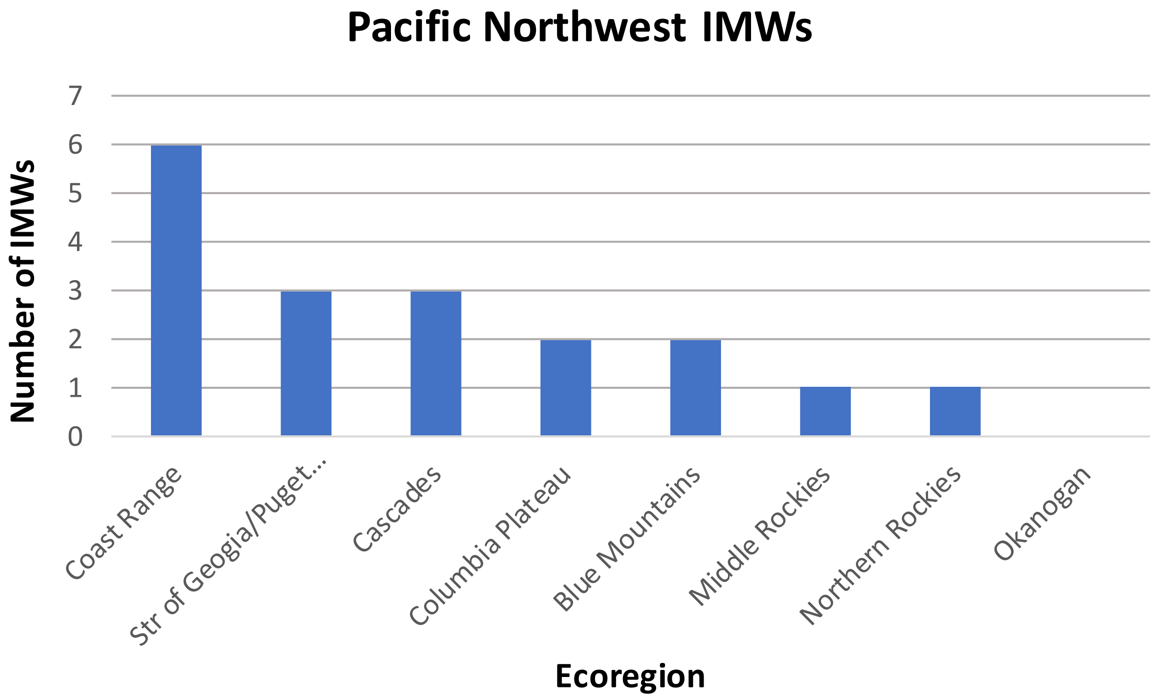

Figure 2. Number of IMWs within each ecoregion within the Pacific Northwest.

3.2 Are the IMWs asking the most appropriate and relevant questions?

In general, all IMWs need to ask if the enhancement actions implemented within the watersheds increase fish population performance at the watershed scale. With this information, one can determine if the results can be extrapolated to other populations or watersheds where intensive monitoring is not possible. Based on our review of the 17 IMWs, we found they all are asking if the enhancement actions increase population performance at the watershed scale (Table 3). In most cases, IMWs are assessing productivity (smolts per spawner), smolt abundance, and/or juvenile survival, all of which are performance indicators at the watershed scale.

Table 3. Primary questions addressed by each IMW within the Pacific Northwest.

IMW	PRIMARY QUESTIONS ADDRESSED
Alsea	• Will the addition of large wood and instream structures, and the construction of alcoves, increase overwinter habitat for coho salmon, steelhead, and coastal cutthroat trout? • Will the enhancement actions increase the abundance, survival, and number of spring migrants of coho salmon, steelhead, and coastal cutthroat trout?
Asotin	• Will the addition of LWD and debris catching structures increase pool habitat, habitat complexity, sediment sorting, the production of dynamic bars and increase lateral exchange through fluvial processes with riparian habitat? • Will grazing exclosure fencing and riparian planting promote the passive recovery of the riparian corridor and improve fish habitat, increase LWD recruitment, and facilitation of fluvial processes with more regular lateral exchanges between the channel and riparian? • Will these enhancement actions increase juvenile steelhead abundance, growth, survival, production, and productivity?
Bridge	• Will the installation of beaver dam analogs promote establishment of persistent beaver complexes leading to channel aggradation and increased floodplain and groundwater connectivity? • Will the treatments decrease stream temperatures, increase groundwater elevation, increase channel aggradation rates, increase extent of riparian vegetation, and ultimately increase juvenile steelhead survival, growth, and abundance?
Elwha	• Will the removal of Elwha and Glines Canyon dams restore natural watershed processes related to movement of water, sediment, and nutrients? • Will restored connectivity increase Chinook salmon, coho salmon, pink salmon, chum salmon, sockeye salmon, steelhead, bull trout, cutthroat trout, and Pacific lamprey abundance, productivity, distribution, and diversity within the watershed?
Entiat	• Will the placement of boulders and large wood and reconnecting floodplain habitat increase habitat complexity within the mainstem Entiat River? • Will treatments increase the density, growth, survival, and productivity of juvenile Chinook salmon and steelhead?
Fish Creek	• Will the placement of large wood and boulders, rehabilitation of riparian vegetation, and construction of off-channel ponds increase spawning habitat and the complexity of pool habitat? • Will the treatments increase coho salmon, steelhead, and Chinook salmon parr and smolt abundance?

IMW	PRIMARY QUESTIONS ADDRESSED
Hood Canal Complex	• Will replacement of culverts, adding large wood, and reconnecting floodplain habitat increase habitat complexity and connectivity within treatment streams? • Will increasing connectivity and habitat complexity increase juvenile coho salmon growth and survival, abundance of parr and smolts, and numbers of redds? • Will increasing connectivity and habitat complexity increase the size and number of cutthroat trout smolts?
Keogh	• Will the addition of large wood and boulder structures, construction of off-channel ponds and side channels, and the addition of inorganic nutrients increase juvenile steelhead and coho salmon abundance, size, smolt yield, and productivity? • Will the augmentation of stream flows during summer increase steelhead smolt production?
Lemhi	• Will the reconnection of important spawning and rearing tributaries to the mainstem Lemhi River, increased stream flows, improved instream habitat, and improved riparian conditions increase habitat capacity? • Will the treatments increase Chinook salmon and steelhead productivity; juvenile abundance, distribution, and survival; and adult abundance and distribution?
Lower Columbia	• Will nutrient enhancement, reconnecting off-channel habitat, adding large wood to increase habitat complexity, and improving fish passage increase coho salmon, Chinook salmon, and steelhead parr and smolt abundance, density, and size?
Middle Fork John Day	• Will fish passage improvements, channel reconfiguration, instream habitat improvements, flow increases, upland management, and riparian fencing and plantings improve habitat conditions and water temperature regimes? • Will treatments increase steelhead and Chinook salmon productivity and juvenile and adult density, distribution, and survival?
Potlatch	• Will removing fish passage barriers and increasing base-flow conditions increase steelhead productivity and juvenile density, distribution, growth, and survival? • Will improving riparian habitat and increasing instream habitat by re-meandering channels, installing log structures, planting riparian areas, and fencing livestock out of riparian areas increase steelhead productivity and juvenile density, distribution, growth, and survival?
Pudding	• Will the addition of large wood increase summer and winter rearing habitat and ultimately increase the survival, abundance, and growth of juvenile coho salmon and steelhead?
Skagit	• Will dike removal, breaching, and setbacks; installation of muted tidal regulators; and fill removal increase juvenile Chinook salmon size, growth, density, residence time, life-history diversity, and survival in the estuary?
Strait of Juan de Fuca	• Will the addition of large wood, removal of roads and culverts, creation of off-channel habitat, and planting riparian vegetation increase habitat complexity and overwinter habitat, reduce landslides, and improve riparian habitat conditions? • Will treatments increase coho salmon and steelhead productivity and juvenile abundance, survival, growth, and life-history diversity?
Tenmile	• Will the addition of large wood increase population size, juvenile survival, and smolt abundance of steelhead, coho salmon, and cutthroat trout?
Wind	• Will the removal of Hemlock Dam and habitat improvements upstream from the dam increase steelhead productivity and parr, smolt, and adult abundance?

Based on the information we reviewed, researchers identified what they believed were the primary factors limiting fish production within their respective watersheds. In many cases, they linked the limiting factors to threats (activities believed to cause the factors to be limiting; e.g., timber harvest, mining, roads, agricultural activities, etc.) and identified which life stages they believed were most limiting within the populations. They then identified enhancement actions that would address the threats and/or limiting factors. Depending on the watershed and its limiting factors, enhancement measures ranged from a single treatment type (e.g., Bridge Creek, Pudding, and Tenmile) to multiple treatment types (e.g., Lemhi, Middle Fork John Day, and Potlatch). In general, larger watersheds tended to include more treatment types than did smaller watersheds. In all cases, the objectives and questions of the IMWs linked the proposed actions to the limiting factors and life stages. By collecting the appropriate habitat and biological data, researchers have answered, or will answer, their primary questions.

Although not a requirement of IMWs, several IMWs are set up to evaluate causal mechanisms. For example, more than 25 hypotheses are associated with the Asotin IMW. Several of these hypotheses are set up to test causal mechanisms. In addition, the designs of several IMWs are set up to identify causal mechanisms. For example, hierarchical staircase designs and nested hierarchical designs (e.g., Asotin, Bridge Creek, Entiat, Middle Fork John Day, and Potlatch) are used to help identify causal mechanisms. In some cases, life-cycle modeling is used to tease out causal mechanisms (e.g., Lemhi, Middle Fork John Day, and Potlatch).

Although not always identified clearly, we believe the IMWs are asking and testing the most appropriate and relevant questions.

3.3 Are the IMWs in watersheds with high potential for learning?

Investigators have implemented IMWs within watersheds ranging in size from about 12 to 3,290 km^2 (the Skagit drains an area or 8,030 km^2, but this IMW focuses on the estuary) and across most of the ecoregions within the Pacific Northwest (see response to question #1). IMWs occur along the Pacific coast, within Puget Sound, and within the Columbia River basin. They also evaluate a wide range of ecological concerns and threats (Figure 3), with larger IMWs generally addressing more limiting factors than smaller IMWs. As indicated earlier, most IMWs address habitat complexity and off-channel connectivity issues. Fewer IMWs address riparian and nutrient issues. In addition, several IMWs are addressing multiple focal fish species (Figure 4). Thus, based on our evaluation of the IMWs, we believe existing IMWs are located within watersheds with a high potential for learning.

It is important to note that the initiation of several IMWs was largely opportunistic. That is, several IMWs were established in locations where monitoring data already existed, in locations were enhancement actions were large and unique (e.g., dam removal in the Elwha, Wind, and Potlatch), or where existing infrastructure allowed for relatively easy implementation of enhancement actions and monitoring programs. In other cases, IMWs were created purposely to address previous FCRPS BiOps (e.g., Lemhi, Methow[3], Entiat, Bridge Creek, and John Day). Regardless of the reason for the initiation of IMWs, they are widely distributed across the Pacific Northwest landscape, address several different limiting factors and focal species, and vary widely in size. All this allows for a high potential for learning.

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[3] The Methow was originally identified as an IMW; however, for a variety of reasons, it is best classified as a reach-scale effectiveness monitoring program.

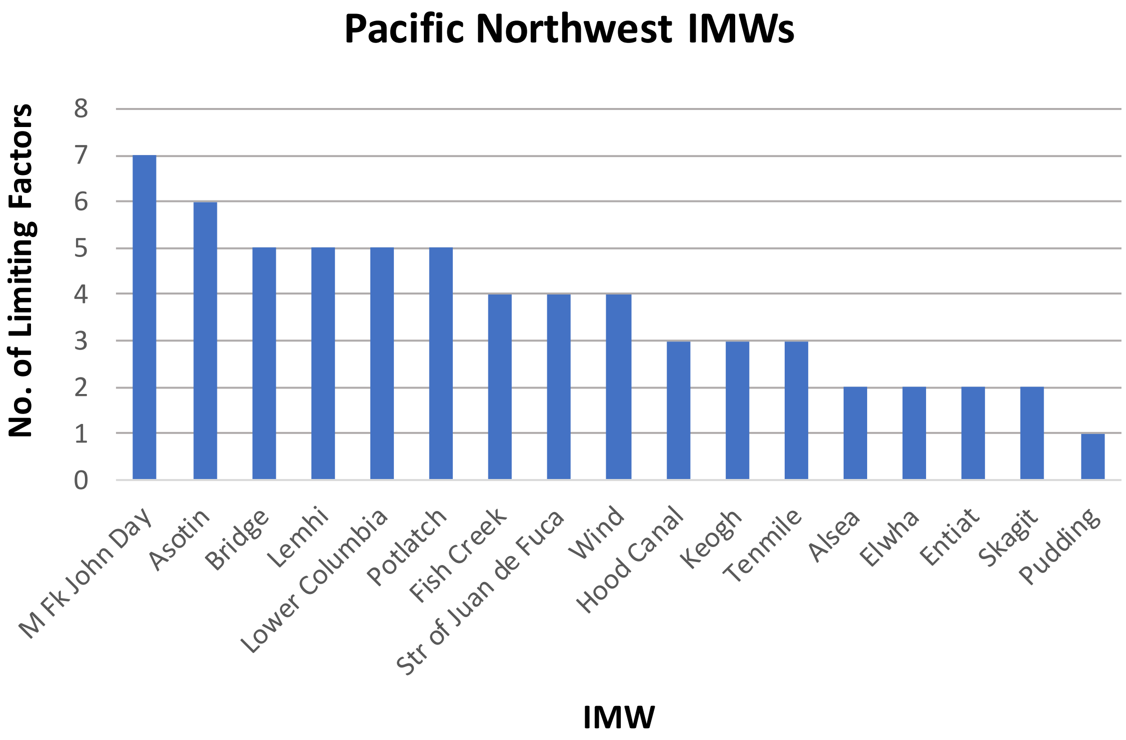

Figure 3. Number of primary limiting factors addressed within each IMW in the Pacific Northwest.

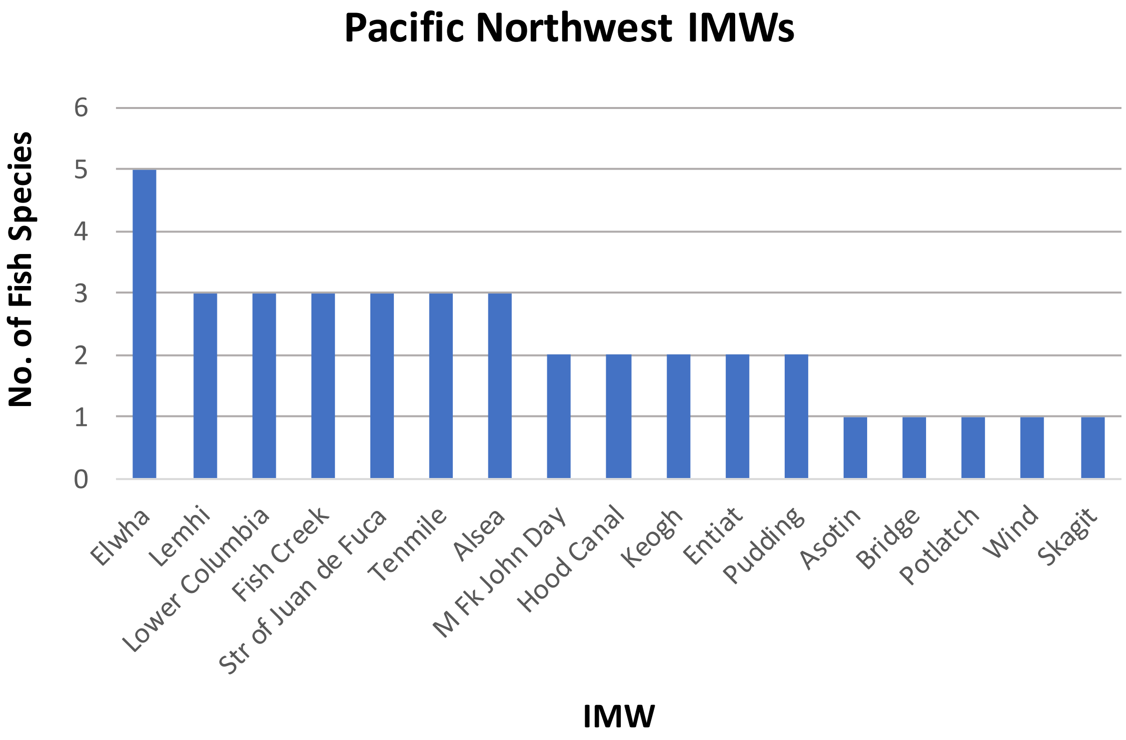

Figure 4. Number of focal fish species addressed within each IMW in the Pacific Northwest.

3.4 What are we learning from IMWs?

Even though IMWs within the Pacific Northwest are in different stages of development, nearly all are providing useful information. This is also true of IMWs that may be considered unsuccessful by some standards. Indeed, it is likely we learn more from failures than successes. For example, the Fish Creek IMW was one of the earliest IMWs and many considered it unsuccessful because it was unable to demonstrate significant treatment effects at the watershed scale. We argue that the Fish Creek IMW provided the research community with valuable information not only on how to monitor at large spatial scales, but also how to plan and implement enhancement actions. Here is a summary of what we learned from the Fish Creek IMW.

1. Enhancement projects need to address watershed-scale processes, including upland processes, and avoid “band-aid” approaches (i.e., treating symptoms, not causes or threats) to stream enhancement.
2. Both spatial and temporal controls are needed to increase certainty of detecting and quantifying treatment effects.
3. Large-scale natural disturbances (e.g., floods, fires, landslides, etc.) can quickly erase treatments and their effects. This is another reason why it is important to focus on rehabilitating watershed-scale processes.
4. More reliance should be placed on biological significance (e.g., focus on achieving biological targets and milestones) than on statistical significance.
5. Adequate spawning escapements and seeding levels are needed to effectively evaluate treatment effects. In the Fish Creek IMW, escapements of Chinook salmon were too low to seed the treated habitat and therefore treatment effects on juvenile Chinook could not be evaluated. In addition, the researchers found it necessary to stock hatchery coho fry into off-channel ponds to fully seed the habitat. This created a disease problem that reduced the success of the project (Reeves et al. 1997).
6. Major changes in sampling methods should be avoided during the life of the study.

IMW researchers are aware of these “lessons learned” and have been diligent in recalling these lessons as they developed their own IMWs.

In addition to the lessons learned from earlier studies, more recent IMWs are revealing important lessons even though several IMWs are still in their infancy. Below, we identify lessons learned from more recently implemented IMWs. Some of these reinforce lessons learned from earlier IMWs.

1. ***Successful IMWs identify and treat the primary factors limiting fish abundance, distribution, and productivity within the watersheds***. For example, researchers in the Alsea determined that overwinter habitat was limiting abundance of juvenile coho salmon, steelhead, and cutthroat in the watershed. They implemented appropriate treatments and successfully increased smolt abundance by 200-800%. In contrast, researchers implemented a nutrient enhancement study as part of the Lower Columbia River IMW and found no response in coho abundance at the watershed scale. As best we can tell, researchers did not identify nutrients as an important limiting factor in the Lower Columbia watersheds before they initiated nutrient treatments. Researchers working in the Middle Fork John Day IMW used life-cycle modeling to help them

determine that high water temperature was the primary limiting factor there. As a result, addressing the many other factors will not elicit a fish response at the watershed scale.

2. ***Treatments need to be large***. The literature indicates that the largest biological benefits are associated with treating more than 20% of the degraded habitat within a watershed (e.g., Roni et al. 2010). Treating small portions of degraded habitat has little biological effect at the watershed scale and the treatments are often overwhelmed by upstream degraded habitat conditions. Large-scale projects such as dam removal result in fish responses at the watershed scale (e.g., Elwha, Potlatch, and Wind IMWs). The Bridge Creek IMW demonstrated that by treating about 30% of the degraded habitat there, juvenile steelhead production increased 175% compared to a control watershed.
3. ***Smaller watersheds respond more quickly to treatments than do larger watersheds***. There are several reasons for this. First, it is generally easier to treat a larger percentage of a smaller watershed than it is a larger watershed. Larger watersheds require more coordination, communication, and funding than do smaller watersheds. Smaller watersheds generally have fewer landowners, which reduces resources spent on coordination. Second, treatments can be implemented within a shorter period of time within smaller watersheds. Treatments implemented within smaller watersheds (e.g., Alsea, Bridge, Elwha, and Tenmile IMWs) are generally completed within one to three years, while treatments within larger watersheds (e.g., Entiat, Lemhi, Middle Fork John Day, Potlatch IMWs) may take five to ten years to implement. Lastly, smaller watersheds tend to have fewer limiting factors to address. Larger watersheds may have multiple factors limiting abundance and productivity at different spatial scales. For example, researchers working in the Middle Fork John Day and Lemhi IMWs are dealing with addressing multiple factors in different locations within the watersheds. In contrast, researchers working in the Alsea, Bridge, Pudding, and Tenmile IMWs are addressing fewer limiting factors.
4. ***IMWs require robust, flexible experimental designs***. BACI-type designs appear to be preferred because they include both spatial and temporal controls. These designs tend to address most of the threats to validity[4] if the controls and treatments are similar. However, as researchers working on the Tenmile IMW found, if treatment and control (or reference) watersheds do not track each other (not correlated), the integrity of the design can be compromised. In this case, the researchers used before-after comparisons to demonstrate treatment effects. We note that treatment and control/reference areas do not necessarily need to track each other to be useful. Simple simulations indicate that BACI effects (aka BACI contrasts) are unbiased even if treatment and control areas do not correlate with each other during the pretreatment period (ISAB 2018). Correlation during the pretreatment period does increase precision, however. Most IMWs incorporate BACI-type designs. Other IMWs use before-after (BA) designs, which may not be as robust as BACI designs, but nevertheless are valid if the researchers can demonstrate that changes in the response variables (habitat and fish performance) were the result of the treatments and not some other extraneous factor or factors. Large IMWs (e.g., Lemhi, Entiat, and Middle Fork John Day IMWs) often incorporate before-after designs because of the difficulty in finding suitable control or reference watersheds for large IMWs. Post-treatment designs include a spatial control but have no temporal control. These designs require close pairing between control and treatment watershed. As noted by researchers working on the Strait of

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[4] Validity of a monitoring design is influenced by the degree to which the investigator can exercise experimental control; that is, the extent to which rival variables or hypotheses can be controlled or dismissed. Threats to validity include sampling units that change naturally over time but independently of the treatment; use of unreliable or inconsistent sampling methods or measuring instruments; measuring instruments that change the sampling unit before the treatment is applied; differential selection of sampling units especially if treatment and control sites are substantially different before the study begins; biased selection of treatment sites; loss of sampling units during the study; and multiple treatment effects. In addition, these threats can interact or work in concert to reduce validity.

Juan de Fuca IMW, the lack of pretreatment data makes it difficult to identify treatment effects. Post-treatment designs are generally not preferred designs for IMWs. Designs that lack spatial and temporal controls/references should be avoided.

5. ***Nested hierarchical designs allow evaluation of treatment effects at multiple spatial scales***. These designs incorporate BACI and BA designs and often allow identification of mechanisms. The benefit of these designs is they allow evaluation of treatment effects at different spatial scales, which is a useful approach within large IMWs (e.g., Lemhi, Entiat, Middle Fork John Day, and Potlatch). Nested within the larger IMW are smaller-scale experiments that are conducted at the sub-watershed (tributary), reach, and project scales. These designs are useful in teasing apart multiple treatment effects. Both the Middle Fork John Day and Potlatch IMWs incorporate BACI and BA designs within a nested hierarchical framework. These IMWs have successfully identified treatment effects at small spatial scales, but not yet at larger scales.
6. ***IMWs benefit from long-term fish and habitat data series***. Because pretreatment data increase the validity and statistical power of IMWs, watersheds that have a long time series of fish and habitat data are more likely to demonstrate treatment effects within a shorter time period. For example, researchers working on the Keogh IMW have a population data series extending back to the mid-1970s. This IMW has successfully demonstrated positive effects of instream structures and nutrient enhancement on steelhead and coho salmon at the watershed scale. Using the long time series of data, they are now evaluating the effects of summer flow augmentation on fish production. The Wind River IMW is also demonstrating the importance of leveraging long-term population data to increase statistical power and the success of the project.
7. ***Changes in controls/references, spawning escapements, and management actions can confound IMWs***. By their very nature, IMWs are long-term studies. This is especially true in larger watersheds where several years are needed to implement treatments. Because of the long period of time needed to conduct IMWs, maintaining controls/references can be very difficult. In many areas (e.g., Entiat), project sponsors look for opportunities to implement enhancement actions even if they occur within control areas. When opportunities arise, and they are designed to benefit ESA-listed species, it can be very difficult to control the placement of enhancement actions. In addition, because of landowner, funding, and permitting constraints, actions implemented within treatment areas may not be to the extent and magnitude envisioned within the implementation plans. This, along with the treatment of control areas reduces effect sizes and confounds monitoring designs. In addition, as researches working on the Tenmile IMW found, variable and low spawning escapements can confound IMW designs. That is, if treatment and control/reference areas have different seeding levels, treatment effects can be confounded with seeding levels. IMWs need to address differences in seeding levels or assume habitat in treatment and control/reference areas are fully seeded. Finally, management changes can confound IMWs. For example, a major change in hatchery production occurred in the Entiat during the implementation of the IMW there. This management change affects production and productivity within the basin and therefore confounds habitat enhancement effects.
8. ***IMWs require extensive coordination and long-term funding***. Nearly all IMWs struggle with coordination and funding. In general, larger IMWs require more coordination and funding than do smaller IMWs. This is because larger IMWs require larger treatments and tend to have more stakeholders than do smaller IMWs. Extensive coordination (and time) is needed among all stakeholders, including managers, funders, implementers, enhancement and monitoring entities, and landowners (Roni et al. 2015). Researchers working on the Entiat, Lemhi, Potlatch,

Middle Fork John Day, Skagit, and other IMWs have indicated the difficulties of coordinating implementation and monitoring plans within IMWs. In addition, there is increasing concern, especially within larger river systems, that placement of instream structures will conflict with recreational activities (e.g., rafting, kayaking, swimming, etc.). Thus, implementers and stakeholders need to balance enhancement needs with societal concerns.

9. ***IMWs benefit from the use of life-cycle models and adaptive management plans***. Life cycle models, although difficult and expensive to develop, provide valuable information on limiting factors, limiting life stages, sequencing of enhancement actions, and potential biological benefits of enhancement actions. Researchers in the Entiat, Lemhi, Middle Fork John Day, and Potlatch watersheds are using life-cycle models to help guide implementation of IMWs. According to the life-cycle model used in the Middle Fork John Day, high water temperature is the primary factor limiting steelhead and Chinook salmon production there and high temperatures override any possible benefits from improving instream habitat. As described by Bouwes et al. (2016b), "active" adaptive management[5] is an important part of any enhancement program and therefore effectiveness monitoring plans need to be designed within the context of adaptive management. Enhancement actions applied under an adaptive management framework will be the most efficient way to understand the effectiveness of enhancement work. In short, adaptive management is an iterative process of exploring uncertain outcomes to management actions while making progress toward broader management goals (Walters and Holling 1990). In general, the cycle of adaptive management includes plan, do, evaluate, and learn (Bouwes et al. 2016b). In the context of stream enhancement work, the hallmark of adaptive management is to adjust either the implementation plan or the enhancement actions based on effectiveness monitoring. Without monitoring, adjustments are simply based on trial and error. Researchers working on the Asotin, Lemhi, and Potlatch IMWs have implemented rigorous adaptive management plans to help guide enhancement work in those watersheds.
10. ***Improvements in freshwater productivity may not translate into increased spawning escapements***. IMWs are designed to determine if enhancement actions increase juvenile fish performance (e.g., increased smolt production) at the watershed scale. Thus, actions that result in improvements in freshwater productivity and abundance are considered successful and those that identify mechanisms by which fish respond to actions are most useful. However, just because enhancement actions increase freshwater abundance and productivity, it does not necessarily mean more adults will return to the watersheds. For example, although researchers working on the Keogh IMW successfully documented significant increases in abundance, size, smolt yield, and productivity of steelhead and coho salmon following placement of instream structures and nutrient enhancement, they did not observe a corresponding increase in adult returns. They noted that poor marine survival and high harvest rates reduced adult returns. This is not to say that IMWs are failures and should not be implemented if enhancement work does not result in greater returns of adults. Implementing enhancement actions designed to increasing juvenile abundance and productivity is important given the widespread occurrence of density dependence found in most populations (ISAB 2015).

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[5] "Active" adaptive management implements actions with the goal to maximize learning or reduce uncertainties that inform management actions. It is needed to understand causal mechanisms of responses (Williams 2011). In contrast, "passive" adaptive management uses models and existing knowledge to describe the most likely action to achieve management goals. Learning is an unintended consequence of passive adaptive management.

3.5 Are all the IMWs still needed to answer the primary questions in the region? If so, for what purposes and for what period of time?

This is a difficult question to answer given that we are unsure what the primary questions are in the region. We believe most managers would like to know if enhancement actions implemented within watersheds are making a difference in fish populations at the watershed scale (i.e., do enhancement actions increase juvenile abundance and productivity at the watershed scale?), and, if so, which actions work the best. If these are the driving questions, then we believe the IMWs are answering, or geared to answer, the primary questions; however, the time needed to answer those questions varies depending on the IMW.

Several IMWs have demonstrated fish population responses at the watershed scale. For example, the Alsea IMW successfully demonstrated increased coho salmon and steelhead abundance and survival at the watershed scale by improving winter habitat. The Bridge Creek IMW showed significant increases in steelhead abundance and growth at the watershed scale following implementation of BDAs. The Keogh IMW showed increases in steelhead and coho salmon smolt yield and productivity (smolts/spawner) following nutrient enhancement and instream structure placement. The Tenmile IMW showed that increasing habitat diversity by adding large wood resulted in increased steelhead and coho salmon survival within the treatment stream. The Elwha IMW is demonstrating large effects of dam removal on Chinook salmon and steelhead at the watershed scale. This IMW also identified changes to bull trout and steelhead life-history trajectories. The Strait of Juan de Fuca IMW is beginning to show increased coho salmon survival and productivity at the watershed scale as a result of large-scale enhancement. The Wind River IMW is demonstrating significant increases in steelhead smolt abundance at the watershed scale following removal of Hemlock Dam. All these IMWs have successfully demonstrated responses at the watershed scale and have or are identifying mechanisms by which fish respond to the treatments.

Other IMWs, which are in various stages of development, are showing positive effects at smaller spatial scales and are likely to demonstrate positive changes at the watershed scale. For example, the Asotin Creek IMW is showing significant increases in juvenile steelhead densities compared to control areas. The Lemhi IMW is showing changes in the distribution of Chinook salmon following treatments. The Potlatch IMW is showing changes in the distribution and abundance of steelhead at the reach and tributary scale. Over time and as more treatments are implemented, these IMWs should demonstrate positive effects at the watershed scale.

The time needed to answer the primary questions is related to several factors. As noted in Section 3.4, identifying treatment effects at the watershed scale is a function of the size of the watershed, size and complexity of the treatments (effect size), experimental design, precision of measurements, seeding levels (spawning escapements), natural and anthropogenic disturbances (e.g., fires, floods, droughts, landslides, and changes in land use and management regulations), and coordination and funding constraints. All IMWs struggle with one or more of these issues and larger IMWs can be especially challenged by these issues. Thus, the time needed for each IMW to answer the primary questions varies depending on the issues that plague each IMW. Because enhancement work and monitoring are expensive endeavors, funding is often a factor affecting the implementation and completion of IMWs.

3.6 Are there IMWs that have reached a logical conclusion or for other reasons should be ramped down or ended?

Although it is wise to review periodically the objectives of any long-term monitoring study (part of adaptive management), decisions to interrupt, modify, or terminate IMWs must be made very carefully. When dealing with the many environmental factors and their inherent variability in complex ecosystems, researchers need to implement spatially extensive, long-term monitoring studies in order to estimate the effects of treatments on population processes. The value of additional information acquired from each year of study can be extremely high, particularly as the frequency of natural disturbances (e.g., weather, fires, floods, drought, etc.) increases. The Keogh IMW is one of the longest running IMWs in the region and much has been learned from the many years of study there. Indeed, more than 100 papers have been published on work conducted in the Keogh River.

In addition to the Keogh IMW, there are others that have clearly demonstrated important treatment effects at the watershed scale. The Alsea IMW showed that improving winter habitat in two small watersheds resulted in large increases in coho salmon and steelhead smolt production and survival. The Bridge Creek IMW demonstrated that the addition of BDAs, which increased habitat complexity, lowered water temperatures, increased off-channel habitat, and raised water levels, significantly increased steelhead production there. The Tenmile IMW showed that increasing habitat diversity by adding large wood resulted in increased steelhead and coho salmon survival within the treatment stream. By all accounts, these were successful IMWs and provided the region with useful information. One could argue they reached their logical conclusion and therefore should end. On the other hand, we believe there is still much to be learned from continuing to monitor these watersheds at a lower intensity and frequency. It would be useful to know how long the treatments in the Alsea and Tenmile watersheds lasted. Are they still functioning as designed or have they been destroyed or relocated? Are fish still experiencing higher abundance and survival, or did they decrease to pretreatment levels? Will the BDA treatments placed in Bridge Creek maintain habitat complexity into the future and if so for how long? These are important questions that cannot be answered unless there is some level of continued monitoring. For IMWs that have demonstrated treatment effects at the watershed scale, we recommend reducing the frequency of monitoring to every three to five years and collecting the most relevant fish and habitat data. To the extent possible, we recommend that researchers use unmanned aerial vehicles to collect relevant habitat data.

Other IMWs are in early development or in various stages of maturation. Several are still implementing treatments, while others are beginning post-treatment sampling. These IMWs need to continue as planned. It would be unwise to terminate or ramp down these IMWs at this time. After at least five years of post-treatment data collection, researchers should evaluate the need to continue rigorous monitoring. If necessary, monitoring efforts could be reduced to sampling every three to five years to demonstrate the longevity of the treatments and responses.

3.7 Are there additional IMWs that should be brought online?

Our review indicates that current IMWs address a wide range of limiting factors and treatment types (see Section 3.1) and they occur within most ecoregions within the Pacific Northwest (see Section 3.2). When we look at the focal species addressed by each IMW, we find that coho salmon and steelhead are well represented, while Chinook salmon, bull trout, coastal cutthroat trout, and Pacific lamprey are less well represented (Table 4). With the loss of the Entiat IMW, the lack of Chinook salmon escaping into Fish Creek during the monitoring period, and the focus of the Skagit IMW on estuary enhancement, there are relatively few IMWs that emphasize Chinook salmon. We believe it would be worthwhile to add IMWs that address Chinook salmon. Reinitiating the Entiat IMW may be appropriate. This IMW was terminated before most of the enhancement actions were implemented (note that the implementation of enhancement actions is moving forward with a large percentage of the stream being treated over the next few years). The original monitoring design will need to be modified to address changes in the implementation schedule and timeline, and the change in hatchery production within the basin. Another possibility is to implement an IMW within the Grande Ronde River basin. An extensive amount of monitoring and enhancement work has been conducted there and researchers have developed models, which can be used to guide enhancement and monitoring work.

Few IMWs address bull trout, coastal cutthroat trout, and Pacific lamprey. Given that several IMWs occur within watersheds that support these species, it may be possible to add these species to existing monitoring efforts. This will take considerable thought as these species display several different life-history characteristics, which will need to be considered by the researchers.

Table 4. Focal species addressed by each IMW.

FOCAL SPECIES	IMW
Chinook Salmon	Elwah Entiat Fish Creek Lemhi Lower Columbia Middle Fork John Day Skagit
Coho Salmon	Alsea Elwah Fish Creek Hood Canal Complex Keogh Lower Columbia Pudding Strait of Juan de Fuca Tenmile

FOCAL SPECIES	IMW
Steelhead	Alsea Asotin Bridge Elwha Entiat Fish Creek Hood Canal Complex Keogh Lemhi Lower Columbia Middle Fork John Day Potlatch Pudding Strait of Juan de Fuca Tenmile Wind
Coastal Cutthroat Trout	Alsea Strait of Juan de Fuca Tenmile
Bull Trout	Elwha Lemhi
Pacific Lamprey	Elwha

3.8 Are any of the IMWs unlikely to meet their intended objectives within the implied 10-year timeline, and, if so, what is constraining them?

There are IMWs that will not meet their intended objectives within a ten-year timeline. This is because it is unrealistic to assume large IMWs (e.g., Entiat, Lemhi, Middle Fork John Day, Potlatch, Elwha, etc.) can implement enhancement actions within a short period of time. Larger IMWs require large and extensive treatments, which cannot be implemented within a year or two because of coordination, funding, and logistical constraints. Smaller IMWs are more likely to achieve their intended objectives within a ten-year period, because there are generally fewer issues with coordination, logistics, and funding in smaller watersheds. However, even smaller IMWs may take many years to implement enhancement actions because of funding and logistical constraints (e.g., Hood Canal Complex IMW).

We are uncertain as to the genesis of the ten-year timeframe for IMWs. In many cases, this timeline is unreasonable given the amount of work needed to design and implement IMWs. Successful IMWs require identification of threats, limiting factors, and limiting life-stages. This information often comes from watershed assessments, limiting factors analysis, reach assessments, and life-cycle modeling, which take time to conduct. Then, one needs to develop an implementation plan that prioritizes locations for enhancement (and protection) and sequences enhancement actions within priority areas. This includes extensive coordination among stakeholders, landowners, funding and monitoring entities, and implementers. Researchers need to identify and implement appropriate monitoring designs, select an appropriate number of spatial and temporal replicates (based on power analysis), and identify sampling methods and parameters to measure (see Roni et al. 2015). Depending on the design, amount of natural variability, and size of treatment effects, two to five years of pretreatment data may need to be collected. Given funding, coordination, and logistical constraints, it may take several years to implement planned enhancement actions, especially within large IMWs. Finally, depending on natural variability and the size, complexity, and type of treatments, several years of post-treatment data may need to be collected to assess treatment effects. Indeed, at least two generations may be needed to detect treatment effects (Pess et al. 2012). Depending on escapement levels, fish typically respond rapidly to treatments such as dam removals, increasing stream and floodplain connectivity, flow enhancement, and addition of instream structures. In contract, it may take fish several years to decades to respond to riparian and upland restoration actions. Roni et al. (2015) indicated that more than ten years of data are needed to detect changes in fish abundance of 25% or greater for BACI studies in paired watersheds. Thus, we believe it is unreasonable to assign a timeline of ten years to IMWs. The timeline for completing IMWs should be tailored specifically to each IMW and its inherent characteristics.

4 Conclusions and Recommendations

Our assignment was to review the IMWs within the Pacific Northwest and respond to the following key questions:

1. Are the IMWs covering a representative range of habitat improvement strategies and environmental conditions?
2. Are the IMWs asking the most appropriate and relevant questions?
3. Are the IMWs in watersheds with high potential for learning?
4. What are we learning from IMWs?
5. Are all the IMWs still needed to answer the primary questions in the region? If so, for what purposes and for what period of time?
6. Are there IMWs that have reached a logical conclusion or for other reasons should be ramped down or ended?
7. Are there additional IMWs that should be brought online?
8. Are any of the IMWs unlikely to meet their intended objectives within the implied 10-year timeline, and, if so, what is constraining them?

Based on our review, we believe the current array of IMWs is covering a representative range of habitat improvements strategies and environmental conditions, and they are asking the right questions. Existing IMWs address a wide range of limiting factors, they include a wide array of treatment types and complexities, they are distributed across most ecoregions, and they vary in size from 12 to 8,030 km^2. Thus, current IMWs are in watersheds with high potential for learning. We note that most IMWs focus on coho salmon and steelhead, while few target Chinook salmon, bull trout, coastal cutthroat trout, and Pacific lamprey. Currently, there are only five IMWs that focus on Chinook salmon, and one of those focuses on the estuary (Skagit IMW). We suggest researchers resurrect the Entiat IMW, which was recently terminated, and implement an IMW in the Grande Ronde River basin. Both watersheds have extensive monitoring data, models have been developed for the watersheds that can be used to guide enhancement and monitoring work, and both watersheds will be treated with habitat projects. As for bull trout, coastal cutthroat trout, and Pacific lamprey, we recommend that researchers evaluate the possibility of adding these species to their existing IMWs.

Our review indicates that all the IMWs are needed to answer the primary questions in the region. Several IMWs have already demonstrated treatment effects at the watershed scale (e.g., Alsea, Bridge, Keogh, Tenmile, Elwha, Strait of Juan de Fuca, and Wind IMWs). Others, which are in various stages of development, have demonstrated treatment effects at smaller scales and will likely show effects at larger scales once treatments are fully implemented. The time needed to answer the primary questions varies depending on the size of the watershed, size and complexity of the treatments (effect size), experimental design, precision of measurements, seeding levels (spawning escapements), natural and anthropogenic disturbances (e.g., fires, floods, droughts, landslides, and changes in land use and management regulations), and coordination and funding constraints. All IMWs struggle with one or more of these issues and therefore the time needed to address the primary questions will vary among IMWs.

Because some of the IMWs have clearly demonstrated treatment effects at the watershed scale, one could argue that these have reached their logical conclusion. We believe, however, that some level of monitoring is still needed to determine the longevity of the treatments and their effects. For these IMWs, we recommend reducing the frequency of monitoring to every three to five years and collecting the most relevant fish and habitat data. To the extent possible, we propose researchers use unmanned aerial vehicles to collect relevant habitat data. Other IMWs, which are in various stages of development, need to continue as planned. We believe it would be unwise to terminate or ramp down these IMWs at this time. After at least five years of post-treatment data collection, researchers should evaluate the need to continue rigorous monitoring. If necessary, monitoring efforts could be reduced to sampling every three to five years to demonstrate the longevity of the treatments and responses.

There are IMWs that will not meet their intended objectives within a ten-year time frame. We question the genesis of the “ten-year time frame” and believe it is unrealistic because it does not consider all the factors that affect the implementation and success of IMWs. Successful IMWs require identification of threats, limiting factors, and limiting life-stages; development of implementation plans that prioritize locations for enhancement (and protection) and sequences enhancement actions within priority areas; extensive coordination among stakeholders, landowners, funding and monitoring entities, and implementers; identification and implementation of appropriate monitoring designs; selection of an appropriate number of spatial and temporal replicates; and identification of sampling methods and parameters to measure. Depending on the design, amount of natural variability, and size of treatment effects, two to five years of pretreatment data may need to be collected. Implementation of treatments may take several years depending on the size of the watershed, type and complexity of treatments, and coordination and funding constraints. Finally, several years of post-treatment data will need to be collected depending on natural variability and the size, complexity, and type of treatments. Thus, we believe the timeline for completing IMWs should be tailored specifically to each IMW and its inherent characteristics.

Although IMWs within the Pacific Northwest are in different stages of development, nearly all are providing useful information. We begin by identifying important lessons from earlier IMWs. The Fish Creek IMW was one of the earliest IMWs and many considered it unsuccessful because it was unable to demonstrate significant treatment effects at the watershed scale. We believe this IMW provided the research community with valuable information not only on how to monitor at large spatial scales, but also how to plan and implement enhancement actions. Here is a summary of what we learned from the Fish Creek IMW.

1. Enhancement projects need to address watershed-scale processes, including upland processes, and avoid “band-aid” approaches (i.e., treating symptoms, not causes or threats) to stream enhancement.
2. Both spatial and temporal controls are needed to increase certainty of detecting and quantifying treatment effects.
3. Large-scale natural disturbances (e.g., floods, fires, landslides, etc.) can quickly erase treatments and their effects.
4. More reliance should be placed on biological significance (e.g., focus on achieving biological targets and milestones) than on statistical significance.
5. Adequate spawning escapements and seeding levels are needed to effectively evaluate treatment effects.
6. Major changes in sampling methods should be avoided during the life of the study.

In addition to the lessons learned from earlier studies, more recent IMWs are revealing important lessons even though several IMWs are still in their infancy. The following is a list of lessons learned from more recent IMWs. Some of these reinforce lessons learned from earlier IMWs.

1. Successful IMWs identify and treat the primary factors limiting fish abundance, distribution, and productivity within the watersheds.
2. Treatments need to be large (>20% of the degraded habitat within a watershed).
3. Smaller watersheds respond more quickly to treatments than do larger watersheds.
4. IMWs require robust, flexible experimental designs.
5. Nested hierarchical designs allow evaluation of treatment effects at multiple spatial scales.
6. IMWs benefit from long-term fish and habitat data series.
7. Changes in controls/references, spawning escapements, and management actions can confound IMWs.
8. IMWs require extensive coordination and long-term funding.
9. IMWs benefit from the use of life-cycle models and adaptive management plans.
10. Improvements in freshwater productivity may not translate into increased spawning escapements if ocean conditions, harvest, or other out-of-basin factors reduce smolt-to-adult returns.

Challenges to implementing IMWs include controlling other management activities (e.g., harvest, hatcheries, etc.), maintaining control/reference areas, dealing with low spawning escapements, coordinating enhancement activities and monitoring across multiple organizations and entities, dealing with natural and anthropogenic disturbances, and working with limited funds. Because IMWs are expensive, long-term studies (>10 years), researchers must balance limited funds with trying to tease out treatment effects that are often confounded with changes in land use, climate, and management activities. Given the large amount of natural variability within the systems, it is not surprising that some of the most "successful" IMWs are those that have implemented large treatments (e.g., dam removal). That said, we agree with the conclusion of Bennett et al. (2016), "*…the intensively monitored watershed approach is the most reliable means of assessing the efficacy of watershed-scale restoration*."

We see great value in the development and use of life-cycle models. These tools can be used to identify limiting factors and life stages, reveal mechanisms, and guide monitoring and adaptive management. We therefore believe a life-cycle model should be associated with each IMW. Given the array of life-cycle models that have been developed, several of which were developed for specific IMWs (e.g., Lemhi, Entiat, Middle Fork John Day, and Potlatch IMWs), these tools can be adapted to each IMW. Model sophistication will depend on the IMW. Our recommendation is to start simple and add complexity as needed, with larger IMWs likely requiring more complexity than smaller IMWs. Importantly, these models can be used to help generalize or extrapolate results from IMWs to watersheds with no or limited monitoring data. Simple generalizations of IMW results are difficult because no two watersheds are alike. Life-cycle models, however, can deal with these differences and can estimate potential responses to treatments with defined levels of certainty.

As a final note, we believe the network of IMWs within the Pacific Northwest should be evaluated as a single, large experiment. In part, this paper begins this process by reviewing the IMWs and summarizing the overall conclusions and lessons learned. However, our review lacks a quantitative methodology, which reduces subjectivity. To that end, we recommend the use of meta-analysis (i.e., the analysis of analyses) to address statistical questions about the data obtained from each IMW. This technique combines information from the independent IMWs to answer questions such as: (1) on average, across all IMWs, how large is the treatment effect, (2) does the collection of IMWs reject the null hypothesis of no treatment effect, and (3) how variable is the treatment effect and what factors explain the variability? The greatest benefit of meta-analysis is that it can greatly increase the statistical power of the collective statistical tests and treats each IMW equally (i.e., IMWs with large treatment effects are not given more weight than IMWs with small or no treatment effects). Others (e.g., Stewart et al. 2009; Whiteway et al. 2010; Miller et al. 2010; Kail et al. 2015) have used meta-analysis to evaluate independent enhancement projects statistically. These studies provide a foundation for evaluating quantitatively the network of Pacific Northwest IMWs.

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Appendix 1: IMW Questionnaire

pacific northwest aquatic
monitoring partnership

PNAMP IMW Questionnaire

Background

Communication products, as described in the PNAMP IMW Action Plan, are being developed. To maximize the usefulness of the products we need your help. Although they are being written/compiled by a handful of people, the products rely heavily on information that will be provided by IMW practitioners. In order to succeed, this needs to be a team effort. Because there is overlap in the information needed for the various products, we are coordinating our request for information into a single questionnaire. While we realize this is not a small request, we want to make it as quick and easy as possible.

Directions

Read through the questions below. If the answer to a question is already documented somewhere (which we hope is true for the vast majority of the questions), the answer can consist of 1) URL link(s) or citation(s) to the document(s), and 2) page number(s) of where the answer can be found. You can also copy and paste the answer into the questionnaire, but we'd still like the link/citation for where the information came from. If citations are provided instead of links, please attach the document(s) to the email when submitting your response to the questionnaire.

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

Because the deadlines for the reports are only a few months away, we want to get started on this as soon as possible. We're proposing a two-step approach to gather the needed information. "Easy stuff" by Nov 20th (i.e., answers that are already documented elsewhere), and then answers to any remaining questions by Dec 20th. Questionnaire responses, as well as any questions you have about this process, should be sent to Amy Puls (apuls@usgs.gov).

Basic Information

1. IMW name:
2. Your name (or name of main point of contact):
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):

Context

7. What are the target populations (or subpopulations) of interest?
8. What is the geographic boundary of the IMW?
9. What factors or threats are contributing to current conditions (e.g., road density, upland activities, etc.)?
10. What habitat action(s) (treatments) were implemented to improve existing conditions?
11. What was the extent of the treatments (e.g., percent of degraded habitat treated)?
12. What are the goals and objectives of the habitat action(s)?
13. What hypotheses are tested?
14. 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)

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

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

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

Measurements

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

Results

28. How will the results inform future management decisions?
29. Over the life of the IMW, what are the key findings?
30. Over the life of the IMW, what are the lessons learned that can help practitioners improve future planning, monitoring, and restoration efforts?