Research, Monitoring, and Evaluation of Fish and Wildlife Restoration Projects in the Columbia River Basin:

Lessons Learned and Suggestions for Large-Scale Monitoring Programs

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ABSTRACT: The year 2006 marked two milestones in the Columbia River Basin and the Pacific Northwest region's efforts to rebuild its once great salmon and steelhead runs—the 25th anniversary of the creation of the Northwest Power and Conservation Council and the 10th anniversary of an amendment to the Northwest Power Act that formalized scientific peer review of the council's Fish and Wildlife Program and its varied individual projects. The authors of this article served as peer reviewers in the last decade. Restoration efforts in the Columbia River constitute a massive long-term attempt at fisheries and ecosystem restoration. In this article we examine some of the lessons we learned in reviewing the research, monitoring, and evaluation efforts of projects and their effects on advancing knowledge (i.e., adaptive management) in the Columbia River Basin Fish and Wildlife Program, one of the most ambitious and expensive long-term ecological restoration programs in the United States.

Investigación, Monitoreo y Evaluación de Proyectos de Pesca y Vida Silvestre en la Cuenca del Río Columbia:

lecciones aprendidas y sugerencias para programas

RESUMEN. El año 2006 representa en dos sentidos una fecha crítica para la cuenca del Río Columbia y para los esfuerzos de recuperación del salmón y la trucha arcoíris en la región Pacífico Noroeste: el 25 aniversario de la creación del Consejo para la Conservación y Poder del Noroeste y el 10° aniversario de la enmienda al Acto de Poder del Noroeste, que formaliza el arbitraje científico del Programa de Pesca y Vida Silvestre de dicho consejo, así como de sus proyectos individuales. Durante la última década, los autores del presente trabajo fungieron como árbitros de estos proyectos. Los esfuerzos de recuperación en el Río Columbia constituyen una iniciativa muy importante en cuanto a la rehabilitación de pesquerías y ecosistemas. En este artículo se examinan algunas lecciones aprendidas durante el proceso de revisión de investigación, monitoreo y evaluación de proyectos y su repercusión sobre el avance del conocimiento (manejo adaptativo) en el Programa de Pesca y Vida Silvestre de la Cuenca del Río Columbia, uno de los programas de recuperación más ambiciosos y de más largo plazo en los Estados Unidos de Norteamérica.

INTRODUCTION

Concern about depressed salmon and steelhead populations and plans for construction of additional dams and hydroelectric power plants in the Columbia River Basin in the late 1970s led to passage of the 1980 Pacific Northwest Electric Power Planning and Conservation Act by Congress (Northwest Power Act) and formation of the Northwest Power Planning Council in 1981 (renamed Northwest Power and Conservation Council in 2004). The act charges the council with developing a Fish and Wildlife Program that balances providing the Pacific Northwest region with a reliable and efficient hydroelectric energy-producing system and protecting, mitigating, and enhancing fish and wildlife (Lee 1993). The act requires the federal Bonneville Power Administration (BPA) to fund fish and wildlife projects consistent with the council's fish and wildlife program.

Since 1981, hundreds of restoration projects have been funded to implement the council's Fish and Wildlife Program. Since the early 1990s, restoration has been affected increasingly by the recovery needs of Endangered Species Act-listed salmon and steelhead stocks (Williams 2006), although hatchery programs, which serve other and sometimes competing goals, still constitute a substantial fraction of the budget. BPA, which funds the council's projects through revenue from the region's electricity consumers, has spent about $3.7 billion on fish and wildlife restoration from 1981 to 2006 (NPCC 2006), with an average annual budget of $130 million over the last 5 years. BPA suggests that the recovery program costs should also include an additional $4.1 billion for power purchases and foregone revenues that it attributes to river operations required to assist fish passage and improve fish survival (e.g., spilling water at dams instead of passing water through turbines).

Despite these expenditures, the abundance of wild salmon and steelhead populations has not recovered to target levels. Annual returns of anadromous salmon and steelhead to the Columbia River Basin ranged from about 7 to 15 million fish in the mid-nineteenth century (NPPC 1986; Chapman 1986). In 1980, when the Northwest Power Act was passed, total runs averaged fewer than 1 million adults at Bonneville Dam, the first census point in the lower river. Total Columbia River runs, catch plus escapement, were estimated at 2.5 million adult fish (average 1976–1981). The council's original goal was to double the run size to 5 million adult fish through mitigation actions associated with its Fish and Wildlife Program. In 2005 and 2006, 25 years into that effort, runs averaged about 1.1 million adults to Bonneville Dam with most returning fish (~75%) being of hatchery origin. Returns of naturally spawning fish are currently about 1–2% of historical numbers (Williams 2006).

PEER REVIEW COMMITTEES AND ADAPTIVE MANAGEMENT

A 1996 amendment to the Northwest Power Act created a formal peer review process for projects seeking funding under the council's Fish and Wildlife Program. The amendment directs the council to appoint an Independent Scientific Review Panel (ISRP), and directs the ISRP to review proposed projects, using the following five criteria. Projects are to: (1) be based on sound science, (2) benefit fish and wildlife, (3) have a clearly defined objective and outcome (4) include provisions for monitoring and evaluation of results, and (5) be consistent with the council's Fish and Wildlife Program. Based in part on the ISRP's technical reviews, the council recommends a suite of projects to BPA for funding. The fourth criterion requiring monitoring and evaluation has been particularly difficult to satisfy by some agencies and scientists, because of a lack of understanding of where and how individual projects fit into the assessment of effects of multiple management actions in large areas. Also, provisions for monitoring and evaluation have been difficult to maintain through the funding process, because there is constant pressure to implement additional projects.

A companion committee for peer review and adaptive management is the Independent Scientific Advisory Board (ISAB), an advisory board appointed by NOAA Fisheries, the Northwest Power and Conservation Council, and the Columbia River Indian Tribes. Unlike the ISRP, which reviews individual projects, the ISAB provides scientific peer review of major and often controversial programmatic issues in fish and wildlife restoration in the Columbia River Basin. The ISAB is charged with making recommendations for research, monitoring, and adaptive management. The authors of this article have served on one or both committees.

Over the 10-year history of the basinwide peer review process, committee recommendations have resulted in a sustained dialog between reviewers, scientists, and fish and wildlife managers about what constitutes appropriate research, monitoring, and evaluation at both project and programmatic levels, leading to improved projects and monitoring program designs. We think that the issues, our experiences, and our recommendations have broad enough application to merit sharing with a larger audience. The design and analysis of monitoring and evaluation projects are problems among fish and wildlife entities for a variety of reasons (e.g., lack of knowledge of statistical theory, practical limitations of real world ecological monitoring, and constant pressure to implement additional management actions), in spite of the fact that information gained is essential for policy makers intending to develop an optimum mix of management actions to achieve their goals (adaptive management; Magnuson et al. 1996).

RESEARCH, MONITORING AND EVALUATION FOR ADAPTIVE MANAGEMENT

Research, monitoring, and evaluation are central to adaptive management and are the means by which the science-policy interface is informed (Magnuson et al. 1996). Monitoring of individual restoration projects allows investigators to know if expected outcomes are being realized, and this information can be used to justify further funding. If desired outcomes are not being realized, mid-course corrections can be made to increase the likelihood of achieving desired results. We recognize the complexities inherent in research and monitoring, especially given limitations on project scope, finances, and personnel. Moreover, it is not easy to condense advice into a simple set of recommendations that apply to all conceivable research and monitoring situations in large ecosystems. Different issues (e.g., understanding the effectiveness of habitat improvement or measuring increases in the survival rates of hatchery fish) require different monitoring approaches. Taking this into account, we describe common research and monitoring needs for projects related to environmental restoration in the Columbia River Basin and summarize our findings in the form of lessons learned about data collection, data analysis, and the evaluation of project effectiveness. We believe that many of these issues are shared by other large ecosystem and natural resource restoration programs and that the lessons learned in the Columbia River Basin will have broad application to fisheries and wildlife management elsewhere.

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Adult weir for spring-summer Chinook on Johnson Creek, Idaho.

1. Research, monitoring, and evaluation terminology is used inconsistently.

We observed inconsistent use of research, monitoring, and evaluation (RM&E) terminology by practitioners of various scientific disciplines (e.g., fisheries, wildlife, hydrology, genetics, and statistics), which has led to confusion in design and analysis of studies. We have attempted to maintain consistency with MacDonald et al. (1991) where they use the phrases "implementation monitoring" to evaluate if individual management actions are installed correctly; "effectiveness monitoring" to determine if the individual installations perform as expected; "project monitoring" to assess if the entire suite of individual management actions installed in a particular project perform as planned; and "validation monitoring" to determine if the anticipated watershed response actually occurs.

The primary inconsistencies in terminology exist with the methodology used for the assessment effort. For example, the words "observational," "mensurative," "quasi-experimental," or simply "monitoring" have been used to identify scientific studies with no management actions or studies where management actions are not allocated to study units by some randomization procedure. In contrast, the words "manipulative," "true," and "randomized-treatment experiment" have been used to identify scientific studies where treatments are allocated by some randomized procedure. We determined that to avoid confusion it would be well to classify research and monitoring studies into (1) observational studies which may include evaluation of effects of "management actions" and (2) randomized-treatment experiments where "treatments" are applied to study units according to some randomized procedure. The roles of these two core types of inference-supporting studies in assessment of large-scale environmental and ecological programs are not always well understood.

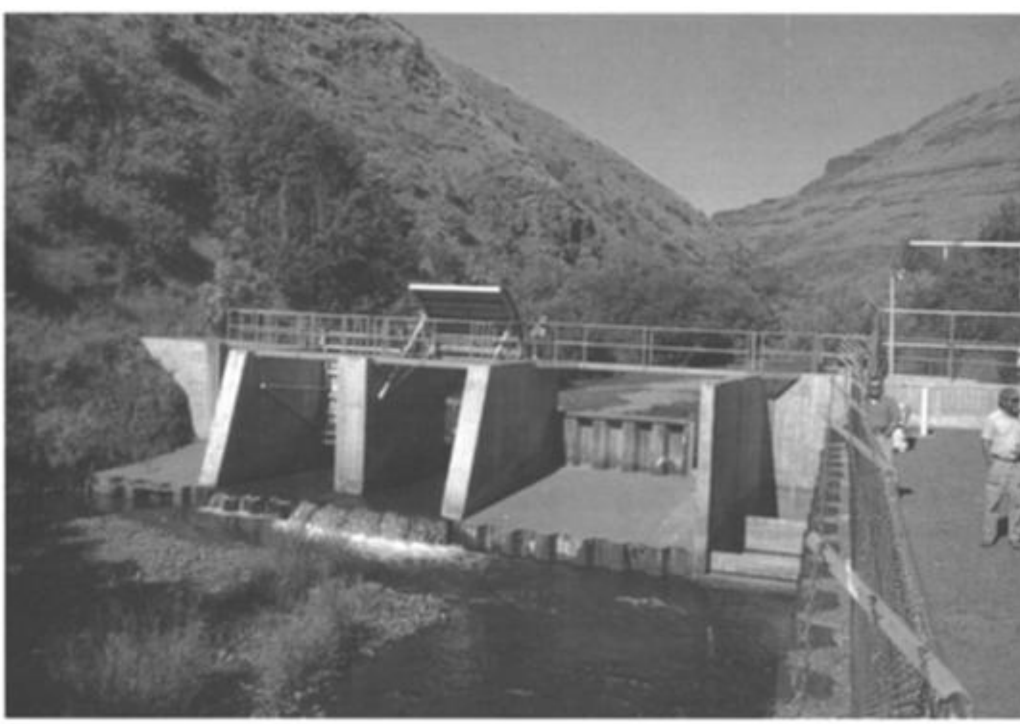
Observational Studies

Observational studies are those in which the research person lacks the full control over the scheduling of experimental stimuli, i.e., imposition of management actions. We found inconsistent use of the term "treatment" in the contexts of randomized-treatment experiments and observational studies. The term "management action" is in widespread use by management agencies, and we propose that it be used in place of the word "treatment" in observational studies of large ecosystems. For example, a stream might be selected to receive a certain aquatic habitat improvement action, and production of naturally spawned fish might be compared before and after the action is implemented. It is useful to refer to "management action" to distinguish the assessment effort from one in which habitat improvement "treatments" and "controls" are randomly assigned to candidate streams.

Professional statisticians often distinguish between observational studies with and without active application of management actions, calling the former "quasi-experiments." Studies of areas without active application of management actions are "pure" observational studies. We do not make that distension, because basic design of sampling efforts and statistical estimation methods do not vary significantly between the two

Randomized-Treatment Experiments

Randomized-treatment experiments require that treatments be randomly assigned to experimental units (Fisher 1935). One or more of the treatments may be designated as a control (or reference). These experiments generate



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Steelhead trap on the Imnaha River, Oregon.

conclusions of causal relations between treatments and effects that are "design based" (i.e., based on explicit design of the experiment to isolate a cause-effect relationship between a treatment and a response) and are easiest to justify; however, the *mechanisms* producing a conclusively demonstrated effect may remain conjectural.

2. *Implementation monitoring is often the only monitoring pursued, but this constrains adaptive learning.*

Implementation monitoring involves assessing whether or not the physical objectives of a restoration project (e.g., adding large wood to a stream, fencing a riparian zone to exclude livestock, or removing a barrier to fish migration) were achieved (MacDonald et al. 1991). Often there is no mention of tracking the ecological effects of such proposed management actions to determine if the installation performed as expected (effectiveness monitoring as defined by MacDonald et al. 1991). Implementation monitoring tracks progress of projects, such as in terms of miles of stream fenced off, but adaptive management requires that project results also be measured in terms of benefits to fish and wildlife and their habitat. All projects should be subject to effectiveness monitoring to verify their physical and ecological benefits (e.g., changes in vegetation, flow, or temperature) or should be included in an overarching integrated monitoring program to evaluate overall benefits of multiple management actions (project monitoring as defined by MacDonald et al 1991).

3. *Complete census by remote means is often effective in assessing status and trends over large areas.*

Complete census (data collected on all units—e.g., individual organisms, habitats, or sites—within areas with no randomization at any level), often provides effective long-term project monitoring of large areas. Where these types of data are available, a census can be a very effective tool for assessing status and trends. In some cases, aerial photography or other remote sensing technology can be used to create census data layers in geographic information systems (GIS) for tracking long term changes in riparian and other terrestrial habitat in sub-basins or watersheds.

A census is often appropriate to document direct possible effects of management actions. For example, a census in a project to supplement a weak stock of naturally spawning fish with hatchery fish might include complete counts of hatchery and naturally produced adults passing a weir to the spawning grounds on small tributary streams. Another example might involve counting the number of pools in a stream before and after habitat restoration. Censuses need not be expensive or time consuming.

4. *Probabilistic sampling is often effective in tracking status and trends for parameters for which census data are not available.*

Data collected on a probabilistic sample of units within areas often provides effective assessment in studies requiring on-the-ground field data collection in relatively small study areas, and inferences can be applied to the total area or population sampled, not just the units on which data were collected. Sampling methods are often labor intensive, and it may not be economically feasible to collect data on all units in a study area. A good illustration of the use of probabilistic sampling in monitoring of salmon status and trend is the Oregon Plan for Salmon and Watersheds Monitoring Program, as implemented in Oregon for coho salmon (*Oncorhynchus kisutch*) in coastal streams (Rodgers 2000). The Oregon Plan applied a rigorous sampling design for probabilistic site selection to answer key monitoring questions for estimating coho salmon distribution and abundance.

When probabilistic sampling is applied to observational studies (i.e., treatments are not randomly assigned to sites), non-subjective conclusions are restricted to changes, differences, and trends for the sampled study areas and time periods. Statistical inferences concerning cause and effect relationships that go beyond the observed "real" differences among study areas and time periods are often made under assumptions that are difficult to justify. Putative causal relations are best stated as tentative working hypotheses warranting further study. There is a large and growing literature concerning the use of Bayesian and other model-based tools (e.g., geostatistical methods) for analysis of observational studies. Because of the extra assumptions or models required, such methods have their limitations, but can be useful when assumptions are judged to be reasonably well satisfied.

5. *Effectiveness monitoring of individual management actions can best support broad-scale project monitoring by using common methods.*

Effectiveness monitoring most easily provides data for monitoring of habitat at a larger scale if similar site selection and data collection methods are used. The more site selection and data collection methods differ among individual management actions, the more difficult it becomes to aggregate data to make inferences about larger regions We persistently have urged use of common methods, and progress has been made recently by the Pacific Northwest Aquatic Monitoring Partnership on developing a set of common methods that can be applied to a variety of monitoring needs.

6. *Intensive research programs are required to answer the question "What was the cause of the change detected in the monitoring program?"*

Properly designed census or probabilistic sampling programs can provide relatively low cost, repeatable data collection with enough accuracy and precision to detect change in the face of background noise. Thus project or validation monitoring programs (MacDonald et al. 1991) are successful if they detect real overall effects of management actions; however, conclusive scientific explanation for the effects may be elusive. Determination of the causes of the effects detected by project and validation monitoring requires the development of testable hypotheses and implementation of appropriate experiments in more intensive research.

7. Randomized-treatment experiments are difficult to conduct on large ecosystems.

Randomized-treatment field experiments on species with complicated life histories may be very difficult. Many species of interest in the Columbia Basin occupy large areas during their life history, requiring the experimental units to be very large. In addition, responses to a treatment may take a considerable time to become apparent. For example, several salmon generations might be required to register an effect from a management action. Over this extended period of time it may be difficult or impossible to ensure that environmental factors, such as streamflow, affect all study sites approximately to the same degree. In addition, unwanted anthropogenic impacts to all study sites must be minimized to avoid confounding results.

A revealing example of the difficulties in implementing large scale effectiveness monitoring in the Columbia River Basin with a randomized-treatment experiment was the Idaho Supplementation Study on Chinook salmon (O. *tshawytscha;* Lutch et al. 2003). During implementation of this study, randomized assignments of treatments to streams were abandoned (e.g., some control sites became treatment sites in the middle of the experiment), and the study converted to an observational one. A rigorous randomized-treatment study will be difficult to maintain when dealing with rare or threatened populations, because there is an ethical dilemma between letting a resource be injured or disappear and gaining information that would lead to better management.

8. Observational studies that corroborate each other provide evidence for the actual effects of management actions.

Monitoring multiple, independent, but similar observational studies, and analyzing them as if they were replicates subject to study-specific random effects, may provide convincing evidence for the effect of an action if results are consistent across the studies. In an inductive sense, monitoring numerous observational studies can suggest causal relations (e.g., Shipley 2000). Good sampling design is required, and conclusions about restoration effectiveness will require some scientific judgment because many uncontrolled factors can influence the results. Ideally, further analysis, and insightful designs for further measurements, may allow replacement of some of the random effects with covariates.

9. Simple evaluation methods and periodic re-evaluations are needed, because evaluation methodologies will improve.

It is important to distinguish evaluation based on data collected as part of long-term monitoring programs (usually data collected from large areas and over long time periods) and evaluation of data collected in more focused randomized-treatment or observational research projects. Many long-term monitoring studies do not yield useful results until a significant period of time has passed. Most research projects are relatively short term, often three to five years, are designed to test specific hypotheses, and require well-defined methods for analysis and evaluation. Evaluation is an equally important part of long-term ecological monitoring, and there is a need for clear procedures for analysis. Ongoing evaluation of the data from long-term monitoring efforts is also important, because it allows detection of unusual events or changes in time for them to be subject to additional scrutiny and to provide information for adaptive management. Long-term monitoring data, however, are expected to have value for many years (decades to centuries), and relatively simple design based analyses are recommended because evaluation methodologies are likely to evolve, and, in any case, the time duration of the study and contrasts in the data will continue to improve. Care should be taken to assure comparability over time as methodologies evolve.

10. Use of different site selection criteria, indicator variables, and data collection methods hampers evaluation of large-scale restoration programs.

Good monitoring design is difficult to attain when participating governments, agencies, and other stakeholders have different (and sometimes conflicting) vested interests. Often organizations have ongoing research and monitoring efforts that use different site selection criteria, indicator variables, and data collection methods, and each is reluctant to adapt its approaches. Government agencies may have been given clear legal mandates they have to meet and legal settlements from previous court-cases have set explicit standards for how and what kinds of data need to be collected. Although such data collections may in aggregate devote exceptional resources for monitoring, their disparate methods and metrics mean that the data they collect are often difficult or impossible to combine into meaningful evaluations at larger scales. Top-down coordination, changes in legal requirements, and adoption of common approaches will require time, however, changes are needed to ensure that data from individual monitoring efforts can be combined.

11. There are two general approaches for collection of empirical data for evaluation of large scale restoration activities: extensive and intensive.

The extensive approach involves sampling of a large number of study units with none, one, or more than one restoration action applied to each. A commonly used extensive study design calls for a large number of pairs of sites in which a certain restoration action (e.g., removal of roads) is applied to one member of a pair and is not applied to the other site. Changes in other management actions are expected to be applied uniformly to both members of a pair during the study. Most often, these are observational studies because the actions are typically not assigned randomly within each pair of sites. An alternative extensive approach is to sample sites with a gradient of conditions of the factors under study.

Definitive conclusions (e.g., that road removal reduces sedimentation in streams) are not justified by extensive study designs in the absence of randomized treatment assignment. If enough sites are sampled, however, and if the results corroborate one another, then there is evidence in an inductive sense that a cause-and-effect relationship is probably being measured.

The intensive approach focuses on a reduced number of sampling units (e.g., watersheds) with a high level of sampling intensity to identify the factors responsible for observed changes in system condition. The basic premise is that cause-effect relationships in complex systems are best understood by concentrating efforts at a few locations where ecosystem processes can be studied in enough detail to reveal mechanisms. Concentration of effort is necessary in an intensive study design to focus sufficient resources and research expertise to tease apart the complex interactions governing ecosystem response to restoration activities. With extensive studies, many sites or pairs of sites are needed. With intensive studies, there are repeated measurements of larger numbers of variables within a few, perhaps more controlled, study areas. Although both approaches constitute observational studies, smaller-scale randomized-treatment experiments can be embedded within either of the two designs.

There are advantages and disadvantages to each approach (Roni et al. 2003). Extensive designs allow reasonable inferences based on the layout of the study, but the number of activities or combinations of activities that can be compared is limited. Intensive designs limit investigations to a smaller number of sites with restricted geographical coverage and combinations of activities, but allow detailed study of more variables, processes, and their relationships. Disadvantages of both approaches can include costs, limited ability to extrapolate results to large regions, and logistical difficulties of dealing with relatively large and long-term monitoring projects. Problems related to unavoidable changes in applications of management actions, however, should be fewer with the intensive approach, because fewer sites are required.

CONCLUSIONS

We recognize the difficulties inherent in assessing the response of ecosystems to restoration actions, given limitations on mandate, finances, expertise, and personnel. Moreover, it is not easy to provide a simple set of recommendations that apply to all conceivable research and monitoring situations in large ecosystems. Based on our experiences in the Columbia River Basin, we offer these five steps for developing a research, monitoring, and evaluation plan for a large area:

1 Develop an extensive census of attributes for large-scale habitat trends based on remote sensing and other appropriate methods, with data layers in a GIS.
2 Develop common site selection procedures and common data collection protocols for on-the-ground population and habitat monitoring.
3 Obtain overall consensus on a design strategy that employs legitimate treatment-control pairs, employs a broad gradient of treatment levels, or that randomizes treatment assignment over enough sites to average out site differences. Implement the design, and stick with it until the important question(s) are resolved or until data show that the uncontrolled variation is so great that the design is not adequate to resolve the question.
4 As data are obtained on status and trends of populations and habitat, develop empirical models for predicting habitat or population level parameters (e.g., presence-absence of focal species and selection of "preferred" habitat). Potential predictor variables include not only physical habitat variables (e.g., vegetation, flow, and temperature), but also the likely biological effects of management actions that are currently in place or will be implemented in the future.
5 Employ best professional judgment, based on available data and with knowledge of the existence of significant data gaps, as to whether or not intensive watershed monitoring projects should be initiated.

These five steps will help accomplish successful large-scale research, long-term monitoring, and evaluation programs. Appropriate and relatively intensive research projects can be implemented when the causes of changes observed in long-term monitoring projects are not obvious and causal mechanisms require elucidation. The results should provide the basis for policy-level selection of an optimum mix of management actions, i.e. adaptive management.

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