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Basin Scale Monitoring of River Restoration: Recommendations from Case Studies in the Pacific Northwest USA

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Abstract.—Monitoring of restoration at a basin rather than reach scale presents both scientific and organizational challenges. Using three case studies in the Pacific Northwest, we demonstrate the key factors and challenges that need to be considered when designing basin-scale evaluation of numerous restoration actions. These include linking reach and basin scale responses to restoration, identifying a core set of parameters to monitor at those different scales, and continuous coordinating of restoration, monitoring, and other fisheries management actions. Linking reach and basin level responses to restoration requires different methods of site selection, sampling design, and scale of measurement than typically used for reach-scale monitoring. In addition, parameters may not be appropriate for measurement at both scales. For example, parameters typically measured at a reach scale, such as fish abundance or pool frequency, may be examined at both a reach and basin scale while others, such as sediment supply, are more appropriately examined at basin level. Parameters that measure processes such as sediment supply or riparian condition respond slowly to restoration actions and require a long term monitoring (>10 years). A core set of parameters for basin scale monitoring of restoration should include: stream discharge and temperature, coarse and fine sediment supply, riparian species diversity and size, pool frequency, wood abundance, fish abundance, macroinvertebrates, and periphyton. Finally, failing to properly coordinate the timing, location, and implementation of restoration, monitoring, and other fisheries and land management activities can prevent the most well designed and costly monitoring program from detecting a restoration response.

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Introduction

Attempts to restore and improve streams, rivers, estuaries, and entire basins have become commonplace throughout the world. In the United States alone, approximately one billion dollars is spent annually on these activities (Bernhardt et al. 2005) and the annual number worldwide is likely in excess of two billion U.S. dollars. Large basin or ecosystem restoration programs such as the Pacific Coastal Salmon Recovery Fund, Chesapeake Bay, and South Florida (Everglades) costing 100s of millions of dollars annually are being implemented.[1] Thousands of projects are initiated under these programs to restore small patches of rivers, estuaries, and other aquatic habitat. For example, Hassett et al. (2005) reported that nearly 5,000 projects have been implemented in the Chesapeake Bay Watershed, and Katz et al. (2007) located data on 23,000 projects that had been implemented in 35,000 locations since 1990 in the U.S. Pacific Northwest.

A major criticism of small and large restoration programs alike has been the lack of effectiveness monitoring (Roni et al. 2002; Roni 2005; Beechie et al. 2009). The vast majority of restoration efforts continue to be opportunistic and lack monitoring and evaluation at both the project and basin level (Roni et al. 2002; Bernhardt et al. 2005; Roni et al. 2008). The National Research Council (NRC) (1992), Kauffman et al. (1997), Beechie et al. (2003, 2008) and many others have discussed the need and the methods for basin level planning of restoration as well as many of the socio-political challenges of implementing such programs. Existing guidance on monitoring has focused on monitoring different types of restoration (see Roni 2005) how to monitor habitat conditions at broad scales (Bryant 1995; Larsen et al. 2001, 2004), or how long to monitor (Ham and Pearsons 2000; Liermann and Roni 2008). Little guidance exists on how to monitor multiple actions at various scales (Beechie et al. 2008). Despite the fact that for decades scientists have been calling for better monitoring and evaluation of restoration (e.g., Tarzwell 1934; Reeves and Roelofs 1982; Rumps et al. 2007), there are still a number of major challenges when trying to determine the effect of reach level projects at a basin scale.[2]

Long-term monitoring attempting to quantify management or restoration actions at the basin scale has occurred in a handful of small basins throughout North America (Bormann and Likens 1979; Tschaplinski 2000; Ward et al. 2003). For example, the Carnation Creek study examined long-term impacts of timber harvest on watershed conditions and salmon production (Tschaplinski 2000). The Hubbard Brook Experimental Forest continues to monitor long-term changes in ecosystem processes in a small New England watershed (Bormann and Likens 1979). These studies typically focused on one basin, and in some cases one control and one treatment basin, had little to ample amounts of pretreatment data at the appropriate spatial scale, and did not examine restoration activities. There have also been some less intensive and shorter-term efforts that have attempted to examine response of whole basins to restoration (e.g., Reeves et al. 1997; Solazzi et al. 2000; Johnson et al. 2005). These studies have produced mixed results with Solazzi et al. (2000) demonstrating an increase in juvenile coho numbers posttreatment, while Reeves et al. (1997) and Johnson et al. (2005) produced inconclusive results. The biggest challenge of long-term ecological monitoring or evaluating of restoration at a basin scale is in design, site selection, and determining monitoring parameters. More recently implemented basin-scale monitoring case studies

[1] see http://www.nemw.org/index.php/policy-areas/water-and-watersheds for overview of large restoration initiatives.

[2] We use the term basin in this paper synonymously with watershed and catchment.

or intensively monitored watersheds as they are commonly called, continue to struggle with these design issues and little guidance exists for basin scale monitoring.

Fortunately, there is guidance available for the steps to consider when designing a restoration monitoring program. The key steps for designing restoration monitoring at any scale include defining restoration goals, identifying the key questions or hypotheses, selecting monitoring designs, determining parameters to monitor and the spatial and temporal replication needed (number of sites and years) and determining sampling scheme. (Roni et al. 2005). Roni et al. (2005) outlined two major questions that need to be evaluated at a basin scale: 1) what is the relative effect of individual reach-scale restoration projects on biota and habitat conditions at a basin scale? And 2) what is the effect of all restoration projects on biota and habitat conditions at a basin scale? Addressing these questions requires different monitoring designs, replication, sampling schemes (i.e., complete census versus stratified random samples), and statistical analysis for some parameters. Moreover, trying to determine the effectiveness of individual projects while at the same time determining whole basin response to a suite of restoration activities has been one of the larger challenges facing restoration ecologists and practitioners.

In this paper, we first use case studies from the U.S. Pacific Northwest to demonstrate how basin-scale restoration monitoring is commonly done, the challenges in implementing basin-scale monitoring of restoration, and how to link evaluation restoration at a reach and a basin scale. Second, based on these case studies and a previous extensive review of parameters for monitoring different types of restoration (Roni 2005), we provide recommendations on a core set of parameters to consider when designing basin-scale evaluation of restoration. We close with recommendations for implementing and maintaining a successful basin-scale evaluation of restoration.

Methods and Case Studies

Using the key monitoring steps outlined in Table 1 (Roni et al. 2005), we examine how each case study responded to these steps and discuss the strengths and weaknesses of each case study and use these to provide recommendations for design of basin-scale restoration monitoring. For each case study we provide a brief description of the overall project (background), the methods (key questions, study design, sampling scheme, parameters monitored) and the results and recommendations. The first two case studies focus on monitoring fish and instream habitat responses to restoration while the third case study focuses on sediment delivery and other watershed processes (Table 1). In addition, the first two are new or ongoing studies with relatively little data available while several years of post project results are available for the third case study. While there certainly are other case studies being implemented, we selected three case studies that cover the range of conditions and actions that one typically encounters (small to large watersheds, instream to upslope restoration), demonstrate the challenges of evaluating restoration at a both a reach and basin scale and with which we had some involvement in either design or monitoring.

Case Study 1: Strait of Juan de Fuca Intensively Monitored Watersheds

Background.—Degradation of rivers and streams in the Pacific Northwest USA has led to large efforts to restore streams and increase numbers of threatened and endangered Pacific salmon and trout (*Oncorhynchus* spp.). In response to the need for basin-level evaluation of habitat restoration efforts

Table 1. Summary of monitoring programs for three basin scale restoration monitoring case studies.

Key monitoring questions	Straits IMW	Entiat River	Illabot Creek
Project goal	Restore habitat throughout basins to increase fish abundance	Restore habitat and increase Chinook salmon and steelhead trout abundance	Reduce sediment and improve habitat and fish survival
Hypotheses/question	What are the effects of a suite of different restoration actions on habitat conditions, juvenile and adult coho salmon and steelhead survival and abundance at a watershed scale?	1. What is the effect of a suite of approximately 80 instream channel restoration prjects on reach-scale physical and biological habitat metrics? 2. What are the effects of approximately 10 side-channel restoration projects on physical and biological habitat metrics? 3. What are the combined effects of changes in physical and biological habitat resulting from restoration actions on the abundance of spring Chinook salmon and steelhead parr, smolts, and adults within the Entiat Basin?	1. Did sediment supply increased due to forest practices, and would decrease subsequent to road rehabilitation? 2. Did pool habitats become shallower as sediment supply increased, and deepened as sediment supply decreased? 3. What was the effect of decreased pools and pool quality on Chinook spawner distribution and abundance?
Monitoring design	BACI	Hierarchical staircase	BACI & Post-treatment

Table 1. Continued.

Key monitoring questions	Straits IMW	Entiat River	Illabot Creek
Parameters	Habitat, substrate, LWD, parr, smolt, and adult abundance and survival	Flow, temperature, sediment supply, fire history, land use riparian condition, channel morphology, substrate, LWD, macroinvertebrates, and parr, smolt, and adult abundance, growth and survival	Sediment supply, habitat, and adult spawner abundance
Replication (# sites and/or years)	10+ (2 before and several after)	20+ years	10–40 years depending upon parameter
Sampling scheme	Census, stratified random sample (EMAP)	Stratified spatially balanced sample (GRTS)	Census, stratified random sample (EMAP)
Analysis	Paired t-test, regression, ANOVA	ANOVA, ANCOVA, multivariate	Graphical interpretation, ANOVA

for threatened and endangered salmonids, the Washington Department of Ecology, Washington Department of Fish and Wildlife, Weyerhaeuser Company, National Oceanic and Atmospheric Administration Northwest Fisheries Science Center, Lower Elwha Klallam Tribe and the U.S. Environmental Protection Agency implemented the Intensively Monitored Watershed Program (IMW) (Bilby et al. 2005). The program is designed to evaluate the basin-level effects of restoration techniques on habitat conditions and salmonid fishes in multiple treatment and control basins in each of three complexes (regions). The project was implemented in 2003 and each group of watersheds examines a unique set of restoration opportunities. Here we describe the study design for the Strait of Juan de Fuca Complex—a group of three 33–45 km^2 watersheds where monitoring is furthest along and restoration is being implemented [two treatments (Deep Creek, East Twin River) and one control (West Twin River); Figure 1)].

Methods.— This study is designed to test the hypothesis that the suite of restoration actions implemented throughout the treatment basins will lead to improved habitat conditions and fish abundance at a basin scale. A before-after control-impact (BACI) design (Schroeter et al. 1993) with two treatments and one control is being used to determine the effect of a suite of restoration activities on watershed conditions and coho salmon *O. kisutch*, steelhead *O. mykiss*, and cutthroat trout *O. clarki* survival and abundance. The three streams are located in the northwest corner of the Olympic Peninsula in Washington State and flow directly into the Strait of Juan de Fuca (Pacific Ocean)(Figure 1). Elevation in these basins ranges from sea level to 915 m in the headwaters and precipitation averages 190 cm per year (Bennett 2006). The primary land use for the last 100 years has been forestry. Logging, removal of in channel woody debris, and construction of logging roads on steep slopes have led to increased landslide frequency and simplified and degraded in-channel habitat conditions (Bilby et al. 2005). Restoration actions proposed and underway include road removal, off-channel connection and construction, large woody debris (LWD) placement, riparian planting, and removal of impassible road culverts (fish migration barriers), with LWD placement being the most widely used restoration technique.

Key habitat and fish parameters monitored include gravel size, mesohabitat quality and area (pool and riffle size, depth etc.), LWD abundance and volume, temperature, flow, and juvenile, smolt and adult salmonid abundance (Table 1). These are all thought to respond in different ways to various restoration strategies being implemented. Because a complete census of all these parameters is not possible, monitoring sites (reaches) were selected within each basin to estimate basin-scale juvenile fish abundance and measure physical habitat variables using generalized random tessellation stratified (GRTS) sample selection (Figure 1; Stevens and Olson 2004). The U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) developed this methodology for broad-scale monitoring of water quality and stream conditions (Kaufmann et al. 1999; Larsen et al. 2001, 2004). The GRTS method uses a statistical sampling design that treats streams as continuous. Sample sites are selected with a balance of random and systematic properties, making it possible to select stream sample locations in proportion to the occurrence of stream features of interest (e.g., gradient or stream order) and that efficiently cover the entire stream network (Hayslip et al. 2004; Stevens and Olsen 2004). This allows one to make accurate estimates from the sample data for the entire basin (Hayslip et al. 2004; Larsen et al. 2001). Physical habitat and juvenile fish surveys are

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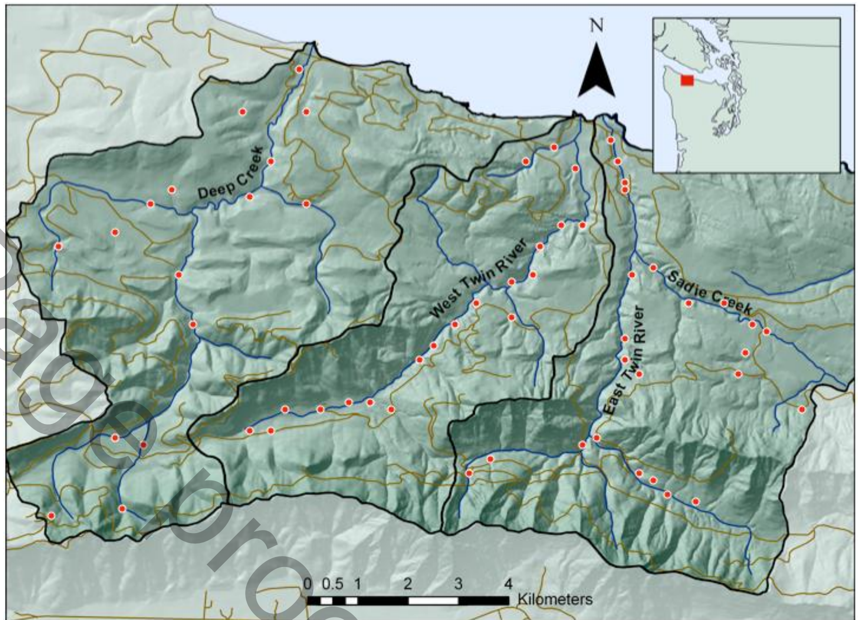

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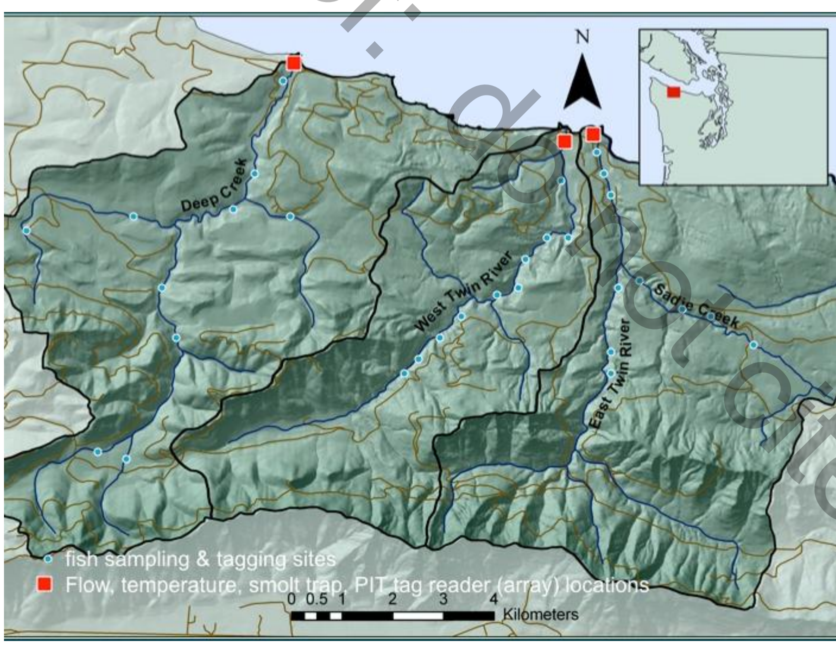

Figure 1. Location of sites (reaches) monitored annually for physical habitat variables (dots) in Case Study 1(A). Map of sites monitored annually for fish and location of temperature, flow, gauges and migrant fish monitoring stations (migrant traps and PIT tag readers) (B). Note that fish sampling sites are located only in areas accessible to anadromous fishes and only mainstem and major tributaries are shown.

conducted annually during summer months. Because of the high cost of fish sampling, only 10 sites were monitored per basin. All juvenile salmon and trout captured are also tagged with passive integrated transponder (PIT) tags to monitor their movements and survival at stationary PIT tag readers located near the stream confluence with the Pacific Ocean (Strait of Juan de Fuca). A downstream migrant trap is located near the mouth of each stream to collect all out-migrating salmon and steelhead smolts (juveniles). Salmon spawner surveys are conducted in the fall and early winter throughout the basins to estimate total adult escapement.

Results and Recommendations.—Initial habitat surveys suggest similar levels of pool habitat and LWD in all three basins, but detailed analysis of habitat data are needed. Coho salmon, steelhead, and cutthroat trout parr and smolt production are higher and more variable in Deep Creek than East Twin River or West Twin River (the control stream), though trends in all three basins are similar (Mike McHenry, Lower Elwha Tribe, personal communication). Results of PIT tagging and juvenile monitoring suggest that survival is slightly higher in treatment watersheds, but not significantly (Roni et al., in press). There are, however, differences in juvenile coho salmon overwinter survival within the each watershed based on location with those fish tagged higher up in the watershed surviving at a lower rate (Roni et al., in press). The probability-based GRTS sampling design was developed to examine basin scale effectiveness of multiple restoration actions, not effectiveness of individual actions. Detecting response of individual restoration actions or reach scale actions would require modification of the current sampling approach or addition of nonrandomly selected treatment and control reaches. This is currently being considered for restoration actions not yet completed.

While this project focuses on habitat and fish, no monitoring has occurred on processes such as sediment transport and hydrology, which are most likely to respond to road removal efforts. Moreover, data are being collected by different agencies and coordination of data collection and data management in the initial years of the project has been challenging. This resulted in some duplicative efforts and some inconsistently data collection in the first few years of monitoring. In addition, only one of the groups involved in monitoring provides and annual report summarizing data. No annual report summarizing results of monitoring by all entities has been prepared. Finally, all management activities could not be controlled in each basin and some restoration activities (wood placement) occurred before adequate preproject data were available. Thus the small amount of preproject data and initial difficulty coordinating activities may make detection of response to restoration treatment difficult particularly for LWD placement. Fortunately, additional restoration in the form of barrier removal and nutrient addition, which can be measured pre- and postrestoration, is planned for future years.

This monitoring program addressed the key steps for designing a monitoring program (Table 1) and appears to be a thoroughly designed monitoring program. The initial results, however, suggest three shortcomings: coordination of restoration and monitoring activities, data not being summarized and analyzed annually, and the need for other parameters to be monitored to detect response to road restoration.

Case Study 2: Entiat River Intensively Monitored Watershed

Background.—The IMW approach was also recently applied to the Entiat River basin—a large drainage (1,193 km^2) located along the arid east slope of the Cascade

Mountains in Washington State (NPPC 2004; Figure 2). The basin ranges in elevation from 216 m (median: 1,302 m) at its confluence with the Columbia River at river kilometer 774–2,763 m in the headwaters and average annual precipitation at Entiat, Washington is 37 cm (NPPC 2004). More than a century of human activity and natural events such as fire and flooding have influenced the Entiat River, resulting in a simplification of stream morphology and loss of fish habitat. Comparisons between historic and current channel morphology and salmonid habitat have found significant loss of complex off-channel habitat and loss of floodplain connectivity, which has had a negative effect on fish populations. In the lower Entiat River, stream channel shape has been simplified by channel straightening/widening and diking, and by streamside vegetation disturbance (CCD 1998). Fish populations within the Entiat subbasin include, but are not limited to, spring and summer Chinook *O. tshawytscha*, coho *O. kisutch*, and sockeye salmon *O. nerka*, summer steelhead *O. mykiss*, bull trout *Salvelinus confluentus*, and Pacific lamprey *Lampetra tridentata*. Proposed restoration treatments include instream structures, riparian replanting, and reconnection of relict side channels. Due to the highly degraded nature

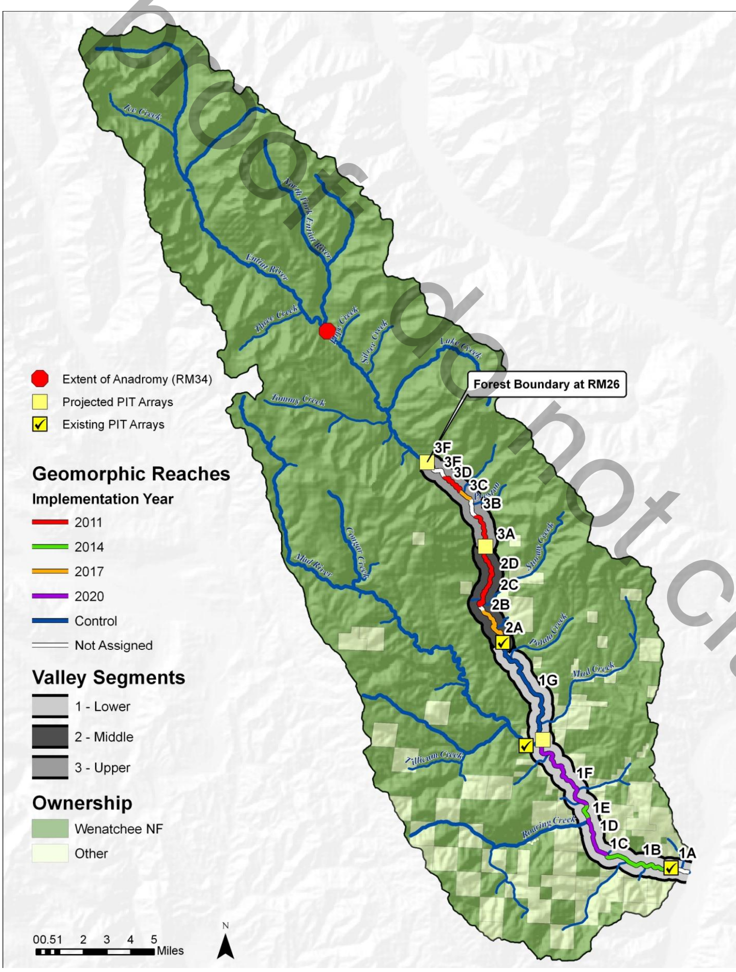

Figure 2. Location and timing of habitat restoration actions under the Entiat River Intensively Monitored Watershed study.

of the channel, the high degree of human use of the floodplain, and its current disconnection from the main channel, the most frequent action is the placement of instream structures (wood and boulders). The restoration plan is to implement all habitat improvement actions within 41.6 km of the Entiat River (Figure 1).

Methods.—A hierarchical staircase design, a variation of a standard BACI approach, underlies the restoration program in the Entiat Basin (Table 1). Three major hypotheses are being tested in regards to spring Chinook salmon and steelhead populations including:

1) What is the effect of a suite of approximately 80 instream channel restoration projects on reach-scale physical and biological habitat indicators?

2) What are the effects of a suite of approximately 10 side-channel restoration projects on physical and biological habitat indicators?

3) What are the combined effects of changes in physical and biological habitat resulting from restoration actions on the abundance, growth and survival of spring Chinook salmon and steelhead parr, smolts, and adults within the Entiat Basin?

A hierarchical staircase statistical design will be used to compare treatment and control sections within the Entiat River subbasin. This experimental design is based on a before-after contrast, but is conducted in a nested hierarchy, and so represents a variation on a standard BACI design (Walters et al. 1988; Loughin 2006; Loughin et al. 2007). A staircase design is a typical BACI design with treatments staggered in time (Loughin 2006). The staggering of the treatments over time allows for the separation of random year effects from year by treatment interactions. By staggering treatments within the treatment area, treatment sections can be used as controls until they are treated, increasing effective sample size and controlling for the loss of reference areas. Finally, in all watershed-scale restoration programs there is fundamental uncertainty as to the optimal spatial extent of treatment response (Underwood 1994). The spatial hierarchy employed in the Enitat design explicitly allows for physical and biological response to restoration to be detected at projects, reaches and at the entire watershed—a bet hedging component of the experimental design that has cost (additional complexity and monitoring locations), but also obvious benefits over a standard BACI design. In addition, a staircase design has logistical benefits since a very large number of actions are implemented as multiple space-time pulses. From a watershed restoration program perspective, this design may be preferred since full implementation results in all control areas being treated, thus even though actions are implemented in an experimental design, an un-treated control area is not left at the end of the project. Most importantly, the multi-scale approach is robust and flexible, ideally accounting for the full range of responses likely to result.

The Entiat hierarchical staircase design uses a geomorphic assessment to divide the lower 40 km of the Entiat mainstem into reaches that can be treated in a spatially and temporally driven manner (USBR 2009). The tributary assessment identifies three valley segments in the mainstem (defined based on changes in the channel gradient and geologic features that control channel morphology) with 17 geomorphic reaches nested within these valley segments. The geomorphic reaches distinguish sections of river with unique physical characteristics and provide a context for customizing river restoration strategies based on specific characteristics of each reach. The geomorphic reaches are the unit of inference in the Entiat design, with restoration actions clustered within these spatial units and the resultant biological and geomorphological change monitored at the unit scale. Restoration actions will be implemented on a 3-year time frame, rotating around the valley segments in four pulses over a 9-year period.

In the Entiat IMW, the habitat and fish monitoring follows the layout of the restoration implementation design. Fourteen geomorphic treatment reaches, eleven temporary control reaches and three permanent control reaches will be evaluated annually. The habitat monitoring response design implemented is from the Columbia Habitat Monitoring Program (Bouwes et al. 2011) and the fish monitoring response design is based on reach-level mark–recapture. Habitat sampling occurs during the summer low flow window which fish sampling occurs during two time periods (July/August and February/March) to get seasonal estimates of abundance, growth and survival. As in case study (1), the reach- and watershed-level mark–recapture based estimates rely on PIT tagging rearing juvenile salmonids and recapturing/redetecting tagged individuals during seasonal surveys or with PIT tag antennas installed at six locations on the Entiat and Mad Rivers.

Approximately 20 years is needed to capture pre- and postrestoration project conditions, interannual variability in fish and other metrics, long-term channel adjustments resulting from the restoration project, and possible changes to restoration project features that might arise from periodic factors like large flood events.

Results and Recommendations.—To date the Entiat IMW program has focused on implementing pretreatment monitoring, developing public support for the basin-scale suite of actions, coordinating restoration funding requests, and developing a programmatic approach to environmental compliance permitting. The feasibility of the restoration implementation schedule for a basin of this size has been called into question given that current restoration actions are planned and implemented in the Entiat at a rate of roughly two to four per year. The implementation schedule calls for an order of magnitude increase in projects and the phasing of projects as batches every third year. Initially, the monitoring design was not aimed at detecting the effect of individual projects; instead it focused on the overall, population-scale response. However, private landowners who had granted access to the river for restoration work were interested in knowing the local effect of the work adjacent to their land more than the overall aggregate basin-level effect of restoration projects. Therefore, the monitoring program was redesigned to also track per-project indicators that could be reported to the interested landowners. Overall, solid communication with the local stakeholders, not necessarily just the aquatic resource co-managers, has been an important component of the project's success to date. Continued communication with all stakeholders will be critical as the project enters the full implementation phase and postrestoration monitoring.

This case study is the newest of the three we examined, addressed all the key monitoring steps (Table 1). The challenges to implementation and success, however, go beyond technical design issues. The ability of this basin-scale effectiveness monitoring program to successfully demonstrate cause-and-effect relationships between restoration project actions and recovery metrics will depend, in large part, on a shift in habitat conditions caused by the rapid implementation of all the restoration actions (in four year or less) followed by lengthy posttreatment monitoring. Successful implementation of the projects is dependent in part on nontechnical issues like securing permitting and landowner participation, which are critical to making the Entiat a successful basin-scale monitoring program, rather than a traditional set of independent reach-scale actions.

Case study 3: Illabot Creek Monitoring of Watershed Processes

Background.—A common restoration strategy in forested basins is rehabilitation of unpaved forest roads to reduce sediment supply to stream channels (Beechie et al. 2005). Forest roads increase sediment supply through both increased landslides and surface erosion (Reid and Dunne 1984; Sidle et al. 1985; Bilby et al. 1989). However, restoration actions aimed at reducing sediment supply to stream channels and changes in habitat and fish populations are rarely monitored and the effectiveness of road rehabilitation actions is poorly understood. One case study for this type of restoration was initiated in a tributary of the Skagit River Basin in Washington State in 1997. The objective of the project was to determine if reductions in sediment supply through road removal and restoration lead to a decrease in stream sediment supply and improved channel conditions and fish abundance (Beamer et al. 1998).

Methods.—The study was conducted in the Illabot Creek basin where sediment supply was thought to have increased and the quality of fish habitats decreased by filling of pools with sediment and increased channel erosion. The Illabot Creek basin has a drainage area of 115 km^2, an average annual precipitation of over 200 cm, and basin relief of approximately 2,200 m—75 m at the mouth to 2,261 m in headwaters. This basin is prone to landslides, and potentially sensitive to timber harvest and forest road building. Illabot Creek originates in alpine terrain, and soon flows into a landslide-formed lake that traps most sediment from the alpine portion of the basin (which comprises roughly the upper 1/3 of the watershed). Downstream of the lake, the channel runs at a relatively steep 5% slope for the next 13 km. Where Illabot Creek meets the Skagit River floodplain, it forms an alluvial fan with an average channel slope of 1.7%. Downstream of the alluvial fan the creek flows at an average gradient of 0.2% to its confluence with the Skagit River 2.3 km. The main response reaches are located on the fan and Skagit floodplain (reaches 1–6), and two low gradient reaches in the middle basin (reaches 13 and 14) (Figure 3). In 1994 the U.S. Forest Service treated all 38 kilometers of roads in the basin to reduce sediment supply. A small percentage of the roads <5% were decommissioned and removed, and the remainder were treated with a combination of sidecast[3] pullback and stream crossing improvements to reduce the likelihood of landslides.

The hypotheses driving the monitoring were:

1. Did sediment supply increased due to forest practices, and would decrease subsequent to road rehabilitation?

2. Did pool habitats become shallower as sediment supply increased, and deepened as sediment supply decreased?

3. What was the effect of decreased pools and pool quality on Chinook spawner distribution and abundance?

A BACI design was used to assess the change in sediment supply due to roads, while a posttreatment design was used and to analyze changes in pool habitats and salmon abundance after the road rehabilitation was completed. The monitoring program included pre and posttreatment sediment budgets, pre- and posttreatment channel morphology

[3]Sidecast refers to the material that was excavated when road is constructed and deposited on downhill side of road. On steep slope it often destabilized the road and slope leading to landslides.

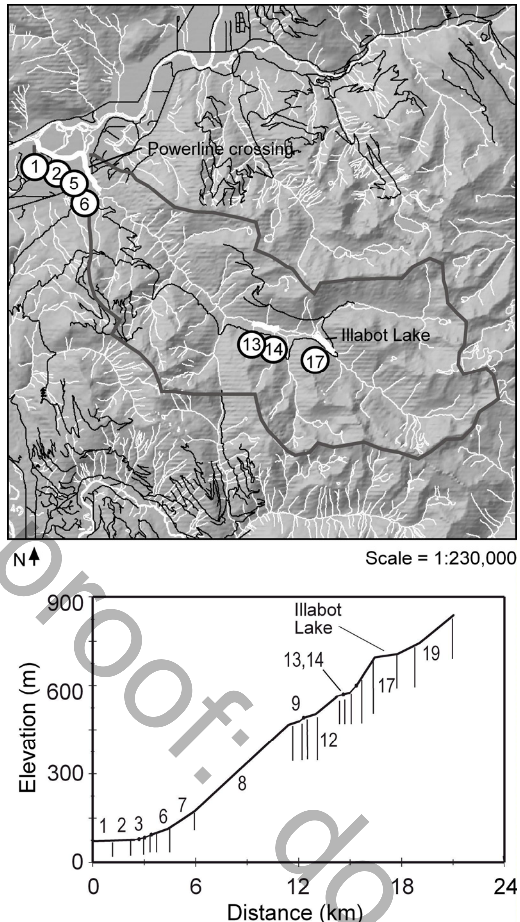

Figure 3. Map and longitudinal profile of Illabot Creek (Case Study 3). Map indicates location of key response reaches (circled numbers), and watershed boundary (heavy gray line) (adapted from Beechie et al. 2005).

measures, and posttreatment habitat and Chinook salmon spawner surveys. The sediment budget and channel morphology were determined from historic aerial photographs taken prior to road treatments (1956–1991). Field surveys of habitats and fish use were conducted after the road treatments (started in 1997). The sediment budget was conducted by measuring surface areas of landslides on aerial photography, field measuring depths of a sample of recent landslides, and estimating volumes of sediment produced from landslides based on photo-measured areas and field-measured average depth. Landslides were also classified by cause (natural, clear-cut, or road-related), and total sediment delivery was thereby separated into amounts delivered from roads, clearcuts, and forests. Thus the sediment budget identified whether the perceived increase in sediment supply had in fact occurred, and also helped to predict whether road rehabilitation actions would reduce total sediment delivered to the creek. The channel and habitat inventories documented channel widening or narrowing (from sequential aerial photographs) and habitat inventories focused on measuring residual pool depths to detect shallowing or deepening of pools (from field measurements). Finally, using posttreatment spawner data we attempted to evaluate whether the number of spawners would increase or decrease in response to changes in channel and habitat conditions based on the relationship of Chinook salmon spawning to prevalence of pools (Montgomery et al. 1999).

Results and Recommendations.—Analysis of the aerial photographs indicated that the sediment supply had increased about 50% over the natural background rate (before logging and road construction), but that the total sediment supply to Illabot Creek remained low compared to most forested watersheds in the North Cascade Mountains in Washington State (Figure 4; Paulson 1997). In three of the five photo periods, there were no landslides from roads, and in the remaining two periods, the percent of landslides that originated from roads ranged from 10% to 40%. Moreover, in the years with highest sediment supply from landslides, no landslides originated from roads or clearcuts.

The middle and upper basin response reaches (reaches 13–14) showed no evidence of increased sediment supply. That is, the historical aerial photograph analysis showed no episodes of channel widening that would indicate increased sediment supply, and residual pool depths were not unusually shallow. By contrast, the lower elevation response reaches near the mouth of the river (reaches 1–6) experienced considerable channel widening coincident with the high sediment supply prior to 1956 (Figure 5), but there were no road-related or timber harvest-related landslides during that time period. The lower reaches have generally narrowed since 1956, indicating that sediment supply has been low despite the occurrence of some road- and harvest-related landslides. Residual pool depths do not appear to have decreased as result of increased sediment supply. Rather, residual pool depth was most strongly related to size of wood that forms the pool (Beamer et al. 1998). However, the pools on the alluvial fan reaches (reaches 3 and 4) are generally shallower than pools in reaches upstream or downstream of the alluvial fan. The lack of preproject spawner data prevented us from directly determining the effect of the reduced sediment supply on Chinook salmon. How-

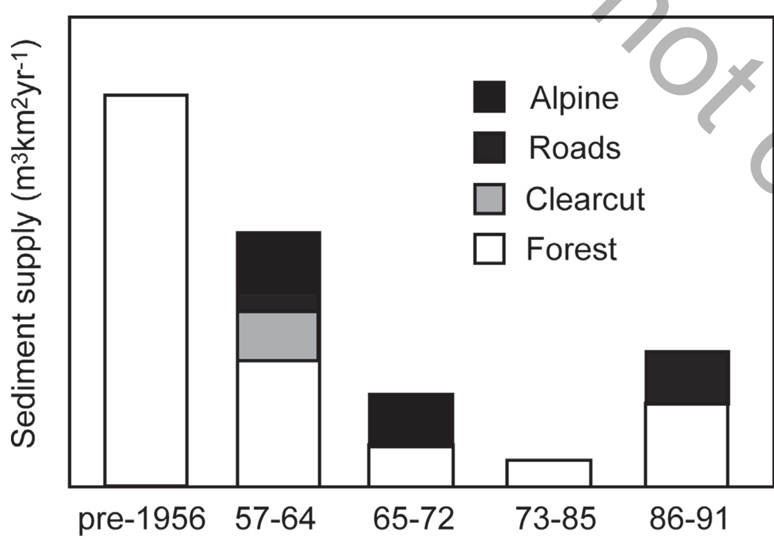

Figure 4. Variation in sediment supply and sources through time in Illabot Creek watershed (adapted from Beamer et al. 1998).

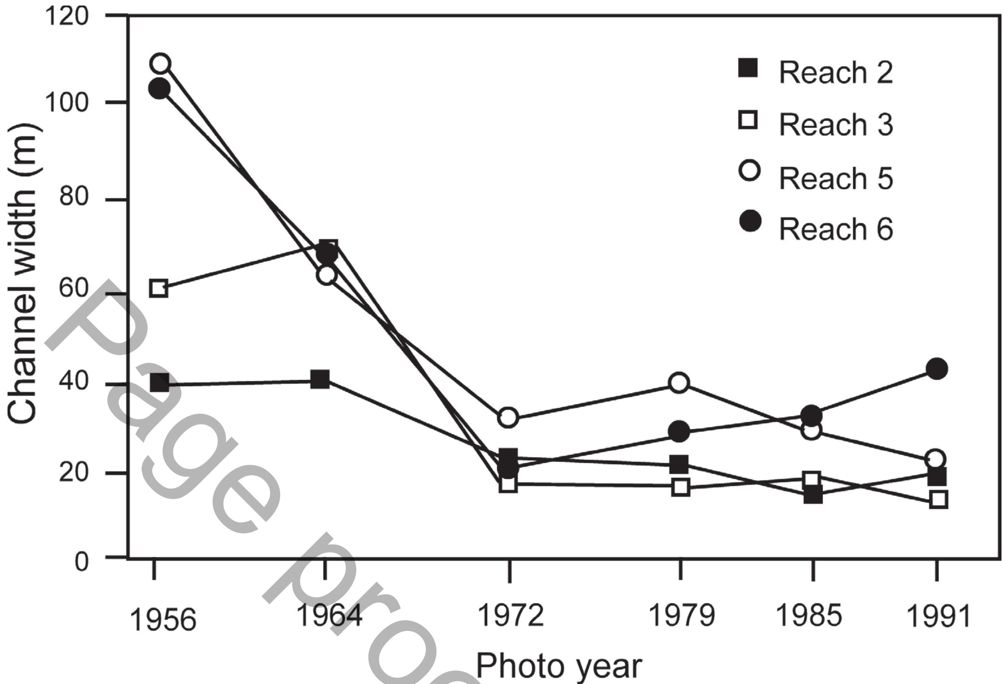

Figure 5. Time sequence of channel width adjustment in four key response reaches in lower Illabot Creek.

ever, limited posttreatment monitoring of Chinook salmon spawning in 1997 and 1998 indicated that Chinook salmon were concentrated in reaches with the highest abundance of wood and pools.

The general conclusion drawn from these monitoring results is that the number and depths of pools were not impacted by increased sediment supply from roads at the time of the initial monitoring in 1997 and 1998. The highest sediment supply occurred in the period prior to 1956, and there was no apparent influence of roads on sediment supply at that time. Channel widths in the lower response reaches were also widest in 1956, and there were no subsequent increases in channel width when a small proportion of the sediment supply was from roads but overall sediment supply was very low compared to other forested mountain basins in the region (Paulson 1997). Finally, residual pool depths and salmon abundance in response reaches was strongly related to wood abundance and size, rather than sediment supply (Beamer et al. 1998). Given that Chinook and other salmon are known to prefer reaches with high pool abundances (Montgomery et al. 1999), and lack of change in number of pools in Illabot Creek, Chinook salmon spawner abundance was not likely affected by sediment supply in Illabot Creek during the study period.

Initially this study appeared to address each of the key steps for designing a monitoring program. However, the major shortcomings of this monitoring program were the failure to continue monitoring long enough to fully detect habitat responses to road treatments, the lack of juvenile salmonid population assessment, and the absence of preproject monitoring of Chinook salmon abundance. Funding for the project ended in 1998 without completion of posttreatment aerial photograph analysis or sediment supply and channel morphology. Therefore, sediment from landslides occurring prior to restoration had not yet been completely transported into these response reaches. Thus, the study design is incomplete with process monitoring concentrated in years prior to road treatments, and habitat monitoring only conducted in years prior to complete response to road treatments. Moreover, the lack of any juvenile fish monitoring and Chinook spawner surveys before restoration activities prevented this study from determining the effects of sediment reduction on juvenile and adult salmonids. The strength of this monitoring program was the integrated assessment of land use, sediment supply, and channel response. By assessing all these components, it was possible to correct the misperception that sediment supply had increased due to road-related landslides, and to clarify that poor channel and habitat conditions at the time of restoration were not a result of prior land use.

Discussion

The three case studies described above addressed the key steps for designing monitoring restoration as outlined in Roni (2005), yet their success still appears to hinge on adequately addressing either technical or and nonscientific issues. The technical issues included design, sample site selection, and selecting and monitoring appropriate parameters. The nonscientific challenges, referred to as procedural challenges (Reid 2001), included coordination of restoration and monitoring activities. Below we discuss each of these major challenges and provide recommendations for addressing these in basin-scale monitoring programs.

Monitoring Design and Sample Site Selection

Previous reviews have clearly outlined a suite of monitoring designs that can be used for evaluating changes in habitat or restoration (Downes et al. 2002: Roni et al. 2005). As demonstrated in our case studies and in other published evaluations of restoration we reviewed (see Roni et al. 2008), evaluation of basin level changes in habitat typically requires a before-after or before-after control-impact design. Evaluation of reach-scale response to restoration activities can be done with retrospective design (posttreatment) or a before-after or BACI design. Linking the two scales of evaluation into one monitoring program is difficult and presents additional study design and sampling challenges. All three case studies were designed to examine basin scale responses, and only case study 2 (Entiat River) attempted to link basin and reach-scale responses. The ongoing work in the Entiat indicates that monitoring at basin scale and reach-scale will require separate site selection methods and, while data may be compatible, they will initially be examined separately. This is in part because random or GRTS probability-based sampling will likely lead to fewer sites that can serve as treatment or controls for project level evaluations. However, if one can anticipate where restoration will occur as in the Entiat Case Study, one can add additional nonrandomly selected sites to basin-scale monitoring and attempt to integrate monitoring at reach and basin scales. In addition, one may be interested in responses that occur at an intermediate scale of subbasin or multiple river reaches. To address this gap, sites upstream and downstream from restoration sites or within restored subbasins could be added to examine the scale the response is occurring. This might be useful when it is known well in advance that restoration will be concentrated in a particular tributary or subbasin.

An important part of design is determining the appropriate spatial or temporal replication (sample size). This was only a minor problem for the studies we examined, as all three case studies involved relatively long-term monitoring. In fact, case studies 1 and 2 are expected to detect changes only after 10–20 years of monitoring and case study 3 used existing preproject ongoing monitoring to look at multiple decades of data. Inadequate spatial and temporal replication, however, are known to be a major reason for failure of other monitoring programs (Reid 2001; Roni et al. 2008). The level of spatial and temporal replication needed obviously depends upon the level of inference desired and the variability of the parameter of interest. The study and sampling design influence variability of a parameter by influencing the amount of measurement error.

A handful of studies have attempted to estimate the length of monitoring needed to detect statistically significant changes in fish or habitat parameters using before and after, BACI, posttreatment, or some combination of these designs (Ham and Pearsons 2000; Roni et al. 2005; Liermann and Roni 2008). Most of these suggest that for salmonid fishes, more than 10 years of data are needed to detect changes in fish abundance of 25% or greater for BACI studies in paired watersheds, more than 30 paired sites for a posttreatment design, or more than 20 sites or basins. However, as little as 4 years of monitoring (2 before and 2 years after) could be needed for a study using a BACI design with extensive spatial replication (20 sites). For restoration actions that lead to relatively rapid (1–2 years) changes in fish or habitat, it is generally better to monitor additional sites or basins rather than more years (Liermann and Roni 2008). However, all of these are either stylized examples or specific to their particular case study and use simple sample size and power estimates that can be done with most statistical packages. Thus estimating adequate replication in space or time is best done by doing a power and sample size analysis using basin specific estimates in parameter variability, the level of inference desired, and the appropriate scale. Estimating sample size to detect statistical significant differences is important, but can suggest the need for costly and lengthy monitoring programs. This may not always the feasible or appropriate depending upon the management needs. In some cases, rather than relying on inferential statistics, simple graphical analysis may be more informative particularly for conveying results to managers (Conquest 2000).

The three case studies presented outline both the pitfalls and benefits of basin scale evaluation of restoration projects. Given the expense and difficulty in these undertaking, it is clear that not every watershed or restoration action should be monitored or that a BACI design is the only suitable approach. In fact, depending upon costs, number of restoration actions and management needs, long-term monitoring may not be the most appropriate approach for most actions (MacGregor et al. 2002; Failing et al. 2004). Further, while better monitoring and evaluation (M&E) of restoration actions is needed, not mean to imply that all restoration actions require intensive monitoring and evaluation. Rather sample size and power estimates can help determine a suitable subset of projects and watersheds that should be part of an intensive monitoring program.

Selecting Parameters

Selecting what parameters to monitor is one of the bigger challenges and is intricately linked to determining appropriate spatial and temporal replication and sampling or survey design. Parameters should be directly linked to monitoring questions and, ideally, change in a direct and measurable way to treatment, be efficient to measure, have limited variability (or variability that can be accounted for by other measurements), and not be confounded by other factors (Conquest and Ralph 1998). Many commonly monitored parameters do not meet these criteria. Moreover, many publications suggest monitoring a time-consuming and costly array of parameters (see Johnson et al. 2001 for a review). The EMAP methodology, while highly rigorous and repeatable, includes detailed measurement of dozens of parameters and may take a field crew a day to sample a few hundred meter reach (Kaufmann et al. 1999)—making sampling of dozens of reaches in a field season costly and time consuming. Measurements and parameters suitable at some scales may not provide useful information at others and recommendations for specific restoration techniques may include dozens of potentially interesting but not necessarily highly useful parameters (Roni 2005). This was highlighted in Case study 1, which started with an initial lengthy list of parameters and reduced them to a more manageable and cost effective approach. Case study 2 selected parameters based on hypotheses and a hypothesized model of watershed function was used to help identify covariates (measurements) that might influence the primary measurements and affect the ability to detect response to restoration. Case study 3 selected only those parameters that were directly linked to changes in sediment supply and habitat conditions.

The challenge in parameter selection is to identify a small but comprehensive set of metrics to monitor basin scale restoration, and to devise metrics that are diagnostic in nature and capable of detecting which aspects of the river ecosystem have been improved by different restoration actions. This suite of metrics should represent physical, chemical, and biological endpoints of restoration, but should also capture landscape and watershed processes that form and sustain riverine ecosystems (Beechie et al. 2009). Moreover, such metrics should consider monitoring parameters relevant to societal goals in order to increase the relevance of river restoration to the general public. Using the results of the case studies and complete lists of parameters to monitor restoration at different scales (Roni 2005), we proposed a short list of parameter to consider when designing a basin-scale restoration monitoring program (Table 2). They include parameters for key watershed processes such as hydrology, sediment delivery, riparian (wood and organic matter) and chemical and biological parameters. We also outline at which scales these would be most appropriate to both monitor and analyze. Often parameters measured at one scale are best analyzed at another. For example, discharge is typically measured at a point in a specific reach, but it is typically analyzed for the basin above that point. Not all the parameters in Table 1 should be monitored in every basin-scale evaluation of restoration as the parameters selected should be linked to the monitoring questions or hypotheses. Rather, our proposed list represents the core set of parameters to initially consider.

Coordination

The steps outlined by Roni et al. (2005) for developing a monitoring program largely focus on technical aspects of monitoring development, but overlook the fact that monitoring restoration actions across a basin requires extensive coordination of management actions—a procedural rather than technical problem. Procedural problems often limit the success of monitoring programs. For example, a review of 30 monitoring programs and found that 50% had procedural problems such as lack of coordination (Reid 2001). The importance of coordination was particularly evident in Case Study 1 where five organizations are involved in implementing both monitoring and restoration. The coordination of efforts and sharing of data have proven challenging because of the number of parties involved and the sheer amount of data being collected. Moreover, there have been some delays in summarizing and analyzing data from annual monitoring. This is problematic because, if data are not summarized or ana-

Table 2. Suggested list of key parameters to monitor basin-scale response to restoration activities and the appropriate level of monitoring and inference. Additional parameters can be monitored but this represents a minimum or starting point. Note that while detection of basin-scale changes typically requires randomly or systematic sampling, selecting sites to evaluate reach level restoration typically requires nonrandom selection of specific treatments and controls.

Category	Parameter	Basin scale	Reach	Sample site extent (point, reach, subbasin)	Sampling frequency	Level of inference
Hydrology	Discharge	Target reaches affected by restoration actions	Target reaches affected by restoration actions	Point	Continuous gauging	Basin, sub-basin
Coarse Sediment	Sediment supply (sediment budget)	Entire basin	NA	Entire basin	5–10 year intervals	Basin
Fine sediment	Sediment supply (sediment budget)	Entire basin	NA	Entire basin	5–10 year intervals	Basin
Fine sediment	Plot-scale sediment yield	Stratified random or stratified systematic samples	Selected reaches	Road segment or field plot	Continuous	Basin, sites
Riparian conditions	Species composition, stem density, and size distributions	Stratified random sampling	Selected reaches	Reach	Decadal for basin-scale trends, annual for newly planted sites	Basin, reach

Table 2. Continued.

Category	Parameter	Basin scale	Reach	Sample site extent (point, reach, subbasin)	Sampling frequency	Level of inference
Channel morphology	Pool frequency	Randomly selected stream reaches	Selected reaches	Reach	Annually	Reach or basin
Channel morphology	Wood abundance and volume	Randomly selected stream reaches	Selected reaches	Reach	Annually	Reach or basin
Channel morphology	Residual pool depth	Target response reaches downstream of restoration actions, choose sites nearest to action to reduce lag time in channel response	Selected reaches	All reaches downstream of restoration	Annual or semi-annual	Basin, sub-basin
Water quality	Temperature	Randomly selected sites	Selected reaches	Reaches	Hourly (Data loggers)	Reach
Fish	Juvenile and adult fish abundance and diversity	Stratified or systematic random selection	Selected reaches	Reach	Annual or seasonal	Reach and basin

Table 2. Continued.

Category	Parameter	Basin scale	Reach	Sample site extent (point, reach, subbasin)	Sampling frequency	Level of inference
Macro-invertebrates	Abundance and diversity	Randomly selected sites	Selected reaches	Reach (multiple samples per reach combined into one sample per reach)	Annually (typically early summer or early fall depending upon climatic region	Reach
Primary productivity	periphyton	Randomly selected sites	Selected reaches	Reaches (multiple samples per reach combined into one sample per reach)	Annually (summer)	Reach

lyzed in a timely fashion, a project can go on for many years before critical errors in either design or data collection is detected (Reid 2001). With extensive coordination among restoration, monitoring, and land owners, the Entiat Case Study appears to be overcoming many of these challenges. As obvious as it may seem, the periodic coordination of restoration actions and regular meetings to discuss sequencing of actions within a basin are needed. The larger the basin and the more complex the actions the more critical this becomes and the more time that must be dedicated to it.

The length of these monitoring programs presents further challenges in coordination as it is unlikely that the same people will collect the data year in and year out. Moreover, some of the principle investigators will likely retire or move to other positions before data collection is completed. The length of these programs necessitates improved documentation and coordination and makes periodic analysis, summary and publication of results even more critical.

Conclusions

Our examination of these case studies from three different basins demonstrates the major challenges in basin scale evaluation of restoration. First, different monitoring and sampling designs are needed to detect basin and reach or project level effectiveness. We recommend the most effective way to detect basin and project level effectiveness is to use a combination of GTRS or some other random method to select sites or reaches to monitor conditions across the basin with nonrandomly selected treatment and control reaches to examine reach-level restoration. A power analysis should be done to determine how many sites are needed and how many years before and after projects should be monitored. Second, because of the large number of sites needed and the large number of potential responses to monitor in a basin, a core set of parameters needs to be measured. We recommend a core set of parameters to choose from that should be directly linked to the restoration goal and monitoring hypotheses are selected. For example, parameters typically measured at a reach scale, such as fish abundance or pool frequency, may be examined at both a reach and basin scale while others, such as sediment supply, are more appropriately examined at basin level. Third, procedural aspects limit the success of most large monitoring efforts, and extensive coordination and planning is needed to implement a successful basin-scale monitoring programs. This includes control over restoration and other management actions to assure that unforeseen and unplanned activities do not override the response due to restoration and render a well designed and expensive monitoring program useless. In order to achieve this, it is critical that those involved in designing the restoration take an active role in designing and implementing monitoring and training monitoring staff and that data are summarized and analyzed at least annually to detect any problems with data compatibility (Reid 2001). For those project that involved numerous agencies, periodic meeting not only of principle investigators, but also field staff are needed to minimize duplicative efforts and compatibility of techniques.

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