Freshwater Habitat Restoration Actions in the Pacific Northwest: A Decade's Investment in Habitat Improvement

Stephen L. Katz,[1,2] Katie Barnas,[1] Ryan Hicks,[3] Jeff Cowen,[3] and Robin Jenkinson[4]

Abstract

Across the Pacific Northwest (PNW), both public and private agents are working to improve riverine habitat for a variety of reasons, including improving conditions for threatened and endangered salmon. These projects are moving forward with little or no knowledge of specific linkages between restoration actions and the responses of target species. Targeted effectiveness monitoring of these actions is required to redress this lack of mechanistic understanding, but such monitoring depends on detailed restoration information—that is, implementation monitoring. This article describes the process of assembling a database of restoration projects intended to improve stream and river habitat throughout the PNW. We designed the database specifically to address the needs of regional monitoring programs that evaluate the effectiveness of restoration actions. The database currently contains spatially referenced, project-level data on over 23,000 restoration actions initiated at over 35,000 locations in the last 15 years (98% of projects report start or end dates between 1991 and 2005) in the states of Washington, Oregon, Idaho, and Montana. Data sources included federal, state, local, nongovernmental organization, and tribal contributors. The process of database production identified difficulties in the design of regional project tracking systems. The technical design issues range from low-level information such as what defines a project or a location to high-level issues that include data validation and legalities of interagency data sharing. The completed database will inform efficient monitoring design, effectiveness assessments, and restoration project planning.

Key words: bioinformatics, data management systems, effectiveness monitoring, fisheries management, habitat conservation, implementation monitoring, river restoration database.

Introduction

Across the Pacific Northwest (PNW), federal, state, and local groups are making extensive investments of time and money as part of diverse efforts to restore riverine habitats. The listing of five species of Pacific salmon under the Endangered Species Act (ESA) motivates much of the restoration in the region (NRC 1996; Frissell & Ralph 1998; Bash & Ryan 2002; NOAA 2005; Roni 2005). Restoration projects are planned and executed with the hope that improving freshwater rearing, spawning, and migrating habitat will enhance survivorship of threatened salmonids and offset some of the anthropogenic sources of mortality (NRC 1992, 1996; Ruckelshaus et al. 2002). However, we generally lack evidence of specific linkages between the restoration actions and the responses of threatened populations (Reeves et al. 1991*a*, 1991*b*; Paulsen & Fisher 2005). In the absence of clear ecological results (Paulsen & Fisher 2005), we have relied on untestable, and therefore, unreliable anecdotes, opinion, and models (NWFSC–NOAA 2004; Sutherland et al. 2004).

The ESA is only one motivator of restoration activity. Other mandates exist such as the Clean Water Act, which instructs states to set standards for water quality and develop implementation plans to improve waters that fail to meet quality standards (EPA 1972; Cooter 2004). In addition to these statutory motivations, small groups plan many river restoration projects to improve locally important habitat. Cumulatively, these projects amount to a substantial effort and, presumably, expense. Restoration projects nationally cost a billion dollars or more each year (Bernhardt et al. 2005). The U.S. GAO (2002) recently estimated that the federal government spends nearly $400 million each year in the Columbia River Basin, with much of the money directed at stream and river restoration.

Given these investments, those working in the PNW increasingly recognize the need for project effectiveness monitoring (Bash & Ryan 2002). For example, the 2000 Federal Columbia River Power System Biological Opinion (FCRPS BiOp; NOAA 2000), which assessed impacts of

[1] Conservation Biology Division, Northwest Fisheries Science Center, NOAA Fisheries Service, Seattle, WA 98112, U.S.A.
[2] Address correspondence to S. L. Katz, email steve.katz@noaa.gov
[3] Scientific Data Management, Northwest Fisheries Science Center, NOAA Fisheries Service, Seattle, WA 98112, U.S.A.
[4] College of Natural Resources, University of Idaho, Moscow, ID 83844, U.S.A.

Table 1. Project types and subtypes.

Project Type	*Project Subtype*
Barrier Removal	Culvert Removal
	Culvert Installation
	Culvert Improvement/Upgrade
	Culvert Replacement
	Dam Removal
	Fish By-pass
	Fish Ladder
	Fish Ladder Improved
	Fish Ladder Installed
	Push-up Dam/Diversion Dam Removal
	Log Jam/Debris Removal
	Tidegate
	Weir
Diversion Screens	Fish Screen
	Fish Screen Replacement
Sediment Reduction	Erosion Control Structure
	Road Closing/Abandonment
	Road Drainage
	Road Relocation
	Rocked Ford
	Sediment Trap
Restore Stream Complexity	Channel Complexity
	Bank Stabilization
	Beaver Introduction/Management
	Channel Connectivity
	Channel Reconfiguration
	Dike Reconfiguration
	Dike Removal
	Off-Channel Habitat
	Off-Channel Habitat: Alcove
	Off-Channel Habitat: Side Channel
	Off-Channel Habitat: Pond
	Wetland Creation
	Wetland Improvement/Enhancement
	Wetland Restoration
	Instream Structure
	Boulders
	Deflectors
	Gravel Placement
	Large Woody Debris
	Log Weir
	Rock Weir
	Rootwads
	Structure/Log Jam
	Weir
Nutrient Enrichment	Carcass Placement
	Fertilizer
Restore Instream Flow	Instream Water Rights
	Reduce/Regulate Water Withdrawal
	Water Quantity
Restore Riparian Function	Fencing
	Forestry Practices
	Livestock Removal
	Livestock Rotation
	Livestock Stream Crossing
	Off-Channel Watering
	Plant Installation/Revegetation
	Plant Removal/Control
Water Quality Improvement	Refuse Removal
	Temperature Control
	Toxic Cleanup
Upland Management	Agriculture Management
	Erosion Structures
	Fencing
	Invasive Plant Control
	Livestock Management
	Planting
	Slope Stabilization
	Vegetation Management
	Water Development
Other	Bridge
	Ditch
	Fencing
	Flood Control
	Roads
	Pond
	Vegetation Management
	Water Control Structures
	Wetland Management
	Water Development

the Federal Columbia River Power System on threatened and endangered salmon, identified eight common restoration types lacking substantial proof of effectiveness: Instream Flow, Nutrient Enhancement, Barrier Removal, Diversion Screens, Sediment Reduction, Riparian Buffer Improvement, Instream Structure, and Water Quality Improvement (Table 1). Although the FCRPS BiOp identified these restoration types, there was no knowledge of the actual distribution of these projects that could inform the design of monitoring to evaluate their effectiveness.

Recognizing the need for implementation monitoring nationally, the National River Restoration Science Synthesis (NRRSS) began an effort to catalog freshwater habitat restoration projects across the United States (Bernhardt et al. 2005). Distinct from the NRRSS project, PNW effort described here was initiated prior to NRRSS and driven solely by regional needs but was extended to service the national vision of NRRSS and provide the data for their PNW node.

This paper reports on the creation of a PNW freshwater restoration database (PNW database) cataloging projects that directly or indirectly alter salmon habitat. High connectivity in lotic systems requires the inclusion of an area larger than that actually occupied by anadromous fishes across the PNW. Further to cover NRRSS's PNW node, we included the full extent of Washington, Oregon, Idaho, and Montana. In addition to documenting the distribution of restoration projects in the PNW, this paper will examine spatial and temporal patterns of restoration and identify potential improvements in regional restoration project tracking.

Roles for Implementation Monitoring

Managing restoration over a large area with diverse land use and habitat impacts, such as the PNW, could be aided by adopting a design scheme that rationally incorporated objectives, monitoring, and planning at the same scales as the desired results (Fig. 1). In such a scheme, historic and current restoration actions would be (1) cataloged and then (2) correlated with knowledge about outcomes of these efforts, derived from rigorous project effectiveness monitoring. These two components form a "library" of knowledge about restoration outcomes in diverse ecological conditions.

Combining this library with baseline monitoring of ecologically important systems can identify habitat limitations and will allow resource managers to design more effective implementation and monitoring plans. Documentation of restoration actions then adds to our knowledge of past actions, and monitoring of new projects advances our knowledge of project effectiveness as indicated by the two feedback arrows in Figure 1. Unfortunately, up until now the PNW has had no regionwide reporting system for restoration actions, leading to a fragmentary library of past project performance (i.e., "Knowledge of Past Projects" in Fig. 1). In those few cases where we have rigorous research on project performance, these studies are uncoordinated and designed on a local level with limited ability to inform restoration on a regional scale. This paper synthesizes the data available in the region and for the first time,

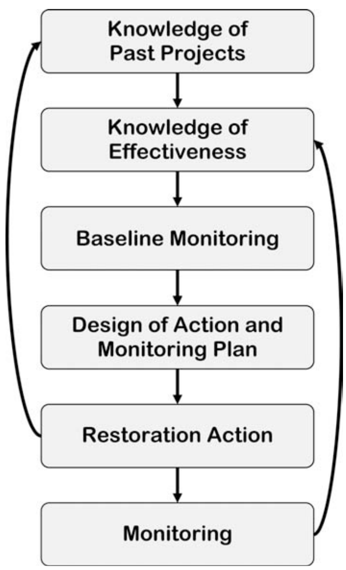

Figure 1. Conceptual model for role of information in a design for effectiveness monitoring of restoration actions. The conceptual model identifies a role for a database of restoration project-level data, identified as "Knowledge of Past Projects," within a rational design scheme. In this case, a knowledge of past projects, the effectiveness of some number of those projects generated with rigorous monitoring, and a knowledge of current conditions, identified as "Baseline Monitoring," one can develop a defensible "Action and Monitoring Plan" to address environmental pathologies. In order to provide performance accountability, restoration implemented to address baseline conditions would be documented and monitored and would feedback into the historical record of treatments and project effectiveness.

provides the knowledge of past actions upon which effectiveness monitoring can be designed.

Methods

Data Acquisition

We began by contacting federal and state agencies that fund restoration activities in the states of Washington, Oregon, Idaho, and Montana, in particular fish and wildlife management agencies and state salmon recovery agencies. Donors later expanded to include federal, state, tribal, local, and nongovernmental organization groups (Appendix I). We solicited data on all projects occurring in and around freshwater systems because many projects not specifically labeled as "salmon habitat restoration" do affect salmon habitat. Each potential data donor received a written request for project-level data and any information on other holders of similar data. Though some data contributors had Web-accessible data, we solicited data from all the contributors by written request in order to obtain the most recent data. Donors were told that the data collected would inform monitoring and were not a regulatory request. We requested the following minimum information set:

(1) *Who* is doing the work and how do we get in contact with them if we need to? (e.g., address, phone number, etc.)
(2) *What Exactly* was the project designed to do? For example, what kind of project is it, how big is it, and within a single project, how many installations are happening?
(3) *Where Exactly*, in some standard coordinate system was the work going to happen? (e.g., Lat./Long., LLID & Stream Mile)
(4) *When* was the work going to happen?

We solicited data contributions beginning in the fall of 2002 and the last data accepted for inclusion were received September 2004. We originally asked data contributors for data on all projects from 1992 to 2002. When data began to arrive, however, it became clear that contributors shared data without exercising discretion regarding the time period. Therefore, we accepted data for any time period.

Initially, we did not request information about project funding sources or project monitoring because we were most interested in the spatial distribution of project types to aid future monitoring design. However, because many data contributors provided these fields unsolicited and the NRRSS wanted these data (Bernhardt et al. 2005), we included funding and monitoring data in our data solicitations.

Data Migration

Currently, there is no regional standard for reporting project-level data. Therefore, data contributors were not asked to change their data from the native format. Many of the larger data sources contributed data in the form of spreadsheets and compiled database files, often as annual summaries. However, many of the smaller data holders lacked compiled digital data but allowed us to compile data from hard-copy reports. The resulting diversity of data types and formats required conversion to a common format for migration into our database (Appendix I). The information received from project sponsors required a significant investment of time to understand and filter the useful information. In all cases, definitions for the fields in the database and other semantic features of data structure (e.g., project types, subtypes) were informed by the data collected from contributors (Table 1). Although this increased the complexity of the process, it avoids excluding otherwise high-quality data because the semantics did not match preconceived expectations.

We assigned all project records a project type. We began with the project types defined in the FCRPS BiOp which, although relevant in addressing habitat-limiting factors, we found insufficiently specific for effectiveness monitoring. Large numbers of projects did not fit into any of the eight FCRPS BiOp project types. Most of these projects described types of upland management not otherwise represented but that had a clear potential to impact stream conditions so we added "Upland Management" as a project type. Further, numerous project records had insufficient documentation to determine if the project had clear relevance to freshwater habitat restoration, but it was considered sufficiently similar to prevent exclusion from the dataset. We assigned these projects a type "Other." A project labeled only as "pond installation" could be an alternative to in-stream livestock watering; then, it would be a then relevant restoration, but if built as a backyard trout pond to improve aesthetics, it would not. The ability to assign records a project type was our minimum criterion for inclusion in the database; if the project so lacked data that we could not identify a type, we deleted the project from the final dataset (Table 1).

The project types created broad categories of restoration. For projects to serve as replicates for effectiveness monitoring control–impact designs, we needed a more specific identifier. In the absence of a regional standard, we created a list of subtypes within each project type (Table 1). Subtype identifiers also served as the basis for the crosswalk of project data with NRRSS intent categories. Barrier Removal projects, for example, include log weirs, fish ladder installations, and culvert repairs as well as large dam breaches. Clearly, the disparate scales of these projects make different demands on monitoring design and expectations for habitat responses.

The description of project type provided by data contributors infrequently used the same project key words or project types listed in the FCRPS BiOp. However, project descriptor fields often referred to subtypes (e.g., Rocked Ford, a reinforced rock stream crossing) that allowed us to determine the project type (e.g., Sediment Reduction). In many cases, we found neither type nor subtype in a specific field but rather both were revealed in narrative description fields provided by the data donor.

Like project type, we found a diversity of definitions and units of measure for location (see Appendices I and II for the list of the fields and units reported by the data contributors). For example, location information arrived in formats that included latitude/longitude identifier (LLID) and river mile, township–range–section (TRS), and latitude and longitude using several units of measure (decimal degrees, degrees:minutes:seconds, etc.). The resolution of location units varied from meters to tens of kilometers. The U.S. Bureau of Land Management (BLM), among others, uses TRS (e.g., township 15S, range 33E, section 10) to indicate a project location. Unfortunately, the smallest unit (section) corresponds to a 1 × 1–mile square, often with multiple possible locations for a stream or river restoration project. Given the lack of consensus on any single location metric, unanimity could not be used to identify any field as a "most effective" or "consensus choice."

Database Design

Because one project could have more than one location, we used a two-level database design. We captured project-level data on one level with each project assigned a project ID code in order to ensure trackability. We maintained external identifiers, such as unique ID codes used by data contributors as an additional field to allow crosschecks between the original and the migrated data. Project-level data included project type and subtype, dates, contact information, cost, and other project- or contract-specific attributes. Each project-level record related to one or more worksites, with location information recorded on the worksite level.

Data Analysis

Much of the data are categorical rather than continuous and quantitative in character. Therefore, we have little a priori information about the distributions of the data or any expectations for error or distribution models. Consequently, we preformed all statistical analyses of the data with nonparametric methods. Correlations among project type and cost distributions were evaluated with Kendall's rank correlation τ (Sokal & Rohlf 1981) and calculated with SYSTAT 11 (SYSTAT Software, Inc., Richmond, CA, U.S.A.).

Results

In all, we received data from 26 sources. Of these, three datasets were hand gathered through telephone calls and personal interviews by staff of the NWFSC NOAA Fisheries. These intensive efforts centered on three target subbasins (John Day River, OR; Wenatchee River, WA; and Salmon River, ID) to support large-scale pilot monitoring projects (Jordan et al. 2003). Of the 23 datasets contributed by external sources, 5 had multistate coverage, 14 were statewide in scale, 2 were subbasin level, and 2 were hand gathered and therefore opportunistic in scale (Appendix I).

In total, the PNW database contains 23,123 records at the project level. Due to the diversity of reporting formats, only two fields, project type and project ID code, were complete for all data sources (Appendix I). Thus, all other fields contain less than 23,123 values. Approximately two-thirds of all records came from the Oregon Watershed Enhancement Board (OWEB), the Washington Salmon Recovery Funding Board (SRFB), the BLM, and the Regional Ecosystem Office (REO) at the U.S. Forest Service (USFS), which manages data collected from federal agencies under the Northwest Forest Plan (NFP) (Appendix II).

Sediment Reduction, Riparian Improvements, and Upland Management projects were the most numerous project types. Nutrient Enrichment (salmon carcass addition), Diversion Screens, and Water Quality Improvement projects were the least numerous (Fig. 2). Surprisingly, projects with type "Other" fell in the middle in terms of total number. Though only 8% of the total, 2,180 projects had a type of "Other" meaning that the project record so lacked in details that its role as restoration was ambiguous.

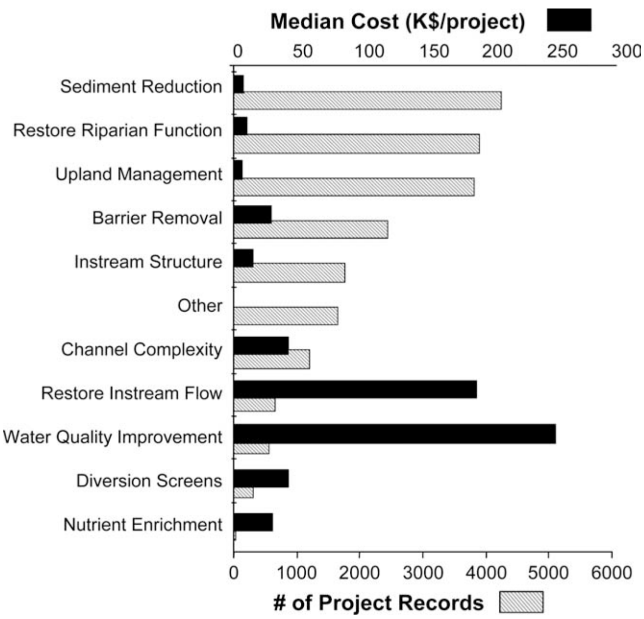

Figure 2. Distribution of project records and median cost per project record as a function of project type. Striped bars indicate numbers of project records. Hundred percent of project records contained the type attribute. Black bars indicate median cost per project record in thousands of dollars per project. Fifty-seven percent of project records included the cost attribute.

The richness of project subtypes could bias the distribution of records into project types. For example, "Diversion Screens," intended to keep fish from being drawn into crop irrigation channels and subsequently onto fields, has only two subtypes: new screens and repair or replacement of existing screens (Table 1). However, there are eight project subtypes under type "Restore Riparian Function" (Table 1). We might expect that with a more diverse set of project subtypes, we could capture more records within a project type category. However, a Kendall's coefficient of rank correlation between project type abundance and number of subtypes was only 0.337 with a $p = 0.17$. This suggests that the observed distribution of projects was not merely a reflection of the differences in subtype richness among project types.

Many projects consisted of multiple types of actions and actions implemented at multiple locations. As a consequence, the database includes 35,679 specific locations (Fig. 3). Almost 80% (28,646) of projects provided location information in a common format. These formats included a geographic information system (56%), latitude and longitude (13%), and stream name and river mile locations (10%). Of the remainder, 5,684 (16%) were located at the centroid of a TRS, with at best a resolution of one square mile. In cases where a single project included actions at multiple locations, sources rarely provided enough detail to map a specific project type to a specific worksite. Thirteen percent of projects reported multiple project types. In addition, 6% of projects did not report location (2%) or had location information so poorly documented or internally inconsistent (4%) that the project could at best be mapped to a watershed or stream. Examples include project records that specified both a county and a lat/long, but the lat/long was not located within that county. Although 6% is a relatively small fraction, it is still over 2,000 projects, a large number to lack this basic information. A query of the NRRSS national database (http://nrrss.nbii.gov/) indicates that of the 13,912 records outside of the PNW, only 6,783 (49%) contain explicit location information (E. Sudduth, personal communication, 2006). Therefore, in tracking location of projects, the PNW does perform well relative to the rest of the nation.

The spatial distribution of projects is not uniform across the landscape (Fig. 3). We found higher project densities and a greater diversity of project types in the western portions of Oregon and Washington. In total, 80% (27,798) of project locations occurred in watersheds with anadromous fish, even though those watersheds were less than half the total area without anadromous fish (320,863 vs. 683,018 km^2). We found a similar pattern when we looked at the spatial distribution of project types. More than 75% of all projects in each type category occur in anadromous areas with the exception of Upland Management and Other types. Areas without anadromous fish had no Nutrient Enrichment projects and only one Diversion Screen.

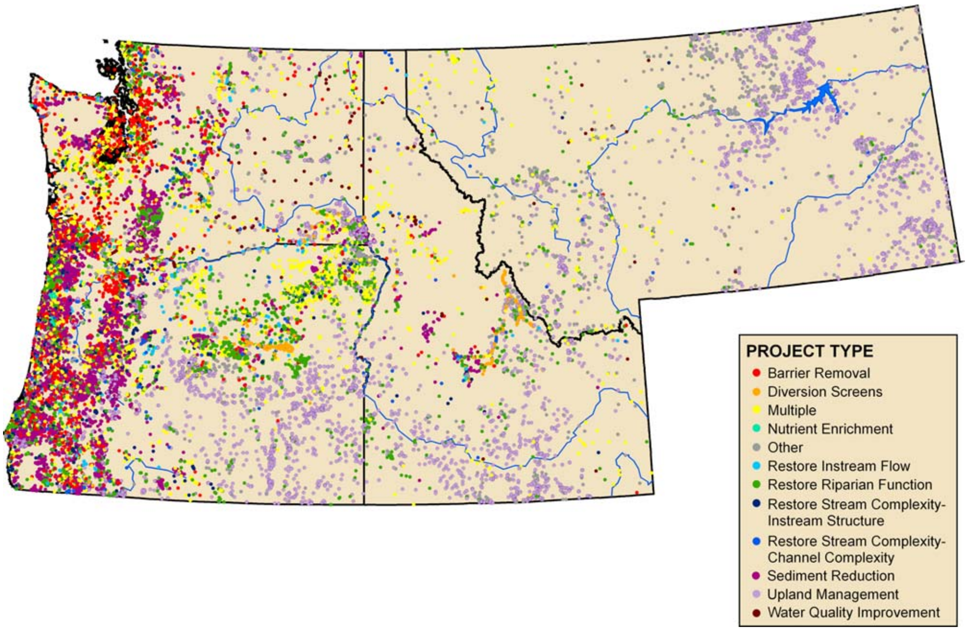

Figure 3. Spatial distribution of river restoration project records in the PNW. Project type is indicated by color of the dots on the map as indicated in the inset box. There are 35,696 restoration project locations plotted on this map. At this resolution, however, many of the points overlap and total project distribution is actually higher than indicated. For example, over two-thirds of all locations are in the far western strip of projects that correlates spatially with the NFP. In this western area, projects are dominated by Barrier Removals (red), Restoration of Riparian Function (green), and Instream Structure (blue). In southern Oregon and Idaho and large areas of Montana, project records are dominated by Upland Management projects (purple) that commonly constitute infrastructure placement to support ranching, such as water supply improvements and cattle control fencing.

Sixty-seven percent of all the project records indicated the source of funding, and 57% (13,920 projects) reported project cost, averaging \$129,222 per project. However, our original request for data did not include cost, so our sampling method for cost differs from the other data types. Despite this, our cost reporting rate is very similar to the cost reporting rate nationally (58%, Bernhardt et al. 2005), suggesting a modest bias if present. In addition to reporting rate, the data quality varies widely. For example, 1,365 project records reported a total project cost of \$1,000 or less, and 580 of these reported total costs of \$1 or less. These costs are so low given the average that it suggests data quality or semantics errors rather than a true expression of project economy. Often projects include "in-kind" effort or other "no-cost" elements in the accounting, so it is arbitrary for us to define a cutoff for lowest reliable cost. Including only projects that report nonzero costs, the average cost per project rises to \$134,840, a marginal increase suggesting that the magnitude of these reporting problems is modest.

More informative than averages for all projects are the costs for each project type (Fig. 2). Among the project types, we found Sediment Reduction, Restore Riparian Function, and Upland Management the least expensive with a median cost of \$8,280 (average = \$59,000). Instream Flow (median = \$187,200, average = \$697,000) and Water Quality Improvement projects (median = \$249,739, average = \$1,500,000) were the most expensive. Water quality projects often include toxic material cleanup, which explains the high cost. Additionally, almost all Instream Flow projects lease water rights, where the water allocation goes unused adding to stream flow. Water leases often span 10–20 years resulting in large total costs.

The most numerous projects (Sediment Reduction) are among the cheapest project types, and the most expensive projects (Water Quality) are the least numerous. In fact, a Kendall's rank correlation of cost and abundance of the project categories was significant ($\tau = -0.66$, $p = 0.035$). Nutrient Enhancement projects, which assume that the reduction of marine-derived nutrients historically supplied by salmon carcasses limits juvenile fish survival, are still experimental and not widely employed as a management strategy (Griswold et al. 2003; Lackey 2003; Slaney et al. 2003; Roni et al. 2005). If we exclude Nutrient Enrichment on the basis that this project type is not yet standard restoration, the Kendall's rank correlation of cost and abundance among project categories is more strongly negative ($\tau = -0.78$, $p = 0.018$).

Eighty-five percent of the projects reported project completion year. The number of projects completed per year increases from the 1980s to 1998 and then levels off until 2003 (Fig. 4). It seems likely that the trend of

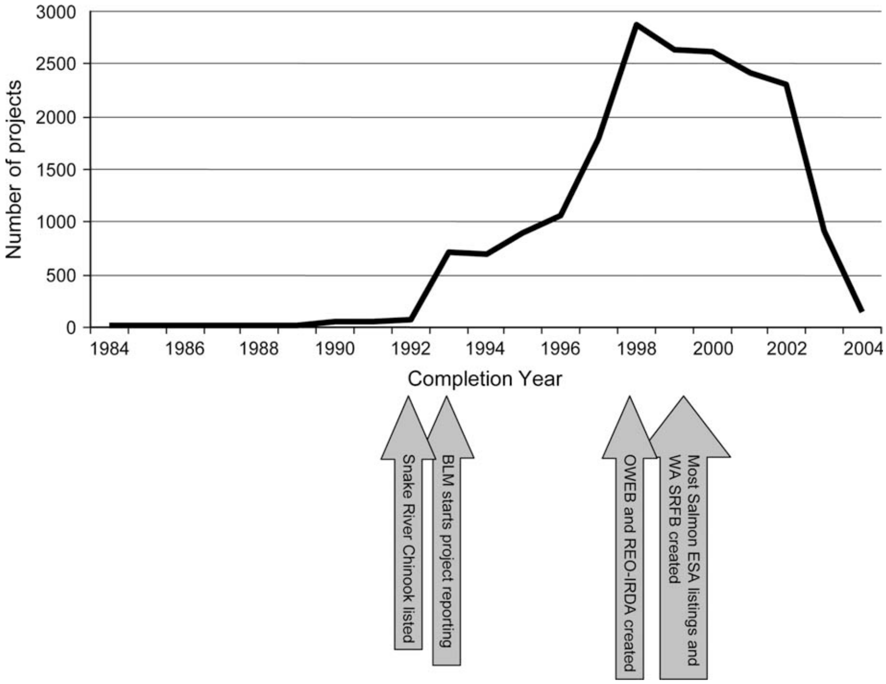

Figure 4. Time series of completion date for all project records. Eighty-five percent of project records contained data on completion date. In many cases, completion date was not recorded in a specific database field but was rather included in an associated narrative description of the project. Arrows indicate correlated dates of consequence in the history of restoration project record keeping. Snake River Chinook Salmon were originally listed under the ESA in 1992. The BLM began their restoration reporting mechanism in 1993. Both the OWEB project tracking mechanism and the REO of the USDA and USDI began project tracking in 1997. The Washington SRFB began project tracking in 1998. Also in 1998, additional species of salmon were listed under the ESA.

2,000–3,000 projects completed per year continues beyond 2003. We lack sufficient information to reject the hypothesis that the decrease in 2003 and 2004 is a product of a time lag in reporting rather than a real decrease in the number of projects completed annually. This suggests that restoration and habitat improvement projects are increasing in number over the entire 10- to 15-year time period. We collected data prior to 1992 opportunistically; consequently, sparser records for that period may represent lesser restoration activity, lower effort in data collection, or a combination of the two.

Examining more closely the total number of projects completed in a given year, we find events coincident with the inflection points in Figure 4. For example, the increase in projects completed between 1992 and 1993 coincides with the final decision to list Snake River Sockeye and Chinook (1991–1992) under the ESA (Federal Register Vol. 56, No. 224, p. 58619, 1991; Federal Register Vol. 57, No. 78, p. 14653, 1992; NOAA 2005). In addition, the increase in projects completed in 1998 is concurrent with both the formation of the OWEB and the REO of the USFS. In 1999, REO organized as part of the NFP, developed to respond to the threatened status of spotted owls (Federal Register Vol. 55, No.26, p. 114, 1990; RIEC 2003). Also in 1999, the State of Washington established the SRFB coincident with the majority of salmon ESA listings. It is impossible to tease apart if the fluctuations in data represent increased effort in implementing habitat restoration, increased effort in reporting of projects, or both (Fig. 4).

Of all project records, only 1,569 or 6.7% reported any type of monitoring. We did not request monitoring data from data donors, so these numbers only represent where data donors volunteered it. However, this did not surprise us given that two of the largest contributors to the database REO (24% of total) and BLM (20% of total) do not record any monitoring information. NRRSS, however, did request monitoring metadata and found a similar monitoring rate nationally (10%, Bernhardt et al. 2005). In almost all cases, the monitoring described checked only if the project was implemented as proposed with techniques such as before and after photodocumentation. Seven hundred and sixty-three project records, or 3%, report that some monitoring data are available from project sponsors. The small fraction of projects reporting monitoring supports the contention that there is little emphasis on monitoring of habitat restoration activities (Bash & Ryan 2002; U.S. GAO 2002).

Discussion

The data summarized here demonstrate substantial effort invested in restoring or improving freshwater habitat in the PNW. It remains to be demonstrated, however, that this effort translated into significantly improved ecological conditions. Demonstrating improved conditions requires targeted monitoring and evaluation ("Knowledge of Effectiveness"), with project effectiveness in the context of large-scale status monitoring of habitat characteristics and biological population health ("Baseline Monitoring"). In the mean time, we have a foundation of past project implementation that will allow (1) a measure of total habitat treated to compare with population responses for gross indexes of project effectiveness, (2) the prioritization of future restoration action placement because future actions should be placed in areas without past actions to avoid confounding results, and (3) the design of targeted monitoring of actions using past project knowledge. This service to regional monitoring needs was implicit in the design of the database. However, the results also reveal important trends in PNW habitat management.

The Driving Role of the ESA

Habitat restoration increased coincident in time with important ESA milestones such as the listings of spotted owls (1990) and salmonid fishes (1991–2000 with most listed in 1999). Moreover, the concentration of project records in the western portion of the region clearly surpasses that of the eastern portion suggesting that ESA listings also influenced the location of projects. The NFP covers Washington, Oregon, and California from the Pacific coast to the crest of the Cascade Mountains south to San Francisco Bay (USDA/USDI 1994). Many of the projects in western Oregon and Washington are USFS sediment control projects undertaken as part of the NFP and state projects to remove passage barriers and improve in-stream habitat for anadromous fish.

The heterogeneity of project types across the entire region gives further insights to the role of the ESA. Areas with anadromous fish clearly show a greater diversity of projects types than elsewhere. Across southeastern Oregon, southern Idaho, and much of Montana, areas outside the range of anadromous salmonids, the Upland Management and Other categories dominate project records. Many of these are water development projects implemented on BLM lands. Other project types are sparse in these areas and largely came from nongovernmental conservation groups focused on habitat for waterfowl and wildlife. The project type distribution suggests a greater effort to improve freshwater habitat in areas with listed salmon. Areas without salmon have a more narrow, land management focus.

In the NRRSS census of freshwater restoration, the PNW represented 62% of all project records (Bernhardt et al. 2005). The large geographic footprint of ESA-listed aquatic species in the Northwest is unparalleled in other parts of the country. Though the impetus for restoration provided by the ESA is not surprising, the geographic concentration and diversity of projects in anadromous use areas provide a measure of impact in more tangible terms than previously available.

Determinants of Project Implementation

In order to answer the question of project effectiveness, one needs specific monitoring designed around a clear definition of effectiveness. For example, many projects are designed to improve fish habitat and thereby improve fish survival. To demonstrate this, however, we would need to show that the project affected both the habitat and a fish population. Short of this, we could develop reasoned hypotheses about anticipated effectiveness by correlating project distribution and perceived ecological need. If the most appropriate projects are in the correct places, one might anticipate a correlation between local ecological conditions and anticipated project consequence. Unfortunately, the data to execute these studies are not yet available.

If the base hypothesis implicit in a rational design scheme—that actions will be placed in the locations of greatest need based on monitoring—were false, then what might have determined the distribution of actions? That project types are so strongly negatively correlated with median project cost is highly suggestive that economics is a dominant driver of action choice. Unfortunately, the nonparametric correlation limits the degree to which one can exclude other sources of variation as explanatory in determining project type distribution. However, the large magnitude of this association implies that if the influence of project cost were removed, there is little variation left that could be explained by other determinants such as ecological need.

The negative correlation between project cost and project abundance suggests three possible mechanisms. First, there may be an economy of scale where the more projects of a type are completed, the more efficient people become at doing them. Second, project planners may feel pressure to spread restoration dollars over a larger footprint than a single, expensive project. Third, cheaper projects are implemented more frequently simply because it is easier to find funding for less expensive projects. These hypotheses are not exclusive, and multiple mechanisms may reinforce the observed pattern. Teasing the relative magnitudes of these processes apart would require targeted monitoring to identify the spatial pattern of ecological need and correlate that with the spatial pattern of project implementation presented. Presently, we can only conclude that the ESA has motivated people to do something, exactly what they do may be influenced by factors other than an identified ecological need.

Project Data versus Projects

Readers should keep in mind that we report here the results of an effort to collect information about restoration and habitat improvement projects. The patterns and conclusions we present pertain to the data we collected rather than the full suite of on-the-ground restoration actions in the northwest. For example, in Northwest Oregon, the Grande Ronde Basin has a much higher density of projects (809) than the Yakima Basin (400), a basin in central Washington with double the area. To explain this difference, we would have to examine the number of projects, the accuracy of local record keeping, and our data collection effort in these basins. In fact, the ecological differences between these basins (e.g., rainfall, vegetation cover) should translate into rational differences in project type prioritization. Some basins also contain active local groups, such as the Grande Ronde Model Watershed program (http://www.fs.fed.us/pnw/modelwatershed/index.htm), motivating both more restoration activity and better accounting of the projects. Although we invested uniform effort and consistent methods in acquiring data, data were easier to acquire in some places. In the face of this diversity of data accessibility, we rely on our large sample size to provide confidence in the fairness of our inferences. Even given our sample size, the impossibility of censusing all restoration actions means that our database remains a conservative estimate.

Currently, there is no regional format for reporting restoration, and this translates into challenges in assembling information. Project reporting lags 18 months from completion to data availability, even without the additional time required to migrate the data into a single format. Additionally, we found little documentation of monitoring activity connected with freshwater restoration projects. Acceptance of a regional standard for project data, such as that described here, and a single database host could motivate, or at least empower, more timely project implementation monitoring—a prerequisite for effectiveness monitoring of project success. We hope that lessons learned from this project will speed development of a single-project tracking system for the PNW.

Implications for Practice

To facilitate the tracking of restoration projects, both for purposes of documentation and to facilitate the design of monitoring to determine the effectiveness of the restoration, the following features of a project tracking system are required:

- *Standardized metrics and reporting system to track restoration projects that includes common semantics for project type, location, timing, and magnitude.* Lack of standardized formats has been shown to introduce delays in reporting and consume valuable resources in the process of data reconciliation.
- *Spatially explicit data on project location (i.e., the worksite), not the location of the project contract.* To identify the relevant habitat data to analyze these projects such as location of relevant reference sites based on stream gradient, vegetation cover type, and so on, one needs to know exactly where the restoration project is in some kind of consistent coordinate system—like latitude and longitude in decimal degrees.
- *Project-level data on all implementations—no matter the data or funding sources.* Characterizing the net impact of diverse restoration actions and clearly identifying replicates that are unimpacted by adjacent restoration actions to design targeted monitoring both require knowledge of all other restoration actions in the domain of inference.
- *A measure of the magnitude of the action.* For each action tracked, some measure of magnitude or "treatment" is necessary. Measures of the treatment magnitude are useful in three contexts.

(1) *To identify potential replicates for an effectiveness M&E study, the level of treatment is critical.* One would not compare the effect of a fencing project that excluded cattle from 1 km of stream length with a project that excluded cattle from 500 km of stream length.
(2) *Assessment of project performance*—Some M&E assessments will be comparisons of levels of treatment with levels of response—although the actual statistical comparison may be more sophisticated than more effect (e.g., number of fish) with more treatment (e.g., number of culverts).
(3) *Prioritizing project placement*—If M&E efforts are to inform the prioritization of new action implementation at any scale, then some measure of implemented treatments must be available to planners. It is unreasonable to expect coordinated results at spatial scales over which there is little coordination of planning or implementation.

Acknowledgments

This paper benefited from technical assistance from R. Kang and the entire staff of the Scientific Data Management Group at the NWFSC NOAA Fisheries. In addition, the work benefited from the collaborations and/or critical review of S. Toshach, G. Pess, T. Beechie, C. Jordan, and the diverse collaborators in the NRRSS. The recommendations and general content presented in this report do not necessarily represent the views or official position of the Department of Commerce, the NOAA, or NOAA Fisheries.

LITERATURE CITED

Bash, J. S., and C. M. Ryan. 2002. Stream restoration and enhancement project: is anyone monitoring? Environmental Management **29:** 877–885.

Bernhardt, E. S., M. A. Palmer, J. D. Allan, G. Alexander, K. Barnas, S. Brooks, et al. 2005. Synthesizing U.S. river restoration efforts. Science **308:**636–637.

Cooter, W. S. 2004. Clean Water Act assessment process in relation to changing U.S. Environmental Protection Agency management strategies. Environmental Science and Technology **38:**5265–5273.

EPA (Environmental Protection Agency). 1972. Federal Water Pollution Control Act. 33 U. S. C. 1251 et seq (available from http://www.epa.gov/region5/water/cwa.htm) accessed 17 June 2007.

Frissell, C. A., and S. C. Ralph. 1998. Stream and watershed restoration. Pages 599–624 in R. J. Naiman and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal Ecoregion. Springer, New York.

U.S. GAO (U.S. General Accounting Office). 2002. Columbia River Basin salmon and steelhead: federal agencies' recovery responsibilities, expenditures and actions. U.S. General Accounting Office Technical Report GAO-02-612 U.S. General Accounting Office, Washington, D.C.

Griswold, R. G., D. Taki, and J. G. Stockner. 2003. Redfish Lake Sockeye salmon: nutrient supplementation as a means of restoration. Pages 111–126 in J. Stockner, editor. Nutrients in salmon ecosystems: sustaining production and biodiversity. American Fisheries Society Symposium 34. American Fisheries Society, Bethesda, Maryland.

Jordan, C. J., J. Geiselman, M. Newsom, and J. Athern. 2003. Federal Columbia River Power System Biological Opinion (available from http://www.salmonrecovery.gov/reports_and_papers/research/docs/RME_Plan_09-2003.pdf) accessed 17 June 2007.

Lackey, R. T. 2003. Nutrient additions to restore salmon runs: considerations for developing environmental protection policies and regulations. Pages 283–285 in J. Stockner, editor. Nutrients in salmon ecosystems: sustaining production and biodiversity. American Fisheries Society Symposium 34. American Fisheries Society, Bethesda, Maryland.

NOAA (National Oceanographic and Atmospheric Administration). 2000. Reinitiation of consultation on operation of the Federal Columbia River Power System, including the Juvenile Fish Transportation Program, and 19 Bureau of Reclamation Projects in the Columbia Basin between the U.S. Army Corps of Engineers, Bonneville Power Administration, Bureau of Reclamation, and the National Marine Fisheries Service. 21 December 2000. National Marine Fisheries Service, Northwest Region, Portland, Oregon.

NOAA (National Oceanographic and Atmospheric Administration). 2005. Endangered and threatened species: final listing determinations for 16 ESUs of West Coast salmon, and final 4(d) protective regulations for threatened salmonid ESUs (50 CFR Parts 223 & 224). Federal Register **70:**37160–37204.

NRC (National Research Council). 1992. Restoration of aquatic ecosystems. National Academy Press, Washington, D.C.

NRC (National Research Council). 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C.

NWFSC–NOAA (Northwest Fisheries Science Center–National Oceanographic and Atmospheric Administration). 2004. The Northwest Fisheries Science Center strategic research plan for salmon (available from http://www.nwfsc.noaa.gov/publications/researchplans/salmon_research_plan6.17.04%20.pdf) accessed 17 June 2007.

Paulsen, C. M., and T. R. Fisher. 2005. Do habitat actions affect juvenile survival? An information-theoretic approach applied to endangered Snake River Chinook Salmon. Transactions of the American Fisheries Society **134:**68–85.

Reeves, G. H., F. H. Everest, and J. R. Sedell. 1991*a*. Responses of anadromous salmonids to habitat modifications: how do we measure them? Pages 62–67 in J. Colt and R.J. White, editors. Fisheries Bioengineering Symposium, American Fisheries Society Symposium 10. American Fisheries Society, Bethesda, Maryland.

Reeves, G. H., J. D. Hall, T. D. Roelofs, T. L. Hickman, and C. O. Baker. 1991*b*. Rehabilitating and modifying stream habitats. Pages 519–557 in W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publications 19, Bethesda, Maryland.

RIEC (Regional Interagency Executive Committee). 2003. Memorandum of understanding for management under the Northwest forest plan at the regional level (available from http://www.reo.gov/library/policy/2003MOU4NWFP.htm) accessed on 7 September 2005.

Roni, P. 2005. Overview and background. Pages 1–12 in P. Roni, editor. Monitoring stream and watershed restoration. American Fisheries Society, Bethesda, Maryland.

Roni, P., K. Hanson, T. J. Beechie, G. R. Press, M. M. Pollock, D. M. Bartley. 2005. Habitat rehabilitation for inland fisheries. Global review of effectiveness and guidance for rehabilitation of freshwater ecosystems. FAO Fisheries Technical Paper No. 484, Food and Agriculture Organization of the United Nations, 116 pp.

Ruckelshaus, M. H., P. S. Levin, J. B. Johnson, and P. M. Kareiva. 2002. The Pacific salmon wars: what science brings to the challenge of recovering species. Annual Review of Ecology and Systematics **33:**665–706.

Slaney, P. A., B. R. Ward, and J. C. Wightman. 2003. Experimental nutrient addition to the Keogh river and application to the salmon river in Coastal British Columbia. Pages 111–126 in J. Stockner, editor. Nutrients in salmon ecosystems: sustaining production and biodiversity. American Fisheries Society Symposium 34. American Fisheries Society, Bethesda, Maryland.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. 2nd edition. W. H. Freeman and Co., San Francisco, California.

Sutherland, W. J., A. S. Pullin, P. M. Dolman, and T. M. Knight. 2004. The need for evidence-based conservation. Trends in Ecology and Evolution **19:**305–308.

USDA/USDI (U.S. Department of Agriculture, Forest Service and Department of Interior, Bureau of Land Management). 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl and standards and guidelines for management of habitat for late-successional and old-growth forest related species within the range of the northern spotted owl (The Northwest Forest Plan). USDA Forest Service, Washington, D.C.

Appendix I. Table of metric formats reported by each data source.

Information Category	Metric Description	Washington Department of Ecology	Washington Department Fish and Wildlife Culvert	BLM	Columbia Basin Fish and Wildlife Authority	OWEB	REO	Ducks Unlimited	Idaho Department of Environmental Quality	Idaho Fish and Game	SFRB	Montana Water Center	NOAA Restoration Center	Oregon Water Trust	Washington Department Fish and Wildlife Fishway	SALMON	StreamNet Idaho	Fisher Fisheries	Washington Department Fish and Wildlife WRIP	Washington Department of Transportation	WENATCHEE	Washington Water Trust	John Day	Idaho Department of Fish and Game—Screen Shop	NRRSS	Astotin Soil and Water Conservation District	Grande Ronde Model Watershed Program
ID #	Our project ID	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Project ID	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Project info	Project name	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X
	Agencies / organizations	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	Description		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X
	Project contact	X	X	X	X	X	X		X		X	X			X		X	X			X	X	X		X	X	
	Address			X	X						X	X					X	X	X		X					X	
	E-mail	X	X		X				X		X	X			X			X	X		X	X	X		X		
	Phone	X	X		X				X		X	X			X		X	X	X		X	X	X		X	X	
Location	Latitude		X		X	X	X	X	X		X	X	X		X	X		X			X		X	X	X		
	Longitude		X		X	X	X	X	X		X	X	X		X	X		X			X		X	X	X		
	County		X			X		X	X	X		X			X		X			X					X		
	State			X		X		X	X	X		X	X				X			X					X		
	HUC fourth field					X			X	X		X					X								X		
	HUC fifth field																										
	Basin (third field HUC)					X											X								X		
	Fourth field HUC name																										
	NWPCC subbasin				X	X						X						X			X	X	X				
	Stream name	X	X			X			X	X		X		X	X		X		X	X	X	X	X	X	X		X
	LLID											X					X						X				
	Township			X		X											X		X				X	X		X	
	Range			X		X											X		X				X	X		X	
	Section			X		X											X		X				X	X		X	
	Begin river mile		X											X	X		X										
	End river mile													X			X										
	Stream length restored		X				X		X																X		X
	Stream area restored						X	X	X		X														X		X
	Location details		X		X					X					X		X	X	X	X					X	X	X
Type	Project type	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Project subtype	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Time	Completed year			X		X			X	X		X					X	X			X	X	X	X	X	X	
	Initiated year	X				X			X	X		X					X	X			X	X	X		X		
	Permitted year																										
	Proposal year										X																
	Proposed begin year																				X						
	Further timing details			X																	X				X		
	Start date							X			X	X	X	X					X		X		X				
	End date						X	X			X	X	X	X					X		X		X				

Appendix I. Continued

Cost	Is cost information available	X	X																X	X							
	If not, is cost information accessible		X																								
	Total cost				X	X	X	X			X	X	X						X	X			X	X	X	X	X
	Funding Y/N?	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	
Goals	Were goals stated in documentation										X					X	X		X	X							
	Describe goals										X					X	X		X	X							
Monitoring	Onsite monitoring?		X						X	X	X				X	X	X	X							X		X
	Monitoring activity								X	X	X				X	X	X	X							X		
	Downstream monitoring																										
	Downstream activity																										
	Monitoring data available?		X												X		X										
	Data available																X										
	Before treatment data collected?																X										
	Species affected/ target species specified		X	X			X			X	X				X		X	X							X	X	

HUC = hydrologic unit code; NWPCC = Northwest Power and Conservation Council.

Appendix II. Data sources and numbers of records contributed by each data source.

External to NWFSC	
Asotin Creek Model Watershed	700
BLM	4,749
Columbia Basin Fish and Wildlife Authority	151
Ducks Unlimited	529
Grande Ronde Model Watershed Program	528
Idaho Department of Environmental Quality	129
Idaho Department of Fish and Game—Fish Screen Shop	220
Idaho Department of Fish and Game	242
Fisher Fisheries (private consultant)	152
Montana Water Trust	311
NOAA Restoration Center	142
NRRSS	726
Oregon Water Trust	492
OWEB	5,292
Washington SRFB	857
REO–USFS	5,625
StreamNet	34
Washington Water Trust	20
Washington Department of Fish and Wildlife (culvert dataset)	130
Washington Department of Fish and Wildlife (fishway dataset)	620
Washington Department of Fish and Wildlife—Watershed Restoration Inventory Project	609
Washington Department of Ecology	433
Washington Department of Transportation	51
Internal to NWFSC	
John Day River Basin (hand-collected dataset, NOAA Fisheries)	185
Salmon River Basin (hand-collected dataset, NOAA Fisheries)	183
Wenatchee River Basin (hand-collected dataset, NOAA Fisheries)	13
Total project records	23,123