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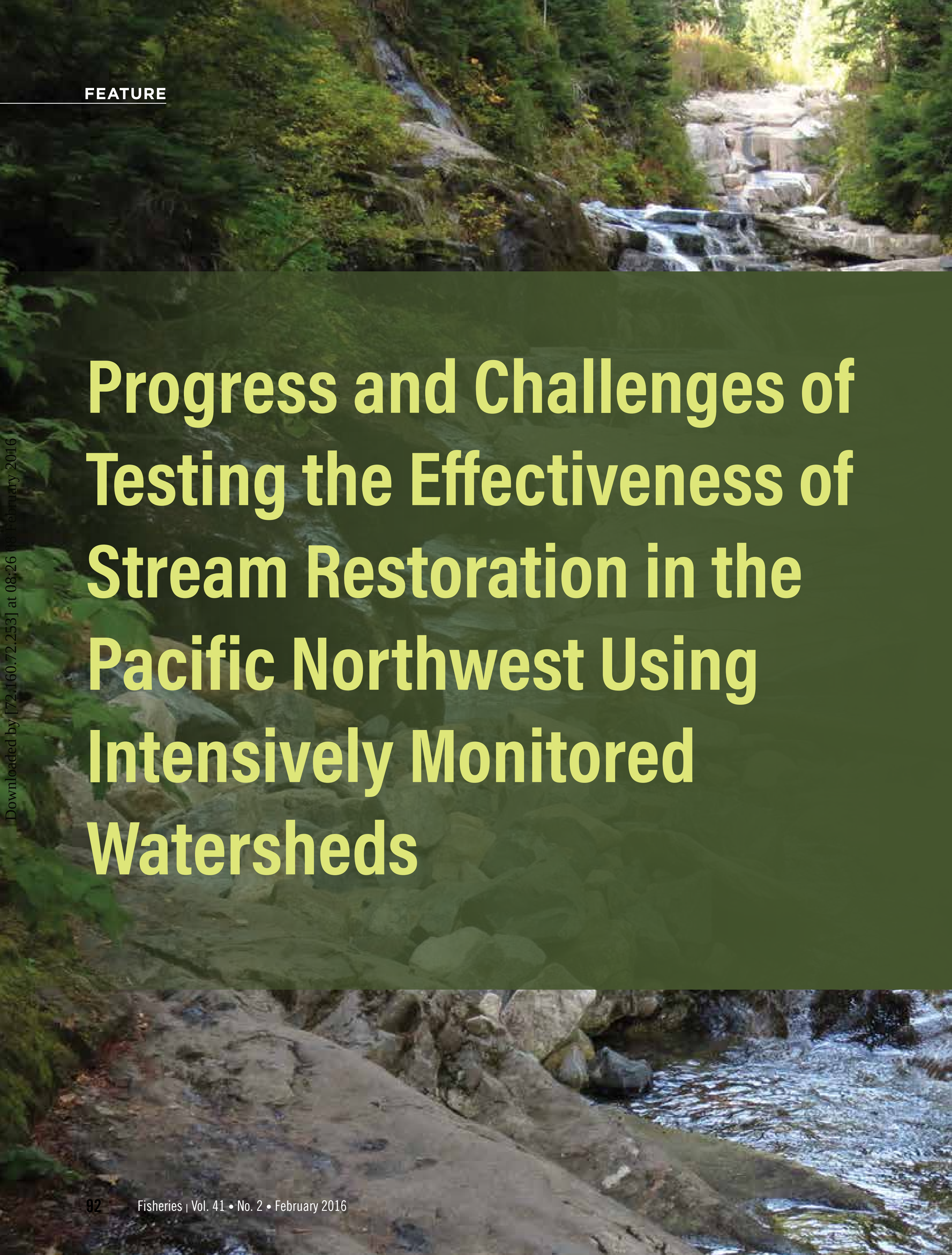

FEATURE

Progress and Challenges of Testing the Effectiveness of Stream Restoration in the Pacific Northwest Using Intensively Monitored Watersheds

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Across the Pacific Northwest, at least 17 intensively monitored watershed projects have been implemented to test the effectiveness of a broad range of stream restoration actions for increasing the freshwater production of salmon and steelhead and to better understand fish–habitat relationships. We assess the scope and status of these projects and report on challenges implementing them. We suggest that all intensively monitored watersheds should contain key elements based on sound experimental design concepts and be implemented within an adaptive management framework to maximize learning. The most significant challenges reported by groups were (1) improving coordination between funders, restoration groups, and researchers so that restoration and monitoring actions occur based on the project design and (2) maintaining consistent funding to conduct annual monitoring and evaluation of data. However, we conclude that despite these challenges, the intensively monitored watershed approach is the most reliable means of assessing the efficacy of watershed-scale restoration.

Progreso y retos de medir la efectividad de la restauración de ríos en el Pacífico noroeste mediante cuencas hidrográficas intensamente monitoreadas

A lo largo del Pacífico noroeste, se han implementado al menos 17 proyectos de monitoreo intensivo de cuencas hidrográficas, para probar la efectividad de un amplio rango de acciones de restauración de ríos con el fin de incrementar la producción de salmón de agua dulce y de comprender mejor la relación entre los peces y su hábitat. En este estudio se evaluó el estado y ámbito de estos proyectos y reportes y se documentaron los retos que supone implementarlos. Se sugiere que todas aquellas cuencas que hayan sido intensamente monitoreadas debieran contener elementos clave, basados en conceptos de diseños experimentales sólidos, que sean implementados mediante un esquema de manejo adaptativo para maximizar el aprendizaje. Los retos más importantes que se reportaron por los grupos fueron (a) mejorar la coordinación entre los patrocinadores, los grupos de restauración y los investigadores para que la restauración y las acciones de monitoreo se den de acuerdo al diseño del proyecto, y (2) mantener un presupuesto consistente para llevar a cabo monitoreos anuales y evaluaciones de datos. Sin embargo se concluye que pese a estos retos, el enfoque de cuencas hidrográficas intensivamente monitoreadas es el enfoque más confiable para evaluar la eficacia de la restauración a nivel de cuencas.

Les Progrès et les Enjeux des Tests d'Efficacité de la Restauration des Cours d’eau dans le Pacifique Nord-Ouest Utilisant des Bassins-versants Surveillés Intensivement

Partout dans le Pacifique Nord-Ouest au moins 17 projets de bassins-versants surveillés intensivement ont été mis en œuvre afin de tester l’efficacité d’un large éventail d’actions de restauration des cours d’eau en vue d’augmenter la production de saumon et de la truite arc-en-ciel en eau douce et de mieux comprendre les relations poisson-habitat. Nous évaluons l’ampleur et l’état de ces projets et nous signalons les difficultés de mise en œuvre. Nous recommandons d’introduire des éléments clés basés sur un plan expérimental fiable dans tous les bassins-versants surveillés intensivement et qu’ils soient équipés dans un cadre de management adaptatif afin d’en tirer le plus grand profit possible. Les difficultés les plus importantes signalées par les groupes étaient (1) l’amélioration de la coordination entre les donateurs, les groupes de restauration, et les chercheurs de sorte à ce que les actions de restauration et de surveillance se déroulent selon la conception du projet, et (2) le maintien d’un financement constant afin d’organiser des surveillances et évaluations annuelles de données. Toutefois, nous concluons qu’en dépit de ces difficultés, la méthode des bassins-versants surveillés intensivement est le moyen le plus fiable d’évaluation de l’efficacité de la restauration à l’échelle du bassin-versant.

INTRODUCTION

Billions of dollars have been invested in stream restoration across the United States since 1990, but opportunities to learn from and improve restoration actions have been severely limited due to a lack of recording of basic project details and limited monitoring (Bernhardt et al. 2005). The Pacific Northwest has some of the largest investments in stream restoration in North America, primarily driven by the listing of anadromous salmon *Oncorhynchus* spp. and steelhead *O. mykiss* populations under the Endangered Species Act (Katz et al. 2007; Roni et al. 2002). An underlying assumption of much of the stream restoration in the Pacific Northwest is that improvements in freshwater habitat will lead to increased population viability and ultimately delisting of threatened or endangered species (National Marine Fisheries Service 2014). However, there is a lack of evidence that past stream restoration projects have benefited salmon and steelhead populations (Roni et al. 2008). Population responses to restoration have rarely been documented because many restoration projects have not conducted effectiveness monitoring at the population scale. Instead, monitoring has tended to focus on the reach scale and has occurred over short time periods (i.e., <5 years; Katz et al. 2007; Roni et al. 2008). Restoration actions have also typically been of a small magnitude relative to the size of the watershed, and high natural environmental variability, as well as sampling “noise,” have limited the power to detect a response (Roni et al. 2002; Wagner et al. 2013). Therefore, there is a need to develop a comprehensive and coordinated effort to assess the effectiveness of stream restoration in the Pacific Northwest and other regions.

Long-term ecosystem experiments are arguably the most direct method available for understanding population or environmental responses to management and provide an ideal model for appropriate ways to test the effectiveness of stream restoration (Likens et al. 1970; Schindler 1987; Carpenter et al. 1995). Recent watershed-scale research efforts in the Pacific Northwest to evaluate salmonid responses to forest practices have contributed greatly to our understanding of ecological processes and have led to changes in management strategies (Hicks et al. 1991; Hartman et al. 1996). However, watershed-scale experiments are often impossible to replicate and thus require monitoring of multiple ecosystem attributes, dedicated studies (e.g., mesoscale experiments and comparative studies), and models to mechanistically link manipulations to responses facilitating extrapolation of results to other systems (Likens et al. 1978; Carpenter 1996).

The few experiments that have focused on determining restoration effectiveness have generally shown that restoration had a positive effect on habitat and fish populations (Solazzi et al. 2000; Johnson et al. 2005; Ward et al. 2007). However, despite these studies being well designed and lasting 8 years or more, the results provide limited information regarding the population response of salmon and steelhead to restoration actions. For example, these studies have been completed on coastal streams, limiting their applicability to interior western basins due to evolutionary differences between coastal and interior salmonid populations (Waples et al. 2008). Both studies in Oregon demonstrated changes in juvenile abundance and smolt yield but did not relate these changes to adult abundance (Solazzi et al. 2000; Johnson et al. 2005). Ward et al. (2007) is likely the best example of a watershed-scale experiment that tests stream restoration, but this study assessed the effects of multiple restoration actions in the Keogh River (e.g., road deactivation, nutrient enhancement, wood and boulder additions), which confounds an assessment of the effectiveness of an individual restoration action type. The Keogh River study also demonstrated the difficulty in definitively determining whether restoration has increased freshwater production of salmon and steelhead because changing climatic conditions in both the ocean and freshwater can confound a fish response (Ward 2000).

Recognition of the value of ecosystem experiments and the need for funding agencies and managers to demonstrate that stream restoration is increasing salmon and steelhead viability has led to the establishment of several intensively monitored watershed (IMW) experiments in the Pacific Northwest (Bilby et al. 2005). We define the IMW approach as an experiment in one or more catchments with a well-developed, long-term monitoring program to determine watershed-scale fish and habitat responses to restoration actions (e.g., Zimmerman et al. 2012). The goals of the IMW approach are to determine the effectiveness of restoration actions at increasing salmon and steelhead productivity, determine the causal mechanisms of fish responses to restoration, and ultimately extrapolate the results to other watersheds where intensive monitoring is not possible due to limited budgets (Bilby et al. 2005; McDonald et al. 2007).

This article was inspired by a workshop held in Portland, Oregon, March 20–21, 2013, where over 80 people participating in the funding and implementation of IMWs met to share information about the progress and challenges involved with implementing these watershed-scale restoration experiments. Although there was some initial guidance on how to develop an IMW through several coordinating meetings and subsequent reports (Bilby et al. 2005), there has been no published reference describing the specific elements an IMW should contain. The goals of this article are to (1) review the scope and status of current IMWs; (2) recommend the ideal elements that should be part of an IMW; (3) provide rank criteria to highlight the range of different approaches to implementing the elements of an IMW; (4) summarize the challenges that IMWs have encountered in implementing the ideal elements and lessons learned from 11 years of IMW implementation; and (5) recommend ways to improve both current and future IMWs. The IMW approach and lessons learned from their implementation should be of general value to any projects focused on determining the population-level responses of fish to stream restoration.

SCOPE AND STATUS OF INTENSIVELY MONITORED WATERSHEDS

We identified 17 projects in the Pacific Northwest that met our definition of an IMW (Figure 1, Table 1). Initially IMWs were established in Washington State west of the Cascade Mountains (Strait of Juan de Fuca, Hood Canal, Lower Columbia, and the Skagit River Basin) and one watershed east of the Cascade Mountains (Entiat; Bilby et al. 2005). Now IMWs have been implemented in four states and eight ecoregions (Figure 1). Most (80%) of the IMWs are in Washington (9) and Oregon (4), and the majority (9) are within the Columbia River Basin. The focal species in most IMWs are steelhead, Coho Salmon *O. kisutch*, and Chinook Salmon *O. tshawytscha*, followed by Coastal Cutthroat Trout *O. clarkii* and Bull Trout *Salvelinus confluentus*.

At least seven common restoration actions are being evaluated (Table 1; Roni et al. 2008). The most common restoration actions are instream placement of large wood (13), reconnection/improved access to tributary and floodplain habitats (8), and barrier removal (5). In 12 IMWs, multiple restoration actions are being implemented concurrently. Riparian enhancement is a restoration action in most IMWs but is not yet being directly assessed for increasing salmonid productivity due to the time required for large trees to grow.

Most restoration actions have not been implemented for long enough to have been fully evaluated (Table 1). However, some preliminary results have demonstrated habitat and fish responses. The most immediate responses have been from reconnecting habitats, which have increased spawning distributions of salmon and steelhead and increased juvenile life history diversity in the Elwha, Lemhi, and Potlatch IMWs. Reconnecting floodplain habitat and reducing incision using beaver dam analogs in the Bridge IMW has led to increases in production of juvenile steelhead at very low cost (Pollock et al. 2014). Another technique that has increased habitat area and fish capacity includes the reconnection of side channels in the Methow IMW (Bellmore et al. 2013; Martens and Connolly 2014). Similar responses have been observed with restoration of estuarine habitats in the Skagit IMW. Restoration using large wood has, in general, changed the physical habitat by increasing pools and side channels. Increases in wood have also resulted in an increase in juvenile fish density and survival and reduced growth rates in some cases. Nutrient enhancement has not been fully evaluated. Three IMWs are completed but still have some ongoing monitoring (Alsea, Keogh, Tenmile), and the remaining IMWs are several years away from any definitive conclusions regarding restoration effectiveness.

KEY ELEMENTS OF AN INTENSIVELY MONITORED WATERSHED

Simply implementing restoration and conducting fish and habitat monitoring does not constitute an IMW. An IMW is an experiment that uses a management action (restoration) as a treatment and intensive monitoring to detect whether a watershed-scale fish response to that action occurred. As such, IMWs are well suited to be designed within an adaptive management framework (Figure 2; Williams et al. 2009). A recent review of habitat restoration in the Columbia River Basin urges the use of adaptive management when implementing restoration to provide the most reliable and informative results to base further restoration decisions while trying to achieve restoration goals (Rieman et al. 2015). Our intent here is not to review the extensive adaptive management literature but instead to outline the key elements that an IMW should contain using the iterative adaptive management framework (Figure 2, Table 2). We present a cursory review of the different approaches to adaptive management and an example of applying adaptive

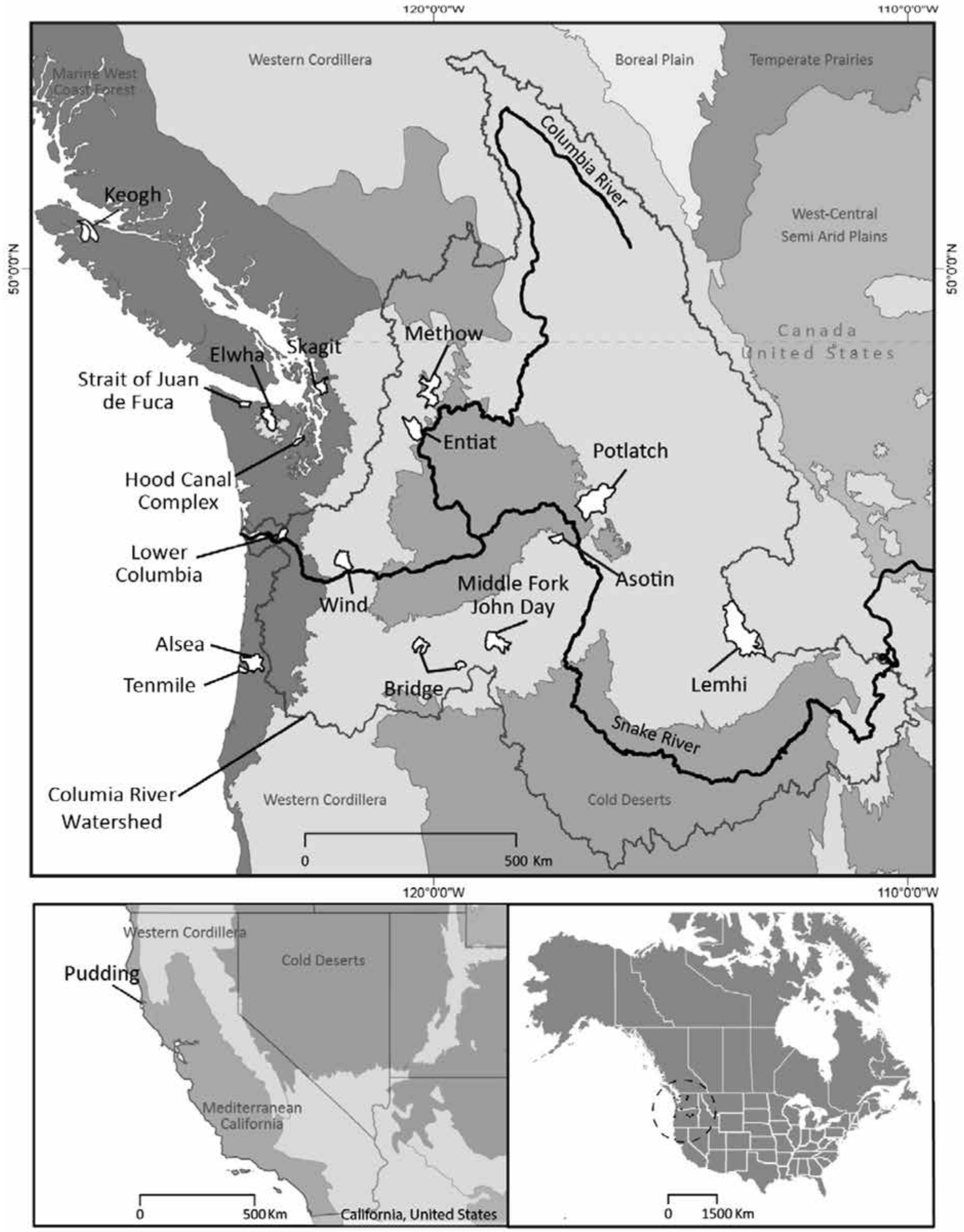

Figure 1. Location of intensively monitored watersheds across the Pacific Northwest. Polygons represent Level III ecoregions.

management in the Asotin Creek IMW in a supporting essay (Bouwes et al. 2016).

The key elements that an IMW should contain are similar to those of large-scale ecological experiments (Carpenter et al. 1995; Scheiner and Gurevitch 2001). Here we describe three levels of rigorousness for each element from an optimal (rank 1) to minimal (rank 3) ability to achieve IMW goals (Table 2) and in the following section we describe the challenges IMWs face implementing these elements.

CHALLENGES IMPLEMENTING IMWS

All IMW teams have faced challenges in implementing the ideal elements that we have identified as essential for assessing watershed-scale fish responses to stream restoration

TABLE 1. Summary of basic intensively monitored watershed (IMW) attributes and preliminary findings across the Pacific Northwest. LWD = large woody debris, ELJ = engineered log jam.

	Year started										
IMW Name	**Monitoring**	**Restoration**	**State/ Province**	**Columbia Basin**	**Eco Region 3**	**Basin/Watersheds**	**Focal species**	**Restoration being tested**	**Magnitude of treatment**	**Habitat response**	**Fish response**
Alsea	1988	1990/91	OR	No	Coast Range	Northern Oregon Coast/ Alsea, Nestucca	Coho, Cutthroat, Steelhead	LWD, floodplain reconnection	51 pools, 21 alcoves	700% increase in average winter rearing habitat	50% increase in summer and 300% increase in overwinter survival of juvenile Coho
Asotin	2008	2012	WA	Yes	Columbia Plateau	Lower Snake/ Charley, North Fork and South Fork Asotin Creeks	Steelhead	LWD	550 wood structures in 12 km	185% increase in wood (3 treatments completed), increased habitat unit diversity	250% significant increase in juvenile steelhead density
Bridge	2005	2009	OR	Yes	Blue Mountains	John Day/ Bridge Creek	Steelhead	Beaver dams	121 beaver dam analog structures in 4 km	Increase in ground water height, bankfull width, pool frequency, and floodplain connectivity. Decrease in stream temperature	Fish abundance, survival, and production increased by 168%, 52%, 175% respectively
Elwha	2000	2011	WA	No	Strait of Georgia/ Puget Lowland	Puget Sound/ Elwha River	Bull Trout, salmon, Steelhead	Barrier removal (30 m dam)	New access to 30 km	300% increase in habitat length	100-200% increase in redds, new species and life history strategies above barrier (Chinook and steelhead)
Entiat	2003	2012	WA	Yes	North Cascades	Upper Columbia/ Entiat River	Chinook, Steelhead	ELJ, floodplain reconnection	35 ELJ structures, 1.9 km reconnected side channels	>600% increase in wood	Higher growth rates and density of Chinook and Steelhead in side channels
Hood Canal Complex	2003	2007	WA	No	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	Pool frequency and pool depth increased downstream of LWD treatment	Adult, parr and smolt monitoring ongoing, response yet to be determined
Keogh	1995	2003	BC	No	Coast Range	Keogh River, Waukwaas River	Coho, Steelhead	Road decommissioning; boulder, LWD, and nutrient additions	Nutrients added to mainstem and several tributaries, 500 instream structures, 7 off-channel ponds, extensive road stabilization/deactivation	Increase in pool frequency, off-channel habitat; 300% increase in inorganic phosphorus	Increase in smolt size and decrease in average age of smolts, increase in smolts per spawner
Lemhi	2007	2009	ID	Yes	Middle Rockies	Upper Salmon/ Lemhi River	Chinook, Steelhead	Barrier removal	Reconnected 275 km of tributary habitat	22% increase in wetted area, 19% increase in pool habitat	Life history expression increase
Lower Columbia	2003	2010	WA	Yes	Coast Range	Lower Columbia/ Mill, Abernathy, and German Creeks	Chinook, Coho, Steelhead	Nutrient addition, floodplain reconnection, LWD	Nutrient enhancement in 27 km	Undetermined	Undetermined
Methow	2009	2012	WA	Yes	Columbia Plateau	Upper Columbia/ Methow	Bull Trout, Chinook, Steelhead	ELJ, floodplain reconnection	Wood placement, floodplain channels in 15 m	Increased side channel connection; riffle habitat increased 100%; mean pool depth increased 300%	Increase in fish abundance of 400% to 800%

TABLE 1. (continued).

Middle Fork John Day	2004	2007	OR	Yes	Blue Mountains	John Day/ Middle Fork John Day River	Chinook, Steelhead	ELJ, floodplain connection, LWD	200 ELJ, 600 pieces of LWD in 12 km, 13 km reconnected side channels	Undetermined	Undetermined
Potlatch	2005	2009	ID	Yes	Columbia Plateau	Clearwater/ Potlatch River	Steelhead	Barrier removal, flow increase, LWD	33 km new access, improved flow, 200 wood structures in 5 km	Some reduced temperatures	Reestablishment of spawning above barrier
Pudding	2006	2015	CA	No	Coast Range	Northern California Coast/ Pudding Creek, Caspar, Noyo Rivers	Coho, Steelhead	LWD	375 pieces LWD in 9 km	Undetermined	Undetermined
Skagit	2005	2000	WA	No	Strait of Georgia/ Puget Lowland	Puget Sound/ Skagit River	Chinook	Estuary reconnection	Reconnected 540 hectares of estuary	Increased connectivity and greater habitat area	Reduced fish density and increased fish residence time
Strait of Juan de Fuca	2003	2007	WA	No	Coast Range	Puget Sound/ East Twin River, West Twin River, and Deep Creek	Coho, Steelhead, Cutthroat	LWD, floodplain reconnection	273 in-channel structures (1997-2004)	Undetermined	Undetermined
Tenmile	1991	1996	OR	No	Coast Range	Northern Oregon Coastal/ Tenmile, Cummins, Mill Creeks	Coho, Steelhead, Cutthroat	LWD	Wood placement, 241 conifers in 11 km	446% increase in key pieces of LWD (wood >12 m long, 60 cm diameter); 71 increase in deep pool percent (>1 m deep)	Increase in steelhead smolt abundance and steelhead and Coho freshwater survival increased
Wind	2000	2009	WA	Yes	Cascades	Lower Columbia/ Wind River, Trout and Panther Creeks	Steelhead	Barrier removal, LWD	Removal of partial 7.5 m barrier dam	Restored sediment transport, natural fish passage, and conversion of reservoir to 0.65 km of stream habitat	Increased proportion of adult steelhead spawners and smolts using affected subbasin

(Table 2). Only three IMWs have an explicit adaptive management plan (Asotin, Bridge, and Elwha). In this section, we discuss the nature of these challenges and in the following section recommend solutions based upon on the experience of IMW teams and literature reviews.

Planning

One of the biggest challenges identified by IMW teams was inadequate coordination between groups that developed the restoration plans and the groups that developed the experimental design of an IMW. Restoration funding typically encourages numerous local entities to apply for restoration funding, resulting in numerous small projects that are dispersed over several watersheds. The Entiat IMW team has invested significant time and planning to address such issues by grouping restoration so that one subwatershed receives most of the restoration funding for 1–3 years and then restoration is focused on a new subwatershed.

Selecting watershed(s) for IMW locations has also been less than optimal in some cases partly due to a lack of explicit criteria (Table 2). In other cases, less than optimal locations for IMWs were chosen because of the "path of least resistance" phenomenon (Hermoso et al. 2012), whereby the location is chosen because restoration is being implemented due to logistical and political feasibility, rather than where it may optimize a robust experimental design. In other cases, the watershed location may be appropriate but the restoration may be focused on the wrong primary ecological concern. This can happen when the primary ecological concerns are misidentified (e.g., relying on expert opinion alone). Field assessments of ecological concerns should be conducted to ensure that other factors that were not formally recognized in restoration planning are not limiting salmon and steelhead populations. For example, large woody debris (LWD) is often added to streams to increase habitat complexity with the explicit assumption that increased habitat complexity will increase fish productivity. However, if other watershed processes such as sediment transport and hydrologic connectivity are impaired and are not prioritized, additions of LWD will likely fail at increasing fish populations (Beechie and Bolton 1999). This challenge highlights the need for more emphasis to be placed on robust experimental designs (e.g., Before-After-Control-Impact [BACI], hierarchical, staircase) that are structured within adaptive management.

Doing

Though most IMW teams are monitoring similar fish and habitat attributes to evaluate restoration actions, there is inconsistency in the monitoring protocols and no direct coordination between IMWs to standardize protocols (but see Crawford and Rumsey 2011; Roni et al. 2015). Smolts per spawner is recognized

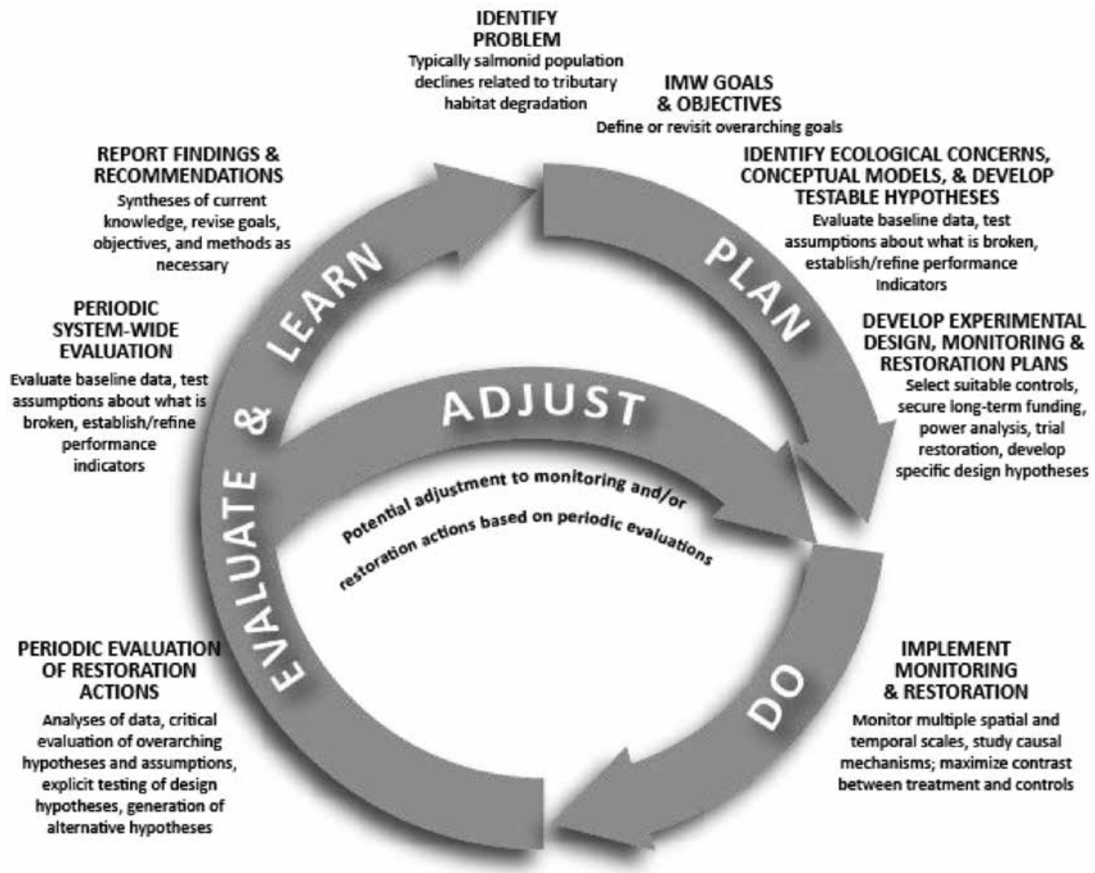

Figure 2. Adaptive management framework for implementing intensively monitored watersheds (IMWs). Key elements of an IMW are outlined in each of three phases of the framework: plan, do, and evaluate and learn. Adjustments to the plan and do phases happen during the evaluate and learn phase. Adapted from Bouwes et al. (2016).

TABLE 2. Key elements of watershed-scale, long-term experiments to test the effectiveness of restoration at increasing freshwater salmon and steelhead production at intensively monitored watersheds (IMWs), ranking criteria, and a summary of the challenges in implementing the elements to date. Ranking criteria defined as follows: 1 = optimal elements most likely to attain IMW goals; 2 = adequate elements likely to attain some of IMW goals; 3 = minimal approach but may have some limited value.

IMW elements	Subcategory	Ranking of criteria for maximizing learning and determining restoration effectiveness	Common factors affecting the potential success of IMWs
Adaptive management		1. Explicit adaptive management plan (Walters 1986; Williams et al. 2009) 2. Explicit hypotheses about fish and habitat responses to restoration 3. Trial and error	Not well understood how to develop or implement and inconsistent among IMWs; hypotheses are not always explicitly stated and alternative hypotheses are seldom articulated and explored
Planning	Coordination/communication	1. Multiple stakeholders' involvement in determining location and design of experiment, monitoring, and restoration to achieve goals and test hypotheses 2. Goals of an IMW integrated within ongoing restoration planning and monitoring 3. Opportunistic approach to implementing monitoring and restoration	Competition with the same funding source; assumption that restoration benefits fish production; restoration practitioners operating outside the experimental design (i.e., implementation of actions in controls or in the pre-project phase)
	Watershed selection	1. Explicit criteria to minimize confounding response (e.g., minimum hatchery influence, exotics, recent restoration, etc.); restoration feasibility consistent with goals and the experiment; suitable controls available; long-term study (>10 years) commitment from multiple stakeholders; previous monitoring data available 2. Long-term support for IMW and meet some basic criteria 3. Opportunistic or path of least resistance	No consistent set of biological and watershed attributes used for selecting IMW locations; past restoration and land use management confound results; difficulty finding control watersheds; control and reference used interchangeably
	Ecological concerns/models of system function	1. Ecological concerns derived from prior data and conceptual or analytical models of system function (Williams et al. 2009); identified ecological concerns treated as hypotheses; clear restoration objectives that address limiting factors 2. Existing recovery plans used to identify ecological concerns but assumptions not tested 3. Ecological concerns not clearly identified	Process-based ecological constraints; opinion-based limiting factors; lack of time, funding, or data to confirm assumptions

TABLE 2. (continued).

IMW elements	Subcategory	Ranking of criteria for maximizing learning and determining restoration effectiveness	Common factors affecting the potential success of IMWs
	Experimental design	1. Clearly defined experimental design elements (e.g., focal species, spatial and temporal scope) and hierarchal sample design (e.g., experimental elements, sample units, experimental units, sample populations; Thompson et al. 1998), multiple treatment and control areas with pre- and postrestoration monitoring (e.g., BACI; Stewart-Oaten et al. 1986; Crawford and Rumsey 2011). Staggered restoration over multiple years (e.g., staircase, Walters et al. 1988), multiple spatial scales (e.g., hierarchical; Underwood 1994), power analyses to determine sample effort (Peterman 1990) 2. Before–after experimental designs, power analysis 3. Observational designs	No minimum standards for experimental designs; designs often not driven by a priori hypotheses; power analyses often suggest >10 years to detect a fish response (i.e., Wind River); minimal preproject monitoring; minimal replication of treatment and controls; covariates often not considered
	Restoration design	1. Actions target ecological concerns and are process based (Kondolf et al. 2007; Beechie et al. 2010); consistent with geomorphic and ecological setting; scope of restoration sufficient to detect fish responses at watershed scale (>25% watershed treated; Roni et al. 2010) 2. Restoration linked to ecological concerns but limited in scope; restoration is process based but not designed within watershed constraints (≤25% of watershed treated) 3. Restoration follows form-based recipes without watershed context of geomorphic and ecological processes; actions are opportunistic and not targeted toward impaired locations	Multiple restoration actions can confound linkages; inappropriate restoration design for the geomorphic or ecological setting; not process based; restoration extent may be insufficient to create an observable effect size
	Monitoring plan	1. Smolts/spawner and multiple life history attributes (e.g., growth, movement, survival, and production) monitored pre- and postrestoration over multiple seasons; habitat monitoring of core set of parameters (Roni et al. 2015); monitoring effort guided by power analyses 2. Smolts/spawner or other life history attributes and expected habitat response monitored pre- and postrestoration targeted to expected critical season (e.g., summer base flow or winter) 3. Monitoring of either treatment and controls or pre- and post-project; monitoring of one life stage and life history attribute (e.g., juvenile abundance); adoption of habitat monitoring protocols	Core set of attributes and metrics not consistently collected across IMWs limit meta-analyses; limited evaluation of life history attributes and multiple life stages; monitoring not tied to a priori hypotheses; insufficient emphasis on understanding the causal mechanisms; insufficient effort to detect restoration response; habitat monitoring protocols implemented without clear understanding of their limitations
Doing	Restoration	1. Implementation occurs at location and timing described by the experimental design (Bisson et al. 2013) 2. Implementation occurred within the locations and timing described by the experimental design but not feasible in all locations; implementation of other unplanned projects occurred 3. Implementation is opportunistic and drives the experiment; large reduction in projects from planned; projects installed without guidance of ecological concerns or geomorphic condition	Experimental design often does not include feasibility; opportunistic restoration results in imbalanced and incomplete experimental contrast; additional restoration often implemented by practitioners not involved in the IMW, confounding results; incomplete restoration results in small effect size difficult to detect
	Monitoring	1. Continual collection (<5% data gaps) of key attributes and consistent monitoring protocols over the life of IMW; directed studies to identify causal mechanisms and appropriate covariates 2. Some data gaps (5%–30%) due to loss of data or inability to collect (e.g., loss of passive integrated transponder tag arrays during high flows); changes in monitoring protocols but cross-walking of data possible; some supplementation of monitoring to improve ability to identify causal mechanisms 3. Significant data gaps (>30%) and inconsistencies in monitoring protocols	Data series are frequently incomplete due to logistical constraints, changes in protocols, or unanticipated restoration; long-term data sets on smolts per spawner difficult to collect; few IMWs are directly assessing changes in watershed impairments (e.g., riparian improvements, road or upslope rehabilitation)
Evaluation and learning	Data management/ reporting/ knowledge transfer	1. Well-structured databases including metadata (Kolb et al. 2013); strong quality assurance/quality control; public access to data; regular reporting and knowledge transfer to managers/funding agencies; frequent analyses identifying data collection not originally anticipated; power analyses to reevaluate effect size or variability in monitoring design that can be used adaptively; assessment of triggers to prevent harm to listed species 2. Lack of any one of the items listed in 1. 3. Lack of two or more of the items listed in 1.	Large volumes of data are overwhelming many IMWs; few regional databases are available to synthesize data across IMW projects; limited metadata documentation; difficulties in producing timely data analysis and reporting, limiting knowledge transfer; analyses to adapt original plan to produce sufficient restoration response, overcome variability through increased monitoring, identify causal mechanisms, and prevent harm not often completed

as an ideal metric to measure fish response at a watershed scale, but IMW teams that are collecting these data report challenges maintaining infrastructure to monitor smolt and adult abundance at the watershed scale. This is especially true for steelhead populations, which spawn in the spring when environmental conditions can inhibit accurate and precise redd counts in some systems. In addition, some IMW teams that are measuring smolts per spawner have limited resources to dedicate to alternative metrics of fish response that are essential to identifying the causal mechanisms of a response such as seasonal estimates of juvenile abundance, growth, movement, and survival.

The greatest challenge with regard to restoration implementation arises from coordination of actions within an IMW plan. Also reported as challenges were maintaining control watersheds (i.e., stopping restoration in certain locations) and being able to restore a large enough proportion of the watershed to detect population level changes (i.e., >25% of the watershed area). Furthermore, many IMWs are being implemented on private lands. Establishing a working relationship with private landowners is extremely valuable; however, these relationships may take time to develop and are not easily put into an adaptive management framework.

Evaluating and Learning

The lack of annual reporting was cited as a hindrance to evaluation of IMWs. The reasons for this are related to absence of a formal iterative evaluation process, limited funding (e.g., most funding dedicated to collection of field data), lack of database systems to aid efficient data reduction, and lack of a consistent IMW template for annual reporting. Few IMW teams have formalized the "adjustment loop" within the adaptive management process that allows for critical and transparent evaluation of ecological concerns, monitoring results, and proposed restoration actions (Figure 2). In addition, a variety of barriers limit sharing data across multiple partners and/or integration of data sets. For example, there are different responsibilities regarding the sharing of data between agencies and monitoring groups. Some IMW teams are decentralized and data are stored on computers at field offices, and there is no consensus on the level of data that should be shared and stored in regional databases.

Data sharing issues also extend to general knowledge transfer about IMWs. There has been no centralized web location for IMW teams to host planning documents, annual reports, and related products. However, many IMWs are collecting valuable data toward viable salmonid population criteria and relaying this data to managers, which illustrates the importance of IMWs beyond testing restoration effectiveness (Crawford and Rumsey 2011). Some IMWs have done significant local public education campaigns on the importance of habitat restoration by way of newspaper articles, agency press releases, and speaking with local angler and conservation groups. However, no regional public relations campaign has been established to inform the public of the need and importance of IMWs. Finally, the extent to which information generated at an IMW can be extended to other locations is currently unknown and could be a challenge in the future.

RECOMMENDATIONS

Planning

We recommend that prior to the IMW planning phase, an adaptive management framework be established to implement IMWs because of the experimental nature of the actions, as well as the uncertainty in how these actions translate to a population-wide response for salmon and steelhead (Rieman et al. 2015). Thus, it is important to strive to incorporate the ideal elements mentioned in this document and acknowledge the uncertainty in a formal fashion. To do so, the planning process needs to include all of the potential participants. It should also be clear from the onset that the priorities of the IMW should be to test the effectiveness of restoration actions at the appropriate scale and to identify the causal mechanisms of the observed responses where possible. Clearly defined objectives, understanding of the ecological concerns (i.e., what is not working), conceptual models of the system function, testable hypotheses, the development of a sound experimental design, and long-term funding are necessary to quantify the response because it will likely take years to decades for such responses to unfold (Table 2).

It is also imperative to standardize, where possible, data collection and data management. The monitoring must be established to explicitly test the assumptions associated with the restoration hypotheses. Only then can potential components of the variation be segregated and quantified in response to the restoration actions. Implementing restoration actions at the appropriate scale is also critical because a detectable contrast between the control or reference and treatment is fundamental to quantifying any real change. The IMW teams should consider a staircase implementation of restoration actions if funds are limited, logistics prevent large areas from being restored in a single year, or the year restoration is implemented could confound the experiment (e.g., year effects such as drought or wet years; Walters et al. 1988). If suitable control watersheds are not available and/or recent restoration actions are likely to confound the testing of proposed restoration actions, a new location for the IMW should be considered.

Doing

We recommend choosing multiple response variables for the species of interest. For example, we suggest a summer steelhead IMW monitor not only smolts per spawner at the watershed scale but also other aspects of juvenile life history such as abundance, growth, movement, and survival. These life history metrics should be monitored during periods that are expected to be bottlenecks for the population and those that the restoration actions are expected to benefit. By measuring multiple metrics at multiple spatial and temporal scales, there is an increased chance of detecting a response and determining the causal connection between the restoration action and ultimate change in fish productivity. This same logic applies to habitat metrics.

Evaluation and Learning

We recommend during the evaluation phase that IMW teams provide an annual evaluation of ecological concerns, monitoring approaches, restoration actions, and habitat/fish responses and document any changes with supporting rationale (see Bouwes et al. 2016). Funding agencies should require evaluations in standardized formats to aid in tracking the progress of IMWs and to allow for timely dissemination of new information. We also recommend that a dedicated website be established to facilitate evaluation of IMW progress and assist in knowledge transfer. This is critical because IMWs require long-term funding that may limit the scope of actual restoration. Managers and the public need to be made aware of why these investments in IMWs are being made and they should have ready access to IMW findings if the increased knowledge is to be translated to future restoration. We can report here that steps are being taken by the Pacific Northwest Aquatic Monitoring Partnership to host a website directed at a technical audience (pnamp.org/IMW/home), and the National Oceanic and Atmospheric Administration is developing a press release, social media plan, and fact sheet directed at the general public.

Supporting the transfer of lessons learned from IMWs to other watersheds will require significantly more work. Results from IMWs are likely to be most applicable to other watersheds with similar geology, topography, climate, vegetation, and other characteristics, which suggests that watershed classification schemes might be useful for this purpose (Beechie and Imaki 2014). Habitat-based (Lichatowich et al. 1995; Sandy River Basin Working Group 2007) and individual-based (Railsback et al. 2009) models are tools that have gained popularity in fish ecology over the last decade and might also be useful for extending the results from IMWs. Work in the Columbia River estuary may also provide an example for extending results from an IMW to other watersheds (Diefenderfer et al. 2012). The Columbia River estuary project recently utilized data from restored and reference sites, hydrodynamic models of the estuary, and a meta-analysis of literature information, all combined in a geographic information systems framework, to assess the extent to which restoration had influenced estuarine properties of interest. An approach of this type, utilizing information from multiple IMWs, could provide a very powerful method for applying results from IMWs across the Pacific Northwest.

CONCLUSION

It is clear that no IMW has implemented all of the most robust elements of an ideal IMW. This is not surprising because watershed-scale experiments are inherently challenging. In addition, IMW teams may not have adopted all the elements because some IMWs were not built "from the ground up" but rather were more opportunistic, taking advantage of large restoration projects or monitoring efforts that were already planned or underway. In this regard, there are likely two classes of IMWs: those that are purposefully designed experiments (with some level of randomization in treatment allocation) and those that are more observational in nature (McDonald et al. 2007). Both types can provide valuable information regarding the effectiveness of restoration, but it will be important in the evaluation phase to make the distinction between these approaches.

There is a strong institutional and scientific need for the type of information provided by watershed-scale experiments. Much of the stream restoration in the Pacific Northwest is undertaken with the explicit assumption that it will increase freshwater production of salmon and steelhead. Despite numerous evaluations of restoration effectiveness, strong evidence validating this basic assumption remains elusive. The IMW approach represents a significant attempt to develop watershed experiments that use restoration actions as treatments to test these assumptions and provide reliable and compelling evidence of the effectiveness of common watershed restoration actions.

Although most IMWs are still in either the pretreatment phase or the early stages of posttreatment, the experimental design, restoration, and monitoring plans are in place to answer questions concerning the effectiveness of restoration actions. Preliminary results from some IMWs provide insight into fish and habitat responses at multiple spatial and temporal scales pre- and postrestoration. However, there have also been numerous reported difficulties, including a lack of coordination between restoration, monitoring, funding, and implementing entities and lack of consistent funding.

This review summarizes many of the issues encountered during the implementation of IMWs throughout the Pacific Northwest. The combined knowledge of the IMW teams and the growing literature on stream restoration effectiveness provide a good foundation for improving current IMWs and a framework for the development of future IMWs. Through careful design and consistent, coordinated implementation, analyses of data collected during IMWs can determine restoration effectiveness, identify causal mechanism for the observed responses, and provide funding and management agencies with insight for allocation of restoration resources in similar but less well-studied watersheds.

However, we end with a note of caution. Identifying good control streams is difficult, and there is no guarantee control streams will remain suitable throughout the life of the project (e.g., Johnson et al. 2005). Similarly, the populations being studied have variable life histories that require monitoring for 2–5 or more years to assess a single cohort. This means that experiments will likely need to be at least 10 years long, if not longer, requiring significant investments in monitoring infrastructure and maintenance. The IMW concept uses broad-scale, long-term ecological experimental designs, so stakeholder expectations need to be informed and patient. Stakeholders and IMW teams should be reminded that in most cases it took over 200 years for watersheds to attain their current degraded state (Rieman et al. 2015). They will not be fixed quickly, and though an IMW experiment takes time, it is currently the fastest, most reliable approach to measure population-level responses and to assess the efficacy of habitat restoration efforts.

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