


Habitat Retrospective Report:

Review and Synthesis of Progress and Challenges in Columbia River Basin Fish and Wildlife Program Habitat Protection and Restoration Projects

INDEPENDENT SCIENTIFIC REVIEW PANEL
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Report cover design by Eric Schrepel, Technical and Web Data Specialist, Northwest Power and Conservation Council

Photos from ISRP visits to Fish and Wildlife Program habitat restoration sites, clockwise from top left: South Fork Clearwater River subbasin, Idaho; Steigerwald Lake National Wildlife Refuge, Lower Columbia River, Washington; John Day River subbasin, Oregon; Fifteenmile Creek, Oregon.

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FOR THE NORTHWEST POWER AND CONSERVATION COUNCIL PORTLAND · NWCOUNCIL.ORG/ISRP

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Briefings and discussions with Northwest Power and Conservation Council members and staff to initiate this ISRP review provided critical context and helped the ISRP focus its review. Council staff Patty O'Toole and Kris Homel briefed us on the Columbia River Basin Fish and Wildlife Program's evolution, the 2020 Addendums, and efforts to evaluate and report on Program performance (see Program Tracker), including progress on habitat restoration. Council staff Eric Schrepel helped with the report's cover design, figures, and formatting, and Kendra Coles and Jasmine McIntosh (intern) helped with the reference section.

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Finally, although we avoided asking for additional material from the many habitat restoration planners, practitioners, and researchers who design, implement, and evaluate Fish and Wildlife Program projects, respecting their already heavy workload, we relied on their past proposals, presentations, and publications to complete this report. We continue to be impressed with their dedication and ever-improving capacity and expertise.

ISRP Habitat Retrospective Report

Preface

This report is intended for multiple audiences and includes a high-level executive summary, a comprehensive summary, and a main body with an introduction and six major chapters. Because the main body of the report presents many technical details, we include a comprehensive summary of the report describing major findings and recommendations for general audiences. Chapters 2, 3, and 4 include evaluations of each of the three major interdependent components of habitat protection and restoration: habitat action planning and prioritization, project implementation methods, and research, monitoring, and evaluation (RM&E) respectively. In Chapter 5, we highlight and consider how Intensively Monitored Watershed (IMW) programs address these three components with information from key findings, lessons learned, and future opportunities to expand and apply the new knowledge generated. In Chapter 6, we assess how projects accommodate and adjust to confounding factors such as climate change and variable ocean conditions. In Chapter 7, we identify elements and characteristics of exemplary projects that display effective project selection, habitat restoration, and evaluation programs, and we provide some examples to highlight their evolution, progress, and areas of improvement. We provide many recommendations designed to improve all components of habitat restoration and RM&E to address major challenges facing projects now and in the future.

The report benefited from and is intended to complement the Council's 1980-2022 Retrospective Report, Program Tracker, and categorical assessments.

Executive Summary

For 28 years, the Independent Scientific Review Panel (ISRP) has reviewed projects that implement the Columbia River Basin Fish and Wildlife Program (hereafter referred to as the Program). The completion of the Anadromous Fish Habitat and Hatchery Review in 2022 marked the end of the sixth major iteration of project reviews. To take advantage of lessons learned and restoration advancements over these three decades of review, the ISRP, in consultation with the Northwest Power and Conservation Council, determined that habitat restoration would benefit from a retrospective report that evaluates progress in habitat protection and restoration projects in the Program, evidence for their success, and ongoing and future challenges. Here, we highlight the report's major findings and selected recommendations to improve Program planning, implementation, and evaluation.

Project Planning and Prioritization

It is clear to the ISRP that there has been significant improvement in habitat protection and restoration efforts over the 40+ year lifespan of the Program. During the Program's first decade, most efforts focused on improving passage of juvenile and adult salmon and steelhead through the mainstem dams, construction of hatcheries to mitigate for lost natural production and harvest, and habitat restoration in some selected subbasins (e.g., the Yakima River). Over time, the efforts expanded significantly and emphasis shifted to include river, lake, and estuary habitat restoration in the tributaries of the mainstem Columbia River.

Key findings

- The Program's restoration efforts have evolved and expanded, in a manner consistent with the state of the science, recognizing the importance of high-quality tributary habitat and associated natural processes for recovery and persistence of fish populations in the Columbia River Basin. Also consistent with the science, there has been an evolution toward greater complexity and integration of restoration actions, both within individual projects and in multiple coordinated projects across large spatial scales.

- Project planning and prioritization have improved through increasing and effective use of models such as habitat and life cycle models, more rigorous analysis of limiting factors, and use of strategic planning.

Recommendations

- Continue to support analyses of limiting factors and density dependence as critical components of habitat restoration planning and prioritization.
- Explore the potential use of habitat and life-cycle models for strategic analyses and general restoration planning for projects that lack necessary information or support for detailed project-scale modeling.

Restoration Methods

We reviewed eight major restoration methods — barrier removal, floodplain reconnection, large wood addition, riparian planting and fencing, estuary habitat restoration, flow augmentation, cold-water habitat restoration, and wildlife habitat restoration.

Key findings

- Assessments conducted by Fish and Wildlife Program projects, as well as out of basin assessments, have provided valuable information on the effectiveness of major restoration methods.
- Of the eight restoration methods we reviewed, removing barriers to restore connectivity and reconnecting side channels and floodplains, including in the estuary, have a strong likelihood of positive benefits for anadromous salmonids.
- Barrier removal, flow augmentation, and some wood additions are likely to achieve their intended outcomes in a short period of time (i.e., 5-10 years). There is substantial uncertainty about the time required for restoration of riparian forests, and restoration of connectivity and complexity of floodplains. In addition, the persistence of restored cold-water refuges is variable and highly uncertain.

Recommendations

- Emphasize habitat protection in tandem with restoration. When possible, implement protection and restoration actions at watershed or sub-watershed scales.
- Continue to emphasize process-based restoration over structural-based approaches alone, a point consistent with past ISRP and Independent Scientific Advisory Board recommendations.
- Develop a coordinated study, building on past work, to monitor and evaluate the long-term effectiveness of floodplain reconnection, riparian forest and meadow restoration, and creation and restoration of cold-water refuges.

Research, Monitoring and Evaluation

Research, monitoring, and evaluation (RM&E) have been fundamental components of the Program since it began in 1982.

Key findings

- The Council made multiple concerted efforts to address deficiencies in monitoring and evaluation in the Program, which resulted in improvements, but challenges remain.
- The Columbia Basin Tributary RM&E Strategy represents a step forward, providing high-level guidance for monitoring, especially at the project and reach level.
- Although implementation and compliance monitoring are expected for every project, rigorous effectiveness monitoring requires substantial time, technical and financial resources, and expertise.
- Effectiveness monitoring should emphasize understanding of how much restoration is needed to produce biologically meaningful effects (i.e., a dose-response) and under what conditions such effects can occur (i.e., geomorphic, hydrologic, and ecological contexts).

Recommendations

- Develop efficient study designs before restoration is initiated and data is collected and employ state-of-the-art spatial and temporal sample designs and statistical analyses.
- Develop and support rigorous, hierarchical, and long-term monitoring designs to generate statistically sound information to show how effectiveness varies with amounts of restoration and across different habitat conditions in different subbasins.
- Establish clearly defined RM&E relationships among projects within major subbasins and geographic areas, and ensure the storage and transfer of information among projects and watersheds.

Intensively Monitored Watersheds

Two challenging questions about habitat restoration for the Program are: 1) did restoration improve habitat at the watershed scale and increase or stabilize viability of fish populations, and 2) what mechanisms caused these improvements? A series of IMWs from California through Washington were established to address these questions across the broadly overlapping distributions of major Pacific salmon and steelhead populations.

Key findings

- To date, IMWs have provided important information at appropriate spatial scales that match management decision scales.
- Although results have not been rigorously analyzed, simple tallies showed positive responses for a range of habitat metrics in nearly all IMWs evaluated to date. Responses for fish metrics were positive in about two-thirds of cases but were equivocal (neither positive nor negative) in the remaining third of cases analyzed.
- Extensive time is needed to conduct successful restoration and to detect change in fish populations across watershed scales amid the background of annual variability.

Recommendations

- Support IMWs to synthesize their data on responses of habitat and fish to the restoration actions implemented.
- Support an integrated analysis of habitat restoration results across the network of IMWs to answer broad questions about 1) treatments and responses for salmon, steelhead, and other important fish across the Pacific Northwest and 2) how well the existing IMWs represent the diversity and distribution of landscapes and fish and wildlife resources of the Columbia River Basin.
- Strengthen the existing network of IMWs by considering new IMWs to address unresolved questions about habitat restoration effectiveness for portions of the Basin, river types, and restoration methods that are underrepresented.

Confounding Factors

Various confounding factors can affect planning and implementation of restoration projects and alter their outcome including climate change, landscape change, variable ocean conditions, nonnative species, predation, supplementation with hatchery fish, dams, water quality, density-dependence, and logistical complexities.

Recommendation

- Develop and employ tools (e.g., models) to forecast future conditions which account for confounding factors and their effects on habitat and population viability, toward which practitioners can plan.

Exemplary Projects

ISRP reviews have identified exemplary projects that displayed certain elements and characteristics that improved their likelihood of success. The report identifies and recommends specific attributes of exemplary projects that are applicable at a local scale and those that could apply at broader scales such as subbasin or watershed.

Concluding Remarks

We commend the Program for the significant improvements in habitat restoration efforts that have occurred over the 40+ year lifespan of the Program. Of particular note have been improvements in the planning and prioritization of projects and in methods of restoration. Issues remain with RM&E in the Program, but we are encouraged that the Council is committed to continuing to improve RM&E. Success of the Program in the future will depend on its ability to accommodate and adapt restoration in the face of a diverse array of challenges, including climate change, variable ocean conditions, non-native species, and ongoing landscape changes. Success will also depend on developing and implementing a sound monitoring and evaluation program to address the remaining key management questions and critical uncertainties.

ISRP Habitat Retrospective Report

Summary

The ISRP has conducted Fish and Wildlife Program project reviews for 28 years, and the completion of the Anadromous Fish Habitat and Hatchery Project Review in 2022 marked the end of the sixth major iteration of project reviews. Consequently, the ISRP, in consultation with the Northwest Power and Conservation Council, determined that habitat restoration, especially with respect to Research, Monitoring, and Evaluation (RM&E), would benefit from a retrospective report. In this report, we identify advances and achievements in habitat protection and restoration projects in the Fish and Wildlife Program (henceforth, "Program"), evidence for their success, and ongoing challenges. There are seven chapters, each summarized below with a list of the ISRP's Recommendations.

Chapter 1. Habitat Protection and Restoration in the Fish and Wildlife Program

Since the Program began in 1982, habitat protection and restoration have been important parts of efforts to mitigate the effects of the Columbia River Basin hydropower system. The Program has provided the framework for planning and selecting projects to restore and protect habitat for anadromous and resident fish and wildlife, and particularly anadromous salmon and steelhead. During the Program's first decade, most efforts focused on improving passage of juvenile and adult salmon and steelhead through the mainstem dams and construction of hatcheries to mitigate for lost natural production. Over time, the emphasis shifted to include river, lake, and estuary habitat restoration in the tributaries of the mainstem Columbia River. In part, this focus on tributary and estuary habitats occurred because modifications to passage at dams and operation of the hydrosystem to improve fish survival could not fully mitigate for system impacts. The expansion in habitat restoration efforts also stemmed from an increased recognition of the importance of high-quality tributary habitat and associated natural processes for recovery and persistence of salmonid and other native fish populations in the Columbia River Basin.

The Program developed Scientific Principles and strategies to rebuild naturally producing fish and wildlife populations adversely affected by the hydrosystem in the Columbia River Basin. Strategies emphasize the restoration of natural processes rather than technological solutions. Four important principles are identified in the habitat strategy:

- Build from strength

- Restore ecosystems, not just single populations
- Use native species wherever feasible
- Address transboundary species in Canada

Habitat protection and restoration are now fundamental components of efforts to achieve the Fish and Wildlife Program's goals and offset the continued impacts of the hydrosystem and ongoing habitat changes in tributaries, estuary, and the mainstem. Habitat restoration and protection projects for resident and anadromous fish and wildlife are underway in all 62 major subbasins in the Columbia River Basin and represent a key component of the Fish and Wildlife Program and its subbasin plans, the Endangered Species Act (ESA) mandated recovery programs, and other management plans.

Importance of habitat protection

Although this report's focus is mostly on restoration, protection of high-quality habitat is as important as restoring degraded habitat and should be considered in tandem with restoration (ISAB 2018-1, 2024-2). Protection that safeguards important healthy aquatic habitats in the face of increasing human populations, changing land uses, and climate change in the region reduces future deterioration of the ecosystem's ability to support fish and wildlife populations. Where it is feasible, protection of habitat can be more effective because many habitat restoration actions (e.g., riparian forest plantings) require decades to centuries to recover full ecological function. Effective conservation and recovery of tributary habitats require a well-integrated approach of both habitat protection and restoration actions.

Purpose of the Habitat Retrospective Review

This review identifies major advances and achievements that have occurred in habitat protection and restoration projects in the Fish and Wildlife Program, and challenges that remain. This retrospective report considers project implementation, actions, and outcomes in the Program. We focus on landscapes and aquatic ecosystems of the tributaries to the Columbia River rather than mainstem habitat or fish passage at dams, but we include the Columbia River Estuary because of its importance to many populations of salmon and estuarine species. We provide recommendations for project improvement that draw on exemplary projects and their characteristics identified from the ISRP's Categorical Reviews, scientific publications and reports, previous comprehensive reviews of habitat restoration effectiveness, and guidance documents such as the Columbia Basin Tributary Habitat RM&E Strategy (BPA/BOR 2022, henceforth Tributary Habitat RM&E Strategy).

Our review focuses on anadromous salmonids because they are a major focus of the Basin's restoration actions, including Chinook, coho, chum and sockeye salmon, and steelhead. In addition, we include salmonids that are culturally or economically important to tribes and those of conservation concern or important in recreational fisheries, notably redband trout, cutthroat trout, and bull trout. We consider similarities and differences in habitat restoration for resident and anadromous salmonid species to assess how broadly recommendations for improvements can be made. Although some significant habitat restoration projects benefit resident non-salmonids (e.g., white sturgeon), these comparatively few projects are not the focus of our review. We highlight several wildlife protection and restoration projects, and we include a discussion of key differences between the Program's approach to mitigating the effects of the hydrosystem on wildlife and the approach for fish and aquatic ecosystems. In addition to our retrospective review of the evolution of actions to restore tributary habitat over the last 43 years, we provide recommendations to the Council to build on the progress already made and strengthen the efforts to protect and restore tributary habitat in the future to meet the mitigation goals of the Fish and Wildlife Program.

Chapter 2. Habitat Action Planning and Prioritization

Initially, the Program focused on the mainstem Columbia River, and early habitat restoration projects targeted a few specific reaches of tributary streams. Gradually the Program recognized that projects needed to increase the spatial scale of restoration to be effective. However, larger scale projects often lacked coordination and integration to achieve Program goals and objectives and required a landscape framework for habitat restoration. A major advance was the Council's decision to develop subbasin plans.

Retrospective of Planning and Prioritization Methods

Historically, project priorities were based on the most critical causes of degradation, potential biological responses, willing landowners and management agencies' priorities, implementation logistics, and financial constraints. Landscape perspectives of watershed assessments and application of life cycle models created contexts for planning and prioritizing habitat restoration that encompassed larger spatial scales and the full life history of salmon and steelhead.

Limiting factors were identified for local sites or reaches. In general, an ecological factor can be viewed as limiting if it limits the performance of populations, communities, or the ecosystem. In a population targeted for restoration, it is important to identify the limiting life stages, processes, and factors. Limiting factors analysis has evolved substantially over the last 40 years and is now a key component of restoration planning. To create a consistent analysis of environmental constraints on salmonid populations across subbasins and to assess historical and current watershed conditions, the Council supported subbasin planners' use of analytical tools, such as Ecosystem Diagnosis and Treatment (EDT).

Life-cycle models are important quantitative tools for identifying limiting factors and expected responses for planning and selection of habitat restoration in the Columbia River Basin. Analysis of density dependence is a critical component of habitat restoration planning and prioritization. Improving local freshwater habitat may not increase overall carrying capacity if factors outside the tributaries limit survival. The ISAB's Density Dependence Report (2015-1), concluded that "*The status of salmon populations or success of restoration actions cannot be fully evaluated without considering the effects of fish density*."

A major challenge for subbasin planning is maintaining up-to-date information on salmon and steelhead abundances, habitat conditions, responses to habitat and management actions, changing land uses, and climate change. Since the subbasin plans were developed, new watershed assessments that take advantage of new technology, link directly to RM&E data, and incorporate life cycle models are used in restoration project design and to assist in planning and implementation.

The landscape and coastal dynamics of the lower Columba River and its estuary require attention to unique processes and challenges for habitat restoration. Changes in the hydrology of the Columbia River caused by the hydrosystem also contribute to habitat change and degradation in the estuary.

An important strategic advancement in the Program's efforts to restore tributary habitats has been the evolution toward greater complexity and integration of restoration actions within individual projects and in coordinated projects. Watershed assessments and life cycle models have created contexts for planning and prioritizing habitat restoration that encompass larger spatial scales and the full life history of salmon and steelhead. These approaches create valuable tools for understanding longer term and larger scale responses to habitat restoration.

Since habitat restoration began in the Program, the paradigm guiding restoration has shifted from one based on restoring structure to one based on restoring processes. Few of the Program's habitat restoration projects meet the full description of process-based restoration.

However, the proportion of projects that are designed to restore impaired processes has increased since the Council revised the Program in 2000 to emphasize ecosystem function (NPCC 2000). Watershed coordination and assessment programs and Intensively Monitored Watersheds (IMWs) represent the most rigorous application of process-based restoration and a major future direction in habitat restoration in the Program.

Strategic guidance has been increasingly employed by management agencies in the Pacific Northwest since the Program was first established and is now used by numerous restoration efforts in the Program. Strategic guidance has occurred in a large part as a way to prioritize restoration actions. We do not recommend specific plans, but we strongly encourage the use of strategic plans.

Recommendations

- The ISRP recommends that analyses of limiting factors and density dependence continue to be critical components of habitat restoration planning and prioritization.
- For projects that lack necessary information or support for detailed site-specific modeling, the ISRP recommends exploring the potential use of habitat and life-cycle models for strategic analyses and general restoration planning. Strategic analyses would include coarse screening of different habitat restoration options to then explore promising approaches more closely. One approach would be to develop a generic Columbia River Basin template or library of templates for the existing models and software. With some modifications for each application, these could be implemented for planning purposes, while recognizing their limitations.
- The ISRP recommends more explicit incorporation of process-based restoration and the assessments necessary to apply it in planning and prioritization.
- Differences in watershed- and landscape-level assessments for restoration planning and prioritization provide test cases for alternative approaches and new lessons for future planning. The ISRP recommends that the Program determine where watershed-level assessment and coordination approaches are effectively guiding restoration and develop additional subbasin assessments to better represent the diversity of landscape types in the Basin.
- Projects that are not part of a larger integrated landscape program and do not have the capacity to use planning tools like Atlas are often at a disadvantage. The Program should

develop enhanced planning tools and strategic guidance to support these projects.

Chapter 3. Methods of Habitat Restoration and Protection

Methods of restoration have evolved in the Columbia River Basin over the Program's 43 years. A major objective in the retrospective review is to identify 1) where we know enough about particular methods to de-emphasize monitoring in the future and 2) where lack of information, risk, and uncertainty require continued or increased monitoring and evaluation. Habitat restoration projects vary greatly in how they implement different types of actions, but several major types of methods are implemented throughout the Columbia River Basin. We reviewed eight major methods — barrier removal, floodplain reconnection, large wood addition, riparian planting and fencing, estuary habitat restoration, flow augmentation, cold-water habitat restoration, and wildlife habitat restoration.

Restoration Methods

Barrier removal

Removal of barriers to upstream fish passage is among the most successful types of habitat restoration projects. This conclusion is based on strong evidence that replacing road crossings to design standards increases access for fish, and that after barrier removal densities of salmon and steelhead upstream often are similar to those downstream of removed barriers.

However, despite the increased access, much fish habitat upstream from former barriers is often unsuitable for colonization because channels are too narrow and steep. Success of barrier removal depends on several factors, including size of source populations, condition of upstream habitat (e.g., channel gradient), presence of other barriers upstream, presence of resident fish populations, and use of appropriate design standards.

Floodplain reconnection

As the spatial scale of habitat restoration has increased, projects have focused on reconnecting floodplains and off-channel habitats. These are typically large, complex projects requiring extensive planning and permitting. In general, studies of reconnecting floodplains and off-channel habitats show rapid recolonization of the newly accessible habitat and other benefits such as higher food production than main-channel habitats, which supports faster growth of juvenile salmonids.

The greater size and complexity of floodplain restoration projects create challenges for assessing effectiveness because adequate control sites are scarce. Nevertheless, there is substantial evidence that within about a decade these projects can increase habitat features important to salmonids and increase abundances of juvenile salmon and steelhead.

Restoration of Habitat Complexity using Large Wood

Addition of wood to streams to provide habitat for fish without restoring riparian forests or upslope sources of long-term input of wood is an example of structural restoration rather than process restoration. Over the last 40 years, restoration projects have greatly increased the amounts of wood added, included both the active channel and floodplain in wood restoration, increased complexity of wood accumulations, and conducted associated riparian restoration.

Studies of individual wood restoration structures show that they increase foraging locations for salmonids, and that fish use them. Results of wood restoration measured at the reach scale during summer, including those in the Columbia River Basin and elsewhere, show substantially increased abundances of anadromous and resident salmonids.

In contrast, studies of wood restoration in IMWs at the watershed scale for whole populations showed variable responses, with about half reporting increases in juvenile salmonids or smolts. A few reported increases in adult returns, although this metric is influenced by many factors beyond the watershed. These studies concluded that responses of fish require many years to decades to evaluate. A key problem is the large amount of wood that needs to be added to illicit a response by fish at the watershed scale.

Riparian restoration

Loss of riparian forests is one of the major causes of stream warming, and stream temperature is the main form of water quality impairment in the Pacific Northwest. Some models in the Columbia River Basin have indicated that the temperature benefits of riparian restoration would potentially offset increases projected for regional warming.

One of the major challenges for assessing the effectiveness of riparian restoration is the time required to restore the characteristics of mature riparian vegetation and the limited age of most riparian restoration projects. Short-term changes do not reflect the ecological objectives for restoration, and recovery of riparian vegetation and aquatic habitat is related to the age of the restoration project. Most studies we reviewed evaluated short-term responses to riparian restoration, highlighting the need for coordinated long-term studies of riparian restoration rather than short-term monitoring and evaluation.

Animal exclosures to restore riparian vegetation and aquatic habitat provide mixed results, and maintaining exclosures is challenging. Livestock exclusion may successfully restore riparian plant communities and reduce bank erosion, but exclosures may not be effective for restoring native plant communities where restored reaches are short relative to adjacent degraded reaches or where aggressive invasive vegetation, such as reed canary grass, is present. Nevertheless, results from outside the Basin indicate that restoring riparian vegetation provides substantial inputs of terrestrial invertebrates that feed salmonids and can increase their abundance.

Dike breaching and tide gate management

Since restoration in the Columbia River Estuary in the early 2000's, most estuary projects have focused on restoring hydrologic connectivity by breaching or eliminating dikes and berms. This is illustrated by the removal of dikes in an Oregon coastal estuary that resulted in recovery of marsh vegetation and wetland morphology. Chinook and coho juveniles occupied the restored marshes and each species re-expressed four different life-history types that enhanced population resilience. The abundance of insect prey also increased after restoration.

One of the main shifts in restoration paradigms was recognition that the estuary boundary should extend to the base of Bonneville Dam and that restoration should also extend to this point, especially because listed populations were found in all parts of the estuary, not just the most saline and tidal portion.

Flow augmentation

Many instream flow restoration projects in the Program and IMWs are water transfer and conservation agreements, and several studies documented measurable increases in fish populations, habitat connectivity, and other measures of aquatic health. One study also showed increased returns and recruitment of natural-origin steelhead following flow augmentation.

Despite improvements in physical habitat, fish population responses often are not immediate. Time required for ecological recovery and the influence of other factors may delay measurable benefits.

Many projects lacked adequate duration or scope to observe meaningful population-scale outcomes. Limited population responses in some tributaries also showed less-than-expected increases in fish populations due to other limiting factors like habitat degradation and predation.

Cold-water refuges

Stream temperature is a widespread and increasingly dominant limiting factor for salmon and other cool-water fishes in the Columbia River Basin. Cold-water habitats provide critical refuges for native salmonids and can reduce effects of pathogens and parasites, but responses to restoration have varied among locations and species.

Shade and hyporheic exchange dampen diurnal temperature cycles, but they alter seasonal temperature cycles differently. Hyporheic exchange warms surface waters in winter, but shade has little effect. In summer, both shade and hyporheic exchange result in cooler stream temperatures, although the effects of shade are generally greater.

The effect of hyporheic exchange on stream temperatures depends on the relative temperatures and volumes, stream depth, and other factors. Field studies of hyporheic exchange may show little effect on stream temperatures if the hyporheic zone is small relative to the volume of the surface water, hydrologic exchange rates are low, net heat exchange between the channel and streambed is low seasonally, or turbulence in the surface water causes rapid mixing. However, even small volumes of moderated temperatures can have large ecological effects.

Process Based vs. Structural Restoration

ISRP and ISAB reviews have called for restoration of habitat processes as well as structures, and the proportion of habitat restoration projects that address biophysical and ecological processes rather than habitat structure has increased. Process-based restoration attempts to restore physical and ecological processes to recover ecosystem productivity and diversity. In contrast, structural-based or engineered restoration attempts to recreate the desired physical structure of stream channels, floodplains, and riparian zones without necessarily addressing the processes that limit populations.

Many habitat restoration projects have attempted to also restore critical physical and ecological processes. However, most of these would not be considered process-based restoration because they do not fully evaluate the range of processes or consider restoration of multiple processes and their interactions.

Large rivers and watersheds that have been extensively altered are major restoration challenges because it is difficult to scale restoration to match the complex and spatially extensive habitat modifications made over an extended period.

Project complexity, spatial extent, and degree of attention to both process and structure have increased markedly since the 2000 Fish and Wildlife Program’s focus on ecosystem function. The most complete examples of process-based habitat restoration in the Program are spatially explicit watershed assessment programs for subbasin-scale restoration.

Habitat restoration for resident fish

Much of the habitat restoration in the Columbia River Basin focuses on anadromous salmon and steelhead.

However, resident fishes are also important, and the Program has funded many projects for resident fish in both the anadromous zone and in blocked areas above the mainstem dams.

Overall, there are likely to be more similarities than differences in the effects and outcomes of habitat protection and restoration for resident salmonids compared to anadromous salmonids. For example, a 30-year basin-wide project in an Upper Columbia River subbasin (not funded by the Program) showed that coordinated restoration of habitat complexity, connectivity, and flows increased abundance of native cutthroat trout and bull trout.

Many salmonids classified as resident, such as rainbow, cutthroat, and bull trout, nevertheless include migratory life histories that require habitats dispersed throughout riverscapes often separated by distances up to 100 km (62 miles). Sustaining robust populations of these large migratory fish can provide resilience that reduces effects of nonnative salmonids.

Populations of resident salmonids that are hampered by nonnative fishes can require isolation to persist. Tradeoffs between isolating resident salmonids above barriers and thereby preventing the expression of migratory life histories that contribute to their resilience will require careful analysis and consideration to select appropriate management strategies.

Wildlife Restoration

Approaches for mitigating the effects of the hydrosystem on terrestrial wildlife in the Columbia River Basin differ in many ways from the methods for planning, implementing, and monitoring mitigation actions for fish and aquatic ecosystems. Unlike restoration of fish habitats in the Basin, restored wildlife habitats are out-of-place, occurring in different locations than the original habitat. Another difference is that although many wildlife acquisition and restoration projects were intended to protect or restore “in-kind” habitat types used by focal species that were impacted by the hydrosystem, many protected or restored wildlife habitats differ ecologically from the original lost habitat (“out-of-kind”), especially when upland habitats are substituted for lost riparian and wetland habitats. Additional major challenges for wildlife habitat restoration in the Fish and Wildlife Program are spatial extent and connectivity of restored habitat.

Monitoring of wildlife habitat restoration projects is frequently qualitative and limited, reflecting a “build it and they will come” approach. While such focus on implementation can have local benefits, it limits our ability to understand outcomes at larger scales and learn from experience.

Wildlife habitat mitigation has some aspects that are more advantageous than fish habitat mitigation. Ocean survival and long-distance migration confined to the Columbia River network are not major factors limiting the success of most wildlife habitat restoration or land acquisition projects.

Although wildlife habitat restoration and fish habitat restoration differ in many ways, they can have synergistic effects, enhancing the success of each other. Greater identification and planning for synergistic outcomes of habitat restoration projects for both fish and wildlife offer potentially increased benefits for the Program.

Recommendations

- Although our focus in this chapter is on restoration methods, we emphasize that protection is also important and should be considered in tandem with restoration, as recommended in past ISRP and ISAB reports.
- Process-based restoration should continue to be emphasized over structural-based approaches alone, a point consistent with past ISAB and ISRP recommendations.
- Of the 8 restoration methods we reviewed, removing barriers to restore connectivity and reconnecting side channels and floodplains, including in the estuary, have a strong likelihood of positive benefits for anadromous salmonids.
- Barrier removal, flow augmentation, and some wood additions are likely to achieve their intended outcomes in a short period of time (i.e., 5-10 years). There is substantial uncertainty about the time required for restoration of riparian forests, and connectivity and complexity of floodplains. In addition, the persistence of restored cold-water refuges is variable and highly uncertain. Current monitoring of these latter habitat restoration methods has been too short to determine the outcomes.
- The ISRP recommends that the Program encourage synthesis by those conducting long-term projects like Intensively Monitored Watersheds and continue to fund those providing long-term data to answer key current questions, and new questions that will arise in the future.
- The ISRP recommends that the Council develop a coordinated study to monitor and evaluate the long-term effectiveness of floodplain reconnection, riparian forest and meadow restoration, and creation and restoration of cold-water refuges.
- Consistent with language in the 2014 Fish and Wildlife Program, the ISRP recommends that the Council continue to pursue and support projects that increase connectivity

between wildlife conservation areas, coordinate with fish restoration and protection projects to further promote terrestrial and aquatic habitat connectivity, and encourage RM&E of habitat and species responses to mitigation actions, especially to evaluate outcomes at larger scales than individual projects. Specifically, the ISRP recommends that the Council identify the major types of wildlife restoration actions that require effectiveness monitoring in the future and develop an approach to implement the monitoring as part of the Tributary Habitat RM&E Strategy.

Chapter 4. Research, Monitoring, and Evaluation

Research, monitoring, and evaluation (RM&E) have been fundamental components of the Fish and Wildlife Program since it began in 1982. The Council made multiple concerted efforts to address deficiencies in monitoring and evaluation in the Program, which resulted in improvements. The latest advance is the recently developed Columbia Basin Tributary RM&E Strategy (BPA/BOR 2022) that provides high-level guidance as to what to monitor.

Development and implementation of RM&E in the Columbia River Basin faces several major challenges. Costs and time associated with monitoring and evaluation limit available resources and constrain the work of actually restoring habitat. Monitoring efforts have often not been prioritized, designed, or funded at a level necessary to demonstrate whether projects were effective or not. Coordination and information sharing and application are major challenges in monitoring and evaluation of habitat restoration projects. Nonetheless, targeted and effective RM&E projects are crucial for documenting effects, adaptively managing outcomes of habitat restoration, and ultimately maximizing benefits and reducing costs.

The ISAB's 2024 Review of the Fish and Wildlife Program (ISAB 2024-2) found that the Program currently lacks but would benefit from fundamental integration of monitoring and evaluation; and, although the Tributary Habitat RM&E Strategy provides useful guidance for RM&E at a site or reach scale, approaches for coordinated monitoring and evaluation for geographical areas or subbasins are needed.

The Integrated Status and Effectiveness Monitoring Program initiated in 2003 and the Columbia Habitat Monitoring Program initiated in 2011 (ISEMP/CHAMP) provided rigorous systematic measures of major habitat components in representative locations in the Basin through 2019. Those projects were a major step in developing consistent, systematic habitat monitoring, and models to project those results across broad spatial scales. The Action Effectiveness Monitoring Project (AEM) developed research to determine the effectiveness of specific restoration methods implemented at reach scales, and the results of AEM are included in this review. The Program needs to consider the history of basinwide efforts, such as CHaMP, ISEMP, and AEM, and critically explore objectives for which they succeeded and how and why they fell short of their intended outcomes.

The Program and its co-managers have taken many steps to increase consistency in the habitat monitoring and evaluation process in the Columbia River Basin. The Council made substantial improvements to monitoring and evaluation through coordinated programs such as the Coordinated Assessments Partnership, Columbia River Basin Coordinated Assessment Data Exchange, and MonitoringResources.org of the Pacific Northwest Aquatic Monitoring Program.

Columbia Basin Tributary Habitat RM&E Strategy

The Tributary Habitat RM&E Strategy (BPA/BOR 2022) represents the most recent and arguably most significant attempt to develop a coordinated and effective M&E strategy. The Strategy describes a consistent and logical approach to habitat RM&E implementation and reporting to assess the physical and biological benefits of restoration actions. Most important is that it was developed through a large collaborative effort of many tribes and government entities in the Columbia River Basin.

The Tributary Habitat RM&E Strategy proposes that many restoration action types do not require effectiveness monitoring. The Strategy's evaluation of restoration literature concluded that evidence is sufficient to assume that most types of projects worked and that further verification of effectiveness with more monitoring is not warranted, a conclusion the ISRP does not fully support. The Strategy concluded that the greatest uncertainty was with the effectiveness of floodplain reconnection/enhancement and channel realignment. The ISRP agrees that the science is sufficient to conclude that certain restoration actions are generally successful in providing benefits to fish and wildlife, whereas there is more uncertainty about outcomes for other restoration methods like floodplain reconnection (see summary for Chapter 3, above).

The Strategy recommends that monitoring programs be designed so that information collected at the project or reach scale can be extrapolated to larger scales. However, there is limited guidance on how such upscaling might be accomplished, and it is uncertain whether some types of information can be scaled up, so more specific guidance will be needed. The Tributary Habitat RM&E Strategy would benefit from a thorough description of how it will be "rolled out" and implemented. It also would create a stronger framework for future RM&E if there was a method for tracking the Strategy's progress and success once it is being used.

Study Designs for Effectiveness Monitoring

Although implementation and compliance monitoring are typically straightforward, monitoring the effectiveness of habitat restoration for increasing survival and abundance of fish or wildlife populations at relevant scales of space and time poses many challenges. Meeting the requirements of scientific experiments for randomization, replication, and controls is increasingly difficult as the experimental units become larger and more diverse, and responses to treatments take more time to manifest. Responses of fish to habitat restoration vary over time and may take years to reach their full effect, as has been found for the Intensively Monitored Watersheds. Mortality occurs at different phases in the life history of the fish, and there may be compensation at different stages creating complexity in the spatial and temporal responses.

The most commonly prescribed method for measuring effects of environmental impacts, such as habitat restoration, is a before-after, control-impact (BACI) design. Within the BACI framework, staircase designs that stagger habitat restoration treatments in time can account for the time needed to conduct restoration across watersheds, address bias from unplanned environmental perturbations, and have been demonstrated to be effective.

Responses of fish to habitat restoration in tributaries of the Columbia River Basin (e.g., the Yakima River) occur at the large spatial scales over which entire fish populations carry out their life cycles. When experiments are conducted at the smaller scale of reaches, fish movement between proximate treatment and control sites can undermine the analyses, but this can be ameliorated by spacing them appropriately if movements are measured. Fish movement is an under-appreciated process driving responses of fish abundance and production to habitat treatments. Movement can increase fish abundance rapidly in response to habitat restoration, in addition to any increases in survival. Despite concerns that habitat restoration could simply concentrate fish leading to no net increase in abundance or production, this seems unlikely in most cases given that any habitat vacated would be quickly filled by other fish that otherwise would have died or emigrated (i.e., increased density-dependent survival).

An additional frontier in the analysis of habitat restoration is the opportunity to synthesize information across projects. For example, evidence from responses in any single IMW often is insufficient to draw strong conclusions from available time series data. However, recently developed statistical methods based on hierarchical state-space models allow "borrowing" information across datasets to provide a weight of evidence to assess the strength of responses of fish to management actions.

Recommendations

- Use efficient designs – When new monitoring efforts are planned, there is a great opportunity to identify clear and specific questions, plan the biological, spatial, and temporal scales of monitoring, and use experimental designs such as the staircase design that lower bias and are efficient despite the expected level of variation.

- Use state-of-the-art statistical analyses – Recently developed statistical analyses allow use of fish recapture information gathered by different methods through time and across whole watersheds (e.g., the Barker model), and synthesizing information from disparate sources across many studies (i.e., hierarchical state-space models). Such analyses can extract new information from multiple studies such as Intensively Monitored Watersheds.

- Effectiveness monitoring has provided evidence that various types of habitat restoration can increase fish abundance, survival, or productivity. However, what is needed next is to understand how much restoration is needed to produce biologically meaningful effects (i.e., a dose-response) and under what conditions such effects can occur (i.e., geomorphic, hydrologic, and ecological contexts). As examples:
  - How much large wood must be added, and how, to elicit a 25% increase in smolt production within 20 years in tributaries east of the Cascades versus those to the west?
  - How much riparian restoration in a process-based restoration project along a tributary is needed to increase wood loads within 100 years to a threshold that supports a given density of juvenile Chinook salmon per kilometer?

- Although implementation and compliance monitoring are expected for every project, as the Tributary RM&E Strategy indicates, rigorous effectiveness monitoring requires substantial time, technical and financial resources, and expertise. Effectiveness monitoring should be undertaken only if these resources are available for decades-long monitoring that will be required to answer questions at appropriate scales of space, time, and biological organization.

- To measure whether, for example, riparian restoration or floodplain reconnection is effective at increasing fish abundances, survival, and production across a range of different basins and habitat conditions will require a coordinated design that is stratified, hierarchical, and planned to be conducted over many decades.

- Planning such an effort is beyond the scope of this report, and will require expertise of managers, fish ecologists, and statisticians. Such an interdisciplinary team would be needed to oversee such an effort and be directed by a strong leader who could organize participants and information, and share and communicate results effectively.
- Data and lessons learned from past efforts such as AEM, CHaMP-ISEMP, and IMWs must be synthesized to provide baseline information about spatial and temporal variability of key components to be monitored.
- Monitoring of critical long-term restoration methods could be coordinated for selected projects that meet monitoring design criteria, fit within the hierarchical framework, and are likely to persist long enough to measure long-term outcomes.

- A goal of such a rigorous, hierarchical, long-term monitoring design is to generate statistically sound information to show how effectiveness varies with amounts of restoration and across different habitat conditions in different subbasins. Such information should be in a form that can be integrated (i.e., “rolled up”) to the Columbia River Basin scale, and show relevant status and trends for key habitats and populations.
- To date, IMWs have provided important information at appropriate spatial scales that match management planning. This information needs to be synthesized across sets of IMWs to determine what has been learned, which questions have been answered, which remain unanswered, which are not answerable, and what monitoring must be continued or stopped.
- Building on lessons learned from past comprehensive RM&E projects (ISEMP, CHAMP, AEM) and the Tributary Habitat RM&E Strategy, the Program should create a hierarchical monitoring and evaluation framework, identify the major components of its RM&E program, establish the clearly defined RM&E relationships among projects within major subbasins and geographic areas, and ensure the transfer of information among those components, as recommended by the

ISAB in its review of the Fish and Wildlife Program (ISAB 2024-2).

Chapter 5. Intensively Monitored Watersheds (IMWs)

Two challenging questions about habitat restoration for the Fish and Wildlife Program are: 1) did restoration improve habitat at the watershed scale and increase or stabilize viability of fish populations, and 2) what mechanisms caused these improvements? A series of IMWs from California through Washington were established to address these questions across the broadly overlapping distributions of major Pacific salmon and steelhead populations.

IMWs evaluate a set of habitat restoration treatments designed to reduce what are judged to be the factors limiting fish populations in a given watershed. During the initial establishment or early stages of an IMW, identification and ranking of priority limiting factors requires extensive discussion, consideration of multiple types and sources of data, and inclusion of multiple interested parties.

Life-cycle models for the targeted fish populations, followed by analysis of limiting factors to help guide project planning and selection, are critical components of such integrated assessments. A key feature of life cycle models is the integration of stage-specific, stock-recruitment relationships, which underscores the importance of density dependence and capacity as key limitations to consider when planning and evaluating habitat restoration.

Although no detailed analysis has been conducted across the entire set of IMWs, most reported positive responses in abundance, survival, or growth of juvenile parr or smolts to treatments that often combined barrier removals with large wood additions. In many cases responses of specific metrics (e.g., growth) for certain life stages were equivocal, but few were negative.

A key lesson from the IMWs is the extensive time needed to conduct successful restoration, and for subsequent flow events to cause geomorphic changes in habitats that influence fish populations. Another key lesson is that detecting change in fish populations across watershed scales amid the background of annual variability requires measuring responses over many salmon generations. Investigators noted that two key factors contributing to the disappointing responses by salmonid populations to habitat restoration throughout the region are insufficient resources to address habitat damage and the inability to identify the most important factors limiting fish populations.

Recommendations

- Each IMW should be required to synthesize their information, in terms of response of habitat and fish to the restoration actions implemented.
- The ISRP recommends that the Fish and Wildlife Program support an integrated analysis of habitat

restoration results across the network of IMWs in the region to answer broad questions about treatments and responses for salmon, steelhead, and other important fish across the Pacific Northwest.

- The ISRP recommends that the Council review how well the existing IMWs represent the diversity and distribution of landscapes and fish and wildlife resources of the Columbia River Basin. The Program should strengthen the existing network of IMWs by considering new IMWs to address unresolved questions about habitat restoration effectiveness for portions of the Basin, river types, and restoration methods that are underrepresented.

Chapter 6. Confounding Factors

Various factors can affect planning and implementation of restoration projects and alter their outcome. We briefly summarize the potential for climate change, landscape change, ocean change, nonnative species, predation, supplementation with hatchery fish, dams, water quality, density-dependence, and logistical complexities to have unanticipated effects on the outcomes of restoration. These confounding factors can interact among themselves, operate at various scales of space and time, can occur intermittently or persistently during the restoration process. Some are related to historical and ongoing habitat degradation and changes to the landscape and some are emerging concerns. Projects vary considerably in how they consider confounding factors and develop alternatives for responding or adapting to different outcomes resulting from them.

Many confounding factors have affected ecosystems in the past and will continue to affect them in future decades. Streams and rivers will continue to change geomorphically, hydrologically, and ecologically due to the influence of past human actions and natural changes (e.g., flood, fire, landslides). Climate change is an ongoing process, the effects of which will depend on how global warming occurs.

The challenge for tributary habitat restoration is anticipating future river system conditions and restoring processes that will create ecosystem benefits under future conditions, not present conditions. Restoration will often fail if we do not understand and address these interactions at the outset. Examples include changes in stream and estuary temperatures, and effects of sea level rise on estuary habitat.

Recommendations

- The ISRP recommends the Program help develop and employ tools to forecast future conditions toward which practitioners can plan. For example, models can identify thermal refuges for anadromous species or opportunities to enhance stream flows where restoration could be targeted. Models can also help identify key areas to protect.

Chapter 7. Exemplary Projects

ISRP reviews have often identified exemplary projects based on multiple performance review criteria. For this report, we identify specific attributes of exemplary projects that are applicable at a local scale and those that could apply at broader scales such as subbasin or watershed. We focus on and highlight a few exemplary projects of three types of tributary habitat restoration from recent categorical reviews because they best reflect advancements in habitat protection and restoration planning, implementation, and monitoring and evaluation.

Elements and Characteristics of Exemplary Projects

Projects that have been recognized as exemplary or outstanding in recent ISRP reviews displayed the following elements and characteristics, although not all elements were necessarily evident in each exemplary project.

- Consistent with and contributing to the Council's Fish and Wildlife Program goals and objectives
- Based on sound scientific principles and strategic guidance
- Guided by clear goals, SMART objectives, and quantitative desired outcomes
- Identified and addressed key habitat limiting factors and threats
- Used state of the art and innovative planning, implementation, and M&E approaches
- Accomplished objectives on schedule with effective action implementation
- Showed strong collaboration and effective partnerships
- Demonstrated effective integration of restoration methods and an appropriate level of M&E
- Utilized clear and effective adaptive management processes at the project level and at broader management scales
- Considered climate change and other emerging threats in developing actions
- Effectively shared results and lessons learned with other projects, agencies, and the public with timely reports, publications, public outreach, and presentations.

Chapter 8. Concluding Remarks

Our retrospective review of habitat restoration in the Fish and Wildlife Program found considerable improvements over time in many Program elements especially in the planning and prioritization of projects and restoration methods. Application of RM&E results contributed to the improvements in planning and restoration methods. However, to evaluate progress towards meeting the Program's mitigation goals and fully understand the benefits, RM&E still needs to improve, especially in evaluating habitat restoration at watershed and population spatial scales. Not surprisingly, the Program faces many future challenges, especially factors causing changes to the landscapes that sustain fish and wildlife such as climate change and human population growth and development.

ISRP Habitat Retrospective Report

1. Introduction

1.1. Evolution of Habitat Protection and Restoration in the Fish and Wildlife Program

The Northwest Power Act of 1980 directs the Northwest Power and Conservation Council to develop and adopt a Fish and Wildlife Program (henceforth "the Program") to "*protect, mitigate and enhance fish and wildlife, including related spawning grounds and habitat*," affected by the development and operation of hydrosystem facilities in the Columbia River and its tributaries. To establish goals for the Program in the 1980s, the Council developed quantitative estimates of the historical returns of adult salmon and steelhead and the losses attributed to the hydropower system. They originally estimated that historical annual returns of salmon and steelhead were 10 to 16 million fish, and the estimate of annual losses caused by the hydrosystem and blockage of upper portions of the Basin was 5 to 11 million fish, roughly half to two-thirds of the returning adults (Homel and Bach 2024, also see ISAB 2024-2). These estimates give a sense of the magnitude of the losses, challenges for mitigation, and the need for implementing multiple strategies to mitigate the losses.

Since the Program began in 1982, habitat protection and restoration have been important parts of efforts to mitigate the effects of the Columbia River Basin hydropower system. The Program has provided the framework for planning and selecting projects to restore and protect habitat for affected anadromous and resident fish and wildlife, and particularly anadromous salmon and steelhead. During the first decade of the Program, most efforts focused on improving passage of juvenile and adult salmon and steelhead through the mainstem dams and construction of hatcheries to mitigate for lost natural production (Homel and Bach 2024). Habitat restoration was limited to a few projects in tributaries, and the Program initially focused on the Yakima River subbasin for habitat restoration and hatchery supplementation. However, over time the emphasis shifted to include tributary river, lake, and estuary habitats. This increase in scope occurred, in part, because it became clear that modifications to passage at dams and operation of the hydrosystem to improve fish survival could not fully mitigate for system impacts. In addition, fisheries biologists and managers increasingly recognized the importance of high-quality tributary habitat and associated natural processes for recovery and persistence of salmonid and other native fish populations in the Columbia River Basin.

By the late 1980s, the need for a broader landscape framework was recognized and led to two key developments. In the first, the Program called for developing plans for 57 major subbasins in the Columbia River basin. Second, in 1988 the Program designated Protected Areas containing 70,800 km (44,000 miles) of streams and rivers in the basin to prevent development of additional hydroelectric dams. The Protected Areas are an important habitat protection component of the overall conservation actions that complement the benefits achieved through habitat restoration.

The Council amends the Program on a regular basis and in 2000 it expanded the vision, created a scientific framework, and developed scientific principles tied to ecosystem function that apply to the entire Columbia River Basin (NPPC 2000-19). It identified three geographic scales for planning and project implementation—the basinwide scale, ecological provinces, and subbasins. This vision recognized the need to improve habitat conditions and production of fish and wildlife in the tributaries as well as the mainstem river. Essentially, this emphasized the Program's commitment to restore freshwater habitat throughout the Basin to help meet its mitigation goals. The 2000 Program also called for developing plans for each Columbia River subbasin to identify priorities for habitat restoration and other mitigation actions based on assessments of limiting factors and desired future conditions. Subbasin Plans for the 57 major watersheds in the Columbia River were completed and adopted by the Council between 2004 to 2011.

The Vision statement for the 2014 Fish and Wildlife Program highlights the role of habitat restoration in mitigation for the effects of the hydrosystem on fish and wildlife:

> "*The vision for this program is a Columbia River ecosystem that sustains an abundant, productive, and diverse community of fish and wildlife, supported by mitigation across the basin for the adverse effects to fish and wildlife caused by the development and operation of the hydrosystem. This envisioned ecosystem provides abundant opportunities for tribal trust and treaty-right harvest, non-tribal harvest, and the conditions that allow for restoration of the fish and wildlife affected by the construction and operation of the hydrosystem.*
>
> *The vision will be accomplished by protecting and restoring the natural ecological functions, habitats, and biological diversity of the Columbia River Basin. Where this is not feasible, other methods that are compatible with self-sustaining fish and wildlife populations will be used, including*

certain forms of production of hatchery fish. Where impacts have irrevocably changed the ecosystem, the program will protect and enhance habitat and species assemblages compatible with the altered ecosystem."

The Program established Scientific Principles, Goals, Objectives, and Strategies to "*rebuild healthy, naturally producing fish and wildlife populations adversely affected by the construction and operation of hydroelectric dams in the Columbia River Basin.*" The Strategies emphasize "*protecting quality habitat and mitigating the Columbia River Basin ecosystem through regeneration of natural processes, rather than through a primary reliance on technological solutions*." The Habitat Sub-strategy highlighted that "*protecting existing quality habitat is as important as enhancing degraded habitats*" and identified four important principles:

- Build from strength
- Restore ecosystems, not just single populations
- Use native species wherever feasible
- Address transboundary species in Canada

The ISAB recently reviewed the 2014 Fish and Wildlife Program and the 2020 Addendum (ISAB 2024-2) and supported these Scientific Principles and Strategies. Further, the ISAB made suggestions for strengthening them in the future Program revisions. Reviews of the Program in 2018 (ISAB 2018-3) and 2024 emphasized that the need for critical information about habitat protection and restoration remains a central requirement of the Program and that a rigorous RM&E program is essential for effective future design and implementation of habitat restoration.

Habitat protection and restoration are now fundamental components of efforts to achieve the Program's goals and offset the continued impacts of the hydrosystem and ongoing habitat changes in tributaries, the estuary, and the mainstem. Habitat restoration and protection projects for wildlife and resident and anadromous fish are underway in all major subbasins in the Columbia River Basin. They represent a key component of not only the Fish and Wildlife Program and its subbasin plans but also Endangered Species Act (ESA) mandated recovery programs and other management plans.

Over the last several decades, habitat protection and restoration projects have improved significantly, for a variety of reasons including scientific and technological advances, better data management, use of process-based protection and restoration strategies, and learning what has worked and not worked. One notable improvement is the increased use of **S**pecific, **M**easurable, **A**chievable, **R**elevant, and **T**ime-bound

(SMART) objectives that have strengthened projects and provided better benchmarks to gauge progress, assess effectiveness, and guide adaptive management decisions. Planning has become increasingly rigorous with, for example, various types of models being used to identify projects and areas to target restoration. In addition, there have been significant advances in research, monitoring, and evaluation. Implementation of intensively monitored watersheds (IMWs), the Integrated Status and Effectiveness Monitoring Program and Columbia Habitat Monitoring Program (ISEMP/CHAMP), Bonneville Power Administration (BPA) Project Action Effectiveness Monitoring Program (AEM), Oregon Plan Habitat Monitoring Protocols, other assessment approaches, and full life-cycle survival and production models have improved the scientific foundation for evaluating responses of fish and habitat to restoration.

Notwithstanding this evolution and improvement of approaches, it was clear to the ISRP from our review of projects funded through the Program that progress in habitat restoration has been inconsistent across species, geographic scales, and subbasins. One recurring theme through all past ISRP reviews and retrospective reports has been the inconsistent and often inadequate monitoring and evaluation of the Program's habitat restoration projects. The ISRP concluded that additional summary and synthesis of approaches being used for project planning, project implementation, and monitoring and evaluation of habitat restoration and protection would be helpful. Although several synthesis reports and guidance documents have recently been completed, the ISRP felt that documenting the evolution of habitat restoration and its project planning, project implementation, and RM&E could be beneficial to the Program and result in improvements in project results.

Importance of habitat protection

Although our focus in this report is mostly on restoration, we emphasize that protection is also important and should be considered in tandem with restoration (ISAB 2018-1, 2024-2). Without protection, restoration may not compensate for ongoing habitat degradation. For example, Bilby et al. (2024) recognized that without an adequate protection program to slow the pace of anthropogenic changes on the landscape in Puget Sound, there likely would be no net benefit of restoration. In the face of increasing human populations, changing land uses, and climate change in the region, protection that safeguards important aquatic habitats reduces future deterioration of the ecosystem's ability to support fish and wildlife populations.

Restoration is designed to restore physical and ecological processes and to reverse a portion of past habitat degradation that limits the recovery of affected populations and communities. Many habitat restoration actions (e.g., riparian forest plantings) require decades to centuries to recover full ecological function. Protection can be more efficient and cost effective than restoration in the long term, but rising costs of land and water resources must be considered as well. Effective conservation and recovery of tributary habitats require a well-integrated approach of habitat protection and restoration.

The Council has long recognized the importance of protection. In 1987, the Program designated Protected Areas that would not be further developed for hydroelectric systems. Other protection strategies could be implemented in the future. The Strongholds Strategy of the 2014 Fish and Wildlife Program recognizes the importance of protecting intact, healthy habitats that support existing populations. While this emphasis on strongholds is a good strategy, the ISRP recommends additional protection efforts, some of which might be beyond the Program's scope and geographic range. For example, it might be necessary to alter management practices that are not under direct purview of the Program such as creating protected zones or reserves where development is not allowed, limiting harmful activities like mining or logging in key areas, and setting rules about how people can use natural spaces.

The ISAB and ISRP have emphasized the importance of habitat protection in past reports and reviews. The ISAB Food Webs Report (ISAB 2011-1) emphasized "It is clear that biotic conservation is most successful where actions are aimed at protecting ecosystems rather than by attempting to restore or reclaim them after the damage is done." The ISRP Resident Fish and Sturgeon Category Review (ISRP 2020-8) recommended that the Council develop strategic approaches for prioritizing or weighting protection of high-quality habitats versus restoration of degraded habitats. The ISAB's review of Spring Chinook in the Upper Columbia River (ISAB 2018-1) called for protection to be the first priority in conservation planning. In particular, they emphasized the need to support actions that protect existing areas with high ecological integrity where natural processes still occur, especially given predictions for future climate change. A key goal is to provide habitats that are resilient to changing conditions and extreme events, and ones that provide connectivity needed to sustain the full range of life history diversity of salmon and steelhead.

1.2. ISRP Retrospective Review Charge and Approach

A retrospective review of habitat protection and restoration in the Program is consistent with directions provided in the 1996 Amendment to the Power Act for the ISRP to review "*the results of prior-year expenditures*" (i.e., retrospective reviews). The Council's 2014 Fish and Wildlife Program provides further guidance for the ISRP to conduct retrospective reviews stating that, among other items, the ISRP's report should summarize "*major basinwide programmatic issues identified during project reviews*." The ISRP accomplishes this by looking at themes that emerged in previous retrospectives and major category reviews and by examining a subset of projects and investigating how they applied the results of their past actions and monitoring to proposed future actions and monitoring. The ISRP has been conducting reviews for 28 years, and the completion of the Anadromous Fish Habitat and Hatchery Review in 2022 (AFHH, ISRP 2022-1) marked the end of the sixth major iteration of project reviews. Given these important milestones, the ISRP explored topics for a potential retrospective review, discussed these with the Council, and identified habitat restoration and related RM&E as a long-standing programmatic topic that could benefit from further evaluation and synthesis through an ISRP retrospective report.

The purposes of this review are to identify major advances and achievements in habitat protection and restoration in the Program, and to identify challenges for projects. This is a retrospective report and therefore it focuses on results of projects in the Program. Some programs considered in this review coordinate and integrate multiple smaller projects, such as the "Umbrella" Projects (Estuary and Lower Columbia; Willamette River; John Day River; Yakima River; Upper Columbia Rivers; Lower Snake, Tucannon, and Asotin Rivers; Grande Ronde and Imnaha Rivers; Salmon River; and Pacific Lamprey Conservation Initiative). The complexity and capacity of these larger programs inherently tend to be greater than that of individual projects.

Our review builds on the perspectives and recommendations of the ISAB's 2003 Review of Strategies for Recovering Tributary Habitat (2003-2) and 2011 Landscape Report, Using a Comprehensive Landscape Approach for More Effective Conservation and Restoration (2011-4). We focus on the landscapes and aquatic ecosystems of the tributaries to the Columbia River and do not address mainstem habitat and dam passage. We include the Columbia River Estuary because of its importance to many populations of salmon and other species as well as the extensive habitat enhancement efforts that are underway. We provide recommendations for project improvement that draw on exemplary projects and their characteristics identified from the ISRP's Categorical Reviews, scientific publications and reports, previous comprehensive reviews of habitat restoration effectiveness, and guidance documents such as the Columbia Basin Tributary Habitat RM&E Strategy (BPA/BOR 2022).

Our review focuses on anadromous salmonids because they are the focus of many restoration actions within the Columbia River Basin. In addition, we include salmonid species of cultural or economic importance to tribes, those important to recreational or commercial fisheries, and those of conservation concern (e.g., redband trout, cutthroat trout, and bull trout). We consider similarities and differences in habitat restoration for resident and anadromous salmonid species to assess how broadly recommendations for improvements can be made. Although some significant habitat restoration projects benefit resident non-salmonids (e.g., white sturgeon), these comparatively few projects are not the focus of our review. Wildlife-oriented projects generally focus on acquiring and protecting land and enhancing habitat to benefit wildlife species. We highlight several wildlife protection and restoration projects, and we include a discussion of key differences between the Program's approach to mitigating the effects of the hydrosystem on wildlife versus the approach for fish and aquatic ecosystems.

We primarily consider projects designed to restore and protect natural processes, watersheds, floodplains, and habitat complexity in tributaries of the mainstem Columbia River. More specifically these include the following types of projects: 1) barrier removal to restore access to upstream habitat, 2) reconnection of floodplains and off-channel habitat, 3) large-wood addition, 4) riparian zone restoration, 5) estuary restoration, 6) environmental flow restoration, 7) restoration of cold-water refuges, and 8) wildlife habitat protection and restoration. Estuary restoration is included because the actions are based on tidal and fluvial processes that support unique freshwater, brackish water, and marine communities, which anadromous salmonids interact with during parts of their life cycle. There are other methods used that contribute to the effectiveness of habitat restoration projects that are not covered in this review. In particular, we do not include an in-depth description or review of fish screens that protect migrating and moving resident and anadromous fish from being stranded by irrigation and other flow diversions. We view fish screens as fish protection not habitat restoration actions.

The 1996 Amendment to the Northwest Power Act directs the ISRP to evaluate whether projects proposed for funding: 1) are based on sound science principles, 2) benefit fish and wildlife, 3) have clearly defined objectives and outcomes, 4) have provisions for monitoring and evaluation of results, and 5) are consistent with the Program. This report is organized to evaluate the elements needed to ensure that habitat projects meet these criteria. The report first evaluates each of the three major interdependent components of habitat protection and restoration: 1) habitat action planning and prioritization, 2) project implementation, and 3) research, monitoring, and evaluation (RM&E). Next, we highlight and consider how Intensively Monitored Watershed (IMW) programs address these three components with information from lessons learned and future opportunities to expand and apply that learning. We also assess how projects accommodate and adjust to confounding factors such as climate change. We describe selected projects that exemplify effective collaboration among management entities regarding integrated approaches to evaluate habitat conditions, limiting factors, status and trends, and restoration effectiveness, and to provide data for life-cycle models. Finally, we identify elements and characteristics of exemplary projects that display effective project selection, habitat restoration, and evaluation programs, and we provide some examples to highlight their evolution, progress, and areas of improvement.

2. Habitat Action Planning and Prioritization

2.1. Retrospective of Current Planning and Prioritization Methods

Habitat restoration planning and prioritization involve a series of steps. First, the population of interest, the problem, and the spatial scale are identified. Second, potential limiting factors are identified based on a given species' life-stage specific requirements relative to the amount and quality of habitat. Third, potential habitat actions at the appropriate scale are compared, contrasted, and ranked. Throughout this process, quantitative tools and models can be applied to evaluate habitat suitability and habitat actions. This process is not static and changes over time as new information becomes available or guiding principles evolve. This section describes these concepts, processes, and changes in more detail.

2.1.1. Limiting Factors as a Basis for Habitat Restoration Actions

One of the first steps in planning habitat restoration is to identify specific ecological impairments and factors that limit the performance of populations, communities, or the ecosystem. A limiting factor analysis seeks to identify one or more factors or processes that determine (i.e., limit) a population's vital rates and carrying capacity. Carrying capacity is a fundamental concept in ecology, and for many decades it has been recognized that salmonid populations are limited by habitat quantity and quality at one or several life history stages or bottlenecks, mediated by density-independent and density-dependent mortality (Sidebar 2.1, Appendix).

The Program has required habitat restoration projects to identify limiting factors since its beginning in 1982. During the early years of the Program, regional fisheries biologists were developing analytical approaches for salmon and steelhead, such as the limiting factors analysis for coho salmon (Reeves et al. 1989) and Ecosystem Diagnosis and Treatment (EDT; Lichatowich et al. 1995, Mobrand et al. 1997). Initially, limiting factors were identified for conditions at local sites or reaches. The process has evolved substantially over the last 40 years, shifting from local population-focused criteria to broader, ecosystem-level criteria and incorporating life-cycle models to address limiting factors over the fishes' full life history and geographic distribution. The Program included identification of limiting factors as an important component of planning, but the term was used broadly.[1] The Program defines limiting factors as:

> "*physical, biological, or chemical features (for example, inadequate spawning habitat, high water temperature, insufficient prey resources) experienced by fish that result in reductions in abundance, productivity, spatial structure, or diversity. Key limiting factors are those with the greatest impacts on a population's ability to reach its desired status*" (NPCC 2014).

More specifically, the 2020 Columbia River System Biological Opinion (BiOp) of the Federal Columbia River Power System defines limiting factors as "*physical, biological, or chemical features (e.g., inadequate spawning habitat, high water temperature, insufficient prey resources) … that result in reductions in viable salmonid population (VSP) parameters (abundance, productivity, spatial structure, and diversity)*."

In 1994, the Council established the Independent Scientific Group, a precursor to the ISAB, to review the scientific foundation of salmon and steelhead recovery and ecosystem health of the Columbia River Basin. The Group produced a sequence of reports, culminating in the book Return to the River (Williams 2005). In their discussion of restoration, the report found that, "*The current approach to restoration in the Fish and Wildlife Program tends to focus on a small subset of habitats or life history types, abstracting them from the whole and neglecting the interaction among elements of the ecosystem and life histories.*" The ISAB's review of Strategies for Recovering Tributary Habitat (2003-2) recommended that "*limiting factor analysis include an assessment of how well the stream system is ecologically connected to its watershed, how the stream has responded to natural and anthropogenic disturbances in the past, how current and potential future conditions are constrained by land and water use, and how fish respond to the current range of conditions.*"

An ecological factor can be viewed as limiting if it determines birth or death rates, and therefore equilibrium population size when births equal deaths. In a stricter sense, a factor or process is limiting if it determines the carrying capacity of a population or life stage through density dependence. In a population targeted for restoration, it is important to identify the limiting life stages, processes, and factors. We

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[1] The ISAB report on Recovering Tributary Habitat (2003-2) described how limiting factors are determined and discussed factors that confound interpretation of habitat monitoring. The ISRP and ISAB review of subbasin plans (2004-13) includes a useful discussion of several common uses of the term "limiting factors."

describe the ecological principles for limiting factors analysis and their application to salmonids and other organisms in greater detail in the Appendix.

To be most useful, a limiting factor analysis would integrate the best available empirical fish and habitat data with local and regional professional expert opinion to parameterize a stock recruitment relationship for specific life stages. Success of habitat restoration can be determined by assessing target populations and evaluating habitat conditions after implementing restoration actions, which can improve subsequent limiting factors analysis and restoration design. See the Appendix (A.3) for further elaboration.

In the context of tributary habitat restoration in the Columbia River Basin, assessments of limiting factors generally focus on physical habitat factors during freshwater life history stages at the reach or watershed scale. Physical habitat factors are the focus because these are the features that could be ameliorated through restoration actions. Within this scope, practitioners may consider water temperature, stream discharge, types and configuration of habitat (e.g., pools and riffles, side channels, large wood, floodplain habitats), connectivity, and geomorphic variables (e.g., bankfull width, stream gradient). However, food availability and competition are biological factors that also limit carrying capacity and may influence the outcome of restoration efforts.

Sidebar 2.1. Carrying Capacity, Density Dependence, and Limiting Factors Analysis

“Limiting factor” can be a difficult term to define precisely. In general, an ecological factor can be viewed as limiting if it determines birth or death rates, and therefore equilibrium population size when births equal deaths. In a stricter sense, an ecological factor or process is limiting if it determines the carrying capacity of a population or life stage through density dependence. However, given that maximum recruitment depends on density-independent and density-dependent mortality, it may be more useful to consider a factor to be limiting if it strongly affects the carrying capacity (i.e., the maximum recruitment). In a population targeted for restoration, it is important to identify the limiting life stages, processes, and factors. A limiting factor analysis seeks to identify the most important factors or processes that determine (i.e., limit) a population’s vital rates and carrying capacity. Limiting factors analysis is described more thoroughly in the Appendix.

Population abundance and density vary greatly but typically are bounded by some upper limit known as the environmental carrying capacity. A major contributor to population limitation is density-dependent mortality, which can arise through several processes, with intraspecific competition for limited resources, such as food or space, being particularly important. In salmonids, population regulation can occur during freshwater life stages, including spawning, incubation, and juvenile rearing, when large numbers of eggs, fry, and juveniles suffer high density-dependent mortality. Density also influences growth of juveniles and size of smolts at seaward migration, which affect survival to adulthood. Density can also cause fish to be displaced into habitats that are less productive or environmentally suitable.

The influence of density on population abundance and productivity can be visualized by relating the number or biomass of individuals entering a life stage (i.e., the stock) to the number of individuals leaving a life stage (i.e., recruitment). For the juvenile rearing stage of salmon, stock-recruitment relationships typically relate the number of spawning females to the number of smolts produced. These relationships (e.g., Figure 2.1) show a characteristic flattening of the curve at high female densities resulting from density-dependent mortality. In salmonids, female competition for suitable breeding space can limit the population, or, if breeding space is abundant, space and food for juveniles to grow in the stream may be limiting. Ultimately, both density-dependent and density-independent mortality (e.g., from floods and drought) determine where this flattening occurs (i.e., the carrying capacity) and how closely the data fit the curve. This stock-recruitment relationship is described in more detail in the Appendix.

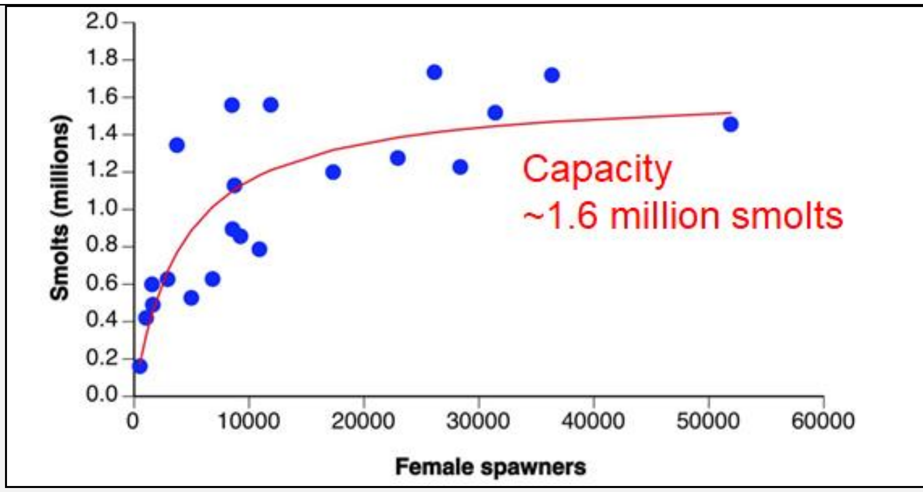

Figure 2.1. Example of density dependence among spring/summer Chinook salmon in the Snake River Basin, for brood years 1990-2010 (ISAB 2015-1). Additional spawners beyond ~20,000 females did not lead to greater smolt production.

In tributary habitat restoration in the Columbia River Basin, assessments of limiting factors generally focus on physical habitat factors during freshwater life history stages at the reach or watershed scale because these factors might be ameliorated through restoration actions. If current fish densities are very near or above carrying capacity, restoration activities to improve habitat quality alone may not produce desired fish responses. Instead, activities to improve habitat quantity in combination with habitat quality may be most effective.

Habitat restoration projects should consider the interactions between density and movement. Juvenile salmonids emerge from gravel redds, commonly exceed the carrying capacity of the stream, and experience local reductions in density from mortality and movement. Habitat features can affect the distribution of spawning by the parental generation, and the survival and propensity for movement by the offspring. Density, resulting from survival and distribution, affects growth, survival, and the timing of life history transitions.

Consequently, habitat restoration projects will likely have effects that extend beyond the project area (Gowan and Fausch 1996a). Thus, it may be necessary to evaluate juvenile production on a broader scale and relate overall production to habitat features (e.g., Sharma and Hilborn 2001). However, benefits of a specific restoration project may not be detectable at the basin scale, especially if the restoration area is very small in relation to the basin's area.

2.1.2. Spatial Considerations in Restoration Planning

2.1.2.1. Site-Level Habitat Restoration

Early habitat restoration projects in the Program targeted a few specific reaches of tributary streams, (e.g., in the Yakima River subbasin) and often were limited longitudinally to less than a mile and only considered the active channel. Between 1984 and 2000, restoration projects in tributary habitats primarily included riparian plantings and fencing, in-stream addition of large wood or boulders, and removal of barriers (e.g., culverts and small dams). While some local improvements in fish production were observed, the extent of the improvements was minimal relative to the extent of the degradation. The ISAB's Landscape Report (ISAB 2011-4) noted that "*Most restoration efforts to date have been small, unconnected projects, completed by willing landowners and managers, and are unlikely to be sufficiently integrated, complementary, and strategically located to be effective at the landscape scale*." It also emphasized that lateral connectivity to floodplain and hillslopes and longitudinal connectivity over multiple reaches within the river network were essential to restoring habitat conditions to benefit fish and wildlife populations.

2.1.2.2. Landscape and Subbasin Scales

The first major effort in creating a landscape-scale framework for habitat restoration was the development of subbasin plans. The first subbasin plans were developed in 1990, soon after the start of the Program. The Council staff's recent Retrospective Report (Homel and Bach 2024) noted that "*The intention of the 2000 Program was for the Fish and Wildlife Program to be implemented through subbasin plans so that regional limiting factors or conditions could govern the kinds of actions implemented throughout the basin*." Ultimately, Subbasin Plans for 59 of the 62 major watersheds in the Columbia River Basin were adopted by the Council between 2004 and 2011.[2] During this period, ESA listings, recovery plans, Biological Opinions, mitigation agreements with Public Utility Districts, and Accords with Tribes and states included strong emphasis on habitat restoration throughout the subbasins.

Major examples of the analysis of limiting factors at subbasin scales in the Columbia River Basin include the Grande Ronde Atlas (BPA 2017), the Upper Columbia Salmon Recovery Board, the Lower Columbia Recovery Board, the Okanogan Basin Monitoring and

[2] The Sandy, Palouse, and Crab Creek subbasins are the three without Council adopted plans. The Sandy had its own planning effort outside the Fish and Wildlife Program.

Evaluation Program, the Intensively Monitored Watersheds (IMWs), and the Upper Columbia United Tribe's Plan for reintroducing salmon above Grand Coulee Dam. To a varying degree, these programs developed spatial databases of upslope landscape conditions, stream habitat, environmental conditions, land use and land ownership, fish distributions, and fish populations. In addition, many of these estimated smolt outmigration, adult returns, and smolt-to-adult survival measures for the basins or populations.

The cumulative effects of multiple factors on populations and their habitats pose major challenges for planning and assessing restoration actions at large spatial scales. Restoration projects can affect different life stages and different processes (growth, mortality, reproduction, movement) and the net response can be additive, synergistic, or antagonistic (Crain et al. 2008). Further, combining effects requires that the life stages be explicitly connected within the analysis so that effects on one life stage are transmitted to the next life stage. Modeling offers an approach for assessing the potential responses to large-scale projects and multiple projects within the same area. Such models can also be combined with monitoring data to develop new understanding of habitat relationships and possible management alternatives to improve the outcomes of habitat restoration. Habitat suitability analyses and life cycle modeling are two approaches that can be used from site to subbasin scales and can also deal with cumulative effects across processes and life stages. Best practices have been proposed that cover both of these modeling approaches (Rose et al. 2015).

Habitat Suitability Analysis

Habitat suitability analysis is widely used to inform management and to assess changes in fish habitat under varying or altered environmental conditions (Nestler et al. 2019). Habitat models have been developed for the Columbia River Basin (e.g., ISRP 2016-1, Upper Columbia United Tribes 2019, Judd et al. 2013). The classical approach is for experts to use laboratory results and other information to derive relationships between suitability (scaled zero to one) and values of explanatory variables; these are then combined (e.g., geometric mean) to obtain an overall suitability. Using habitat suitability as the ecological response variable has advantages as it avoids dealing with the population and food web dynamics (which can be challenging and uncertain), uses available laboratory and monitoring data, and has the flexibility to include many different explanatory variables. Multiple restoration actions can be included if one can quantify how they would change the variables that determine habitat suitability. Habitat suitability modeling can also accept data from other models, such as model-generated water temperature and river flows.

Disadvantages of habitat suitability analysis include that results are specific to life stages (no link between life stages), representation is limited to average or snapshot conditions whereas habitat is dynamic and fish move, and consideration of trophic interactions is limited. One should not interpret predictions from habitat modeling as equivalent to changes in abundance or biomass. Habitat suitability predicts the capacity for species, and life cycle modeling predicts population dynamics, but neither is necessarily what will be realized in nature.

Ecosystem Diagnosis and Treatment (EDT) models have been used for habitat suitability analyses in the Program. For the Subbasin Plans, the Council supported use of habitat analysis to create a consistent assessment of environmental conditions and constraints on salmonid populations and to assess historical and current watershed conditions. Planners primarily used the EDT model and a simpler derivative of EDT called the Qualitative Habitat Assessment (QHA) model that required less data input than EDT. However, not all subbasins used these analytical tools (see ISRP/ISAB 2004-13).

The EDT model is a habitat suitability approach that expands upon the classical approach of suitability (a value from zero to one) by expressing the effects of explanatory variables on survival so that predictions can be expressed as life-stage specific abundances. The EDT model used in the Program's Subbasin Plans was based on a common set of 46 reach-level habitat attributes that link habitat to fish performance. However, EDT is not a life cycle model in the strict sense. Rather, EDT characterizes environmental attributes relevant to salmonids (e.g., physical habitat, water quality, competitors, predators, pathogens, food availability) on a reach scale at monthly intervals, relates them to life-stage specific survival, and uses a multiple-stage Beverton-Holt model to calculate capacity and productivity parameters (e.g., smolts/spawner). EDT uses a random sampling approach to ensure coverage of the many possible pathways or trajectories individuals can take through the life history space and the connected habitats. However, EDT is not an individual or agent-based population model because the individual trajectories in EDT do not respond to the conditions they experience. Thus, we consider the EDT an advanced habitat suitability modeling approach. Similar cautions about how to appropriately interpret classical habitat suitability also apply to EDT predictions.

The habitat assessments for planning the possible reintroduction of Chinook salmon into the blocked area above Chief Joseph and Grand Coulee dams (Giorgi 2018, Upper Columbia United Tribes 2019) is a recent application of habitat suitability analysis in the Program. An intrinsic potential model and EDT models were used to assess the potential production of Chinook salmon, steelhead, and sockeye salmon under current conditions and also the conditions if passage is provided above other existing barriers.

Intrinsic habitat potential models are based on known relationships between salmon abundance and specific habitat characteristics (Burnett et al. 2007). One of the advantages of intrinsic habitat potential models is that they provide preliminary estimates of habitat quality without requiring expensive, detailed field measurements of fine-scale habitat characteristics. The reintroduction plan also used regression models to estimate adult spawning habitat and capacity in the large rivers where habitat suitability models and EDT models could not be applied.

EDT models can provide a consistent and comparable (across subbasins and time) approach to relate freshwater habitat conditions to fish population performance and address most of the Viable Salmonid Population parameters (productivity, abundance, diversity, and spatial structure; McElhany et al. 2000). The EDT approach is well-documented and includes guidance documents and many examples. The confidence level appropriate to EDT predictions necessarily varies across applications because of the different availability of information and the specific questions being asked in each application. Thus, although there were many constraints on the application of the EDT models to specific subbasins (e.g., data availability, use of expert opinion, rough estimates of survival downstream of the subbasins and in the ocean), the EDT applications performed adequately for some applications compared to quantitative data on smolt outmigration and the results of the Integrated Watershed Assessment (Lower Columbia Fish Recovery Board 2004) or other models (McElhany et al. 2010). More recently, revised and updated versions of the EDT models have been used by projects in the Program to evaluate relationships between salmon and steelhead populations and habitat conditions in the Willamette, Okanogan, Methow, Sanpoil, and Spokane rivers, and the Upper Columbia River above Lake Roosevelt. Each application should include documentation and discussion of certainties and uncertainties (ideally with model sensitivity runs) to ensure confidence in the interpretation of results for a location and also enable comparability of results to other applications.

While analyses of habitat suitability in the Program rely on expert-derived relationships between environmental/habitat variables and suitability, recent advances rely more on statistical estimation to determine the suitability functions and formulation of functions that are not simply scaled zero to one but based on physiology and ecological theory (Guillera-Arroita 2017; Robinson et al. 2017). These new methods for habitat suitability include species distribution models (SDM), niche modeling, and bioclimatic models, all of which use the framework of mapping spatial information on environmental and habitat conditions to species presence or densities (Fabrizio et al. 2022). Species distribution and related modeling uses the same concept as the expert-derived suitability modeling. However, it compares the presence or density of fish in monitoring samples with values of environmental variables (e.g., temperature) and features of the habitat (e.g., bottom type). Statistical methods are then used to fit the response of suitability to the suite of environmental and habitat variables.

The fundamental assumption of SDM and related statistically based approaches is that fish are found where habitat is of high quality. This movement from expert-derived relationships to data-based estimation grounds the modeling in empirical data and well-established statistical methods. Another advance follows the idea behind EDT and moves the response variables from scaled index of quality to abundance, vital rates (growth, mortality, reproduction), and even combines the vital rates into productivity, although still not via a full life cycle model. An advantage is that the relationships are empirically based and therefore more defensible. However, a major challenge is that all relevant explanatory variables (important to habitat and under control of management) need to be estimated and spatially co-located and temporally matched with fish samples.

Life-cycle Modeling

Life cycle modeling has been widely used within the Columbia River Basin (Zabel and Jordan 2020). Models are often stage and/or age-structured and spatially explicit. Growth and mortality affect the progression through the life cycle, reproduction initiates each year-class, and movement among spatial boxes is affected by habitat conditions (e.g., Scheuerell et al. 2006, Pess and Jordan 2019). Life-cycle models use equations that combine growth, mortality, and reproduction rates, rather than statistical analysis of densities as in habitat suitability. The equations are then solved to estimate densities and abundances in spatially explicit cells and over time.

Life cycle models continue to be developed for assessing river restoration, including versions that combine habitat and life cycle modeling (Justice et al. 2017, Jorgensen et al. 2021, Faro and Wolter 2024). Life cycle modeling enables the outcomes of multiple projects to be combined by representing their effects on process rates (e.g., growth, mortality, reproduction; Bellmore et al. 2017). Combining the effects of different types of projects is difficult in habitat modeling, which use environmental and habitat variables to predict scaled habitat or static abundances. However, life cycle models require a relatively rich database of information, specialized expertise, and significant time and money to develop. Generally, such efforts are reserved for watershed or basin scale assessments, very large restoration programs, and analyses for ESA-listed independent populations.

Life cycle models provide additional quantitative tools for identifying limiting factors for planning and selection of habitat restoration in the Columbia River Basin (ISAB 2001-1, ISAB 2008-1, ISAB 2017-1, ISAB 2023-1). A major strength of life cycle models is the inclusion of the full life history of the fish represented as linked life stages (survivors from a stage become the entrants to the next stage), allowing the identification of factors that limit the population over their full life cycle. The models include the full extent of freshwater and ocean distributions and survival of fish, rather than considering abundance and survival for only specific life stages or reaches in freshwater habitat as in some advanced habitat-based methods. Such models have been developed for the Snake River (fall Chinook, spring/summer Chinook), Grande Ronde River (spring Chinook), Wenatchee River (spring Chinook), Yakima River (steelhead), Willamette River (spring Chinook, steelhead), and three Intensively Monitored Watersheds (IMWs) – Entiat, John Day, and Lemhi Rivers (spring/summer Chinook). The ISAB found that the models were generally appropriate for identifying limiting factors related to habitat and informing management on expected population responses relative to model-generated baseline conditions in order to compare restoration scenarios and analyze potential effects of climate (ISAB 2017-1).

Life cycle models generate highly relevant predictions in terms of projected population dynamics including key viability metrics of abundance and spawner-to-spawner productivity, which is ultimately what is of management and public interest. However, there are challenges with developing life cycle models, some common to all ecological models and others because of the need to represent the entire complex life cycles of salmonids (e.g., movement, marine survival). Further, many management actions are place-based and often occur simultaneously requiring a relatively high level of confidence in the spatial aspects (explicitly or implicitly represented) of life cycle models. The available life cycle models are general codes that can be set for different populations and systems. Developing a general Columbia River Basin template has advantages including ensuring consistency across applications within the Basin and for analyses at the strategic level; however, the models are always pushed towards generating predictions for tactical decision-making and a generic Columbia River Basin template would provide the starting point that would then need to be made as site-specific as possible. Columbia River conditions are increasingly changing (e.g., climate, invasive species), which precludes easy interpretation of historical data, complicates how to establish a baseline, and requires methods for projecting future conditions.

Evolution of Subbasin Plans

A major challenge of subbasin-scale restoration planning is maintaining up-to-date information on juvenile and adult salmon and steelhead abundances, habitat conditions, new land uses, and climate. The Council originally called for Subbasin Plans to be updated as needed, and the 2018 ISAB review of the Program (ISAB 2018-3) recommended the Council identify plans that need updating. However, in the 2024 ISAB Program review (ISAB 2024-2), the ISAB acknowledged that several subbasins have developed geographically specific databases and project guidance since the original Subbasin Plans, including the:

- Restoration Atlas of the Grande Ronde Model Watershed
- Upper Grande Ronde Tributary Assessment
- Columbia Estuary Ecosystem Restoration Program (CEERP)
- Okanogan Basin Monitoring and Evaluation Program
- Recovery Program of the Upper Columbia River Salmon Recovery Board
- Umatilla Initiative

These watershed assessments capitalize on new technology, link directly to RM&E data, incorporate life cycle models, can be used in the design of restoration projects, and provide readily available information in many forms to assist in planning and implementation (ISAB 2024-2).[3] These plans are continuously updated with new data and information, and are explicitly linked to recovery plans, technical recovery teams, and management plans of state and federal agencies in the subbasins. Projects have independently developed these recent watershed assessments, which differ greatly in focal species, landscapes, identification of limiting factors, technical structure and data management, and coordination with regional recovery plans. These differences are a major strength in watershed assessment in the Fish and Wildlife Program, providing test cases for alternative approaches to watershed assessment and new lessons for future restoration planning. However, these

[3] In addition to these examples of watershed assessments and plans focused on habitat restoration and protection, the Lower Snake River Compensation Plan has developed goals, databases, and guidance documents for hatchery production programs for steelhead, spring/summer and fall Chinook in the Lower Snake River.

programmatic strengths can be realized only if the Program ensures that results from independently developed programs are compared, integrated, and synthesized.

2.1.2.3. Habitats in the Estuary and Lower Columbia River

The landscape and coastal dynamics of the lower Columbia River and its estuary (henceforth referred to as estuary) have unique processes and pose special challenges for habitat restoration. Projects in the estuary have been designed to restore hydrologic connections between the mainstem and floodplain, enhance shallow-water habitat, remove barriers, and re-establish native vegetation. Emphasis on restoring floodplain connections is based on research indicating that disconnecting floodplain wetland habitat from the river is the most extensive and detrimental limiting factor in the lower Columbia River (Bottom et al. 2005; Brophy et al. 2019). Approximately 70% of the 1,624 km^2 (401,300 acres) historical floodplain has been lost due to dikes and berms, flow regulation, and loss of floodplain in tidal portions of lower river tributaries (Kukula and Jay 2003, Marcoe and Pilson 2017). Access by fish to and from floodplain habitats has also been reduced by tidegates. Some areas behind the dikes have been drained, and subsequent sediment deposition or erosion has altered the elevation and availability of estuarine habitat.

The emphasis on restoring floodplain connectivity in estuaries has occurred because of the evidence that tidal wetlands throughout the river are important to multiple size classes and populations of salmon, although species and life history forms differ markedly in duration of occupancy and habitat use in estuaries (Roegner et al. 2011, 2012, 2016; Teel et al. 2009). As a result, a major role of estuary restoration has been supporting life history diversity of listed populations and especially Chinook salmon. In general, there is a gradient in size classes with smaller fish in shallower habitats and larger fish using main channel areas (Roegner et al. 2011, 2016). Populations also vary horizontally and longitudinally in the river depending on their origin, time of year, and body sizes (Bottom et al. 2021). For example, in the upper reaches of the estuary, fish from upper river populations dominate (Teel et al. 2014), and they are joined by lower river ESUs farther downriver. In addition, steelhead pass through the estuary relatively early (April and May) and rapidly with few fish found in other months. Subbasins produce diverse life history types that enter the estuary at different times, such as spring Chinook salmon from the Willamette subbasin (Schroeder et al. 2016). Use and benefits of estuaries can be both direct (i.e., fish occupy the habitats) and indirect, if food is transported from wetlands to the main channel where it is consumed by fish (Roegner and Johnson 2023).

Changes in the hydrology of the Columbia River caused by the hydrosystem also contribute to habitat loss and degradation in the estuary (Helaire et al. 2019). Altered flow patterns have reduced the duration and spatial extent of floodplain inundation, and some estuarine habitat is no longer inundated because elevations are too high. Extreme overbank flows, which build and maintain floodplains and estuarian wetlands, are smaller in magnitude and occur less often. Reduction in flows and construction of dams have reduced sediment transport to the estuary by >50% (Naik and Jay 2011) and decreased the amount of large wood that historically was transported downstream and deposited in the estuary.

Early projects were opportunistic and focused on small areas (Littles et al. 2022). In recent years, both larger (>0.4 km^2 or 100 acres) and smaller projects have been completed, including dike/berm breaches, full removal of dikes, and tide gate removal. From 2000 to 2019, restoration partners in the Estuary have protected or restored 115 km^2 (28,387 acres) of habitat in the lower Columbia River estuary (NMFS 2020a).

2.1.2.4. Increased Scale and Complexity of Habitat Restoration

Another trend in the evolution of habitat restoration has been the complexity of restoration actions included in projects funded to implement the Program. Early projects tended to focus on one or a few actions such as the addition of large wood or removal of barriers. As project proponents became more experienced with multiple restoration methods and funders became more willing to support larger and more costly projects, the actions implemented within single projects became more complex. A growing number of restoration projects combine multiple restoration actions, such as wood additions, creating off-channel habitats, increasing channel complexity, barrier removal, and riparian plantings and fencing.

One of the first and most important shifts toward restoration at larger spatial scales has been the restoration of connectivity between active channels and their floodplains. Planning the restoration of floodplains in rivers requires greater spatial scales both laterally and longitudinally compared to projects in smaller streams. Major floodplain restoration in the Okanogan, Tucannon, Grande Ronde, Methow, and Entiat rivers extend for 8 km to more than 56 km (5 to 35 miles) (Bellmore et al. 2013, Roni et al. 2025). An important ecological implication of larger spatial extents, especially in floodplain restoration, is the increased abundance and diversity of food resources and benefits to fish communities (ISAB 2011-4, Bellmore et al. 2013, 2017). The same trend in increased spatial scale has occurred in restoration projects to re-meander channels or create multiple side channels.

The increase in spatial extent of restoration over the last 20 years is also evident in restoration of large wood. Initially, most wood addition projects were limited to the wetted channel over distances of less than a mile. Gradually, proponents of wood restoration projects recognized the need to restore wood over longer distances to accommodate the movement and redistribution of wood, and to achieve a greater increase in fish populations. The limited ecological benefits and short-term persistence of the wood became apparent in projects limited to the low flow or active channel, and projects began to design wood addition to both floodplains and active channels. The movement of wood introduced for habitat restoration caused some proponents to increase the amount and area of their wood restoration, adding thousands of logs across large areas of channel and their floodplains, such as in the Yakima, Okanogan, Grande Ronde, and lower Columbia subbasins.

The ISAB's Review of Spring Chinook Salmon in the Upper Columbia River (ISAB 2018-1) identified challenges for designing restoration at multiple spatial scales from local habitats, reaches, stream networks, to entire watersheds, and described approaches for measuring fish responses to habitat restoration at these different scales. Experimental designs and evaluation of fish responses to restoration actions differ by spatial scales and become more limited at larger spatial extents. Small numbers of treatment and control sites limit the statistical power of the experimental designs. The logistics and cost of measuring outcomes of multiple types of restoration actions make such studies challenging, and the interactions of multiple restoration actions make it difficult to attribute responses to specific actions or combinations of actions. The ISAB suggested alternative measurements when direct population responses to restoration cannot be measured accurately, such as determining whether 1) habitat is changing in response to the actions, 2) fish are using the restored habitat, 3) densities and growth rates are responding, or 4) survival has improved for different life stages. Constraints of spatial scale and complexity are described in more detail for monitoring in Chapter 4. Habitat RM&E.

2.1.3. Biological Considerations in Restoration Planning

Since the beginning of the Fish and Wildlife Program, projects have relied on local data for distributions and abundance of salmon and steelhead populations and habitat conditions to design and select habitat restoration. Generally, project planning initially focused on degraded habitats (e.g., degraded channel structure, stream discharge, wood abundance, and riparian conditions, and sedimentation and barriers) and adverse environmental conditions (e.g., temperature, dissolved oxygen). Projects also used conceptual models or empirical relationships between habitat conditions and juvenile abundance, smolt outmigration, and trends in adult returns to identify limiting factors for salmon and steelhead. Several biological metrics were commonly used in planning and selecting restoration actions, such as fish use of different habitat types, local densities, growth rates, survival, and smolt outmigration. Project priorities were based on the most critical causes of degradation, potential biological responses, willing landowners and management agencies' priorities, implementation logistics, and financial constraints.

The ISAB found that many populations of salmon and steelhead, especially ESA-listed populations, in the Columbia River Basin are limited by density-dependent processes (ISAB 2015-1). In compensatory density-dependence, smolt production increases with increased numbers of spawners to a point and then does not change with greater numbers of spawners (see stock-recruitment relationship in Figure 2.1 above).

Once carrying capacity has been reached or exceeded, habitat restoration can increase long-term population abundance only if it reduces density-dependent constraints and thereby increases carrying capacity or reduces density-independent sources of mortality that may contribute to interannual variation in production. However, improving local freshwater habitat will not increase long-term adult salmon abundance if factors outside the tributaries (e.g., in-river survival, passage efficiency, predators, ocean conditions, harvest, toxics) primarily limit survival. Likewise, in populations for which food limitations reduce growth rates, size at age, and survival, restoration of physical habitat that does not increase total food availability will not improve fish production. For example, restoration of riparian vegetation and stream complexity can increase the supply of terrestrial food sources (leaves, fine organic matter, insects) but may reduce instream food sources of aquatic primary production if restored stream reaches become heavily shaded. The ISAB Density Dependence Report (ISAB 2015-1), concluded that "*The status of salmon populations or success of restoration actions cannot be fully evaluated without considering the effects of fish density*." This critical component of restoration planning will be addressed in greater detail in the chapters of this report on RM&E and Confounding Factors.

2.1.4. Process-based Restoration

In its simplest sense, process-based restoration restores physical and ecological processes with the goal of recovering ecosystem productivity and diversity. In contrast, structural-based restoration attempts to recreate the desired physical structure of stream channels, floodplains, and riparian zones without addressing the processes that create and degrade such structure. Many of the Program's early habitat restoration projects were structural-based actions designed to create channels with the attributes associated with non-degraded habitat or pre-degradation conditions, often referred to as high-quality habitat. ISRP and ISAB reviews raised concerns about the restoration of form rather than process, and the ISAB Landscape Report (ISAB 2011-4) emphasized the critical role of considering biophysical processes and socioeconomic processes in conservation and restoration of ecosystems.

Beechie et al. (2010) defined process-based restoration as an approach designed "*to reestablish normative rates and magnitudes of physical, chemical, and biological processes that create and sustain river and floodplain ecosystems*." While few habitat restoration projects of the Fish and Wildlife Program fully meet the description of process-based restoration, the number of projects that attempt to identify impaired processes and develop actions to restore them has increased markedly since the 2000 Fish and Wildlife Program. As described in the Council staff's Retrospective (Homel and Bach 2024), "*There was a new emphasis on ecosystem function and better approximation of natural conditions, along with an emphasis that the natural environment was meant to serve as a baseline. The scientific framework contained elements of the frameworks of the late 1980s and 1990s, but it was much more detailed and integrated*." The larger landscape coordination and assessment programs described earlier in this chapter and the Intensively Monitored Watersheds described in Chapter 5 represent the most rigorous applications of process-based restoration in the Program. The growth of more complex, spatially extensive, and integrated projects demonstrates the importance of process-based actions in the Program and its future direction in habitat restoration.

2.1.5. Consideration of Strategic Guidance

Addressing past, current, and future anthropogenic impacts on fish and wildlife habitats and associated natural processes is essential for achieving goals and objectives of the Council's Program, other management plans, and recovery plans. The strategic guidance in the Program provides an important framework for developing habitat protection and restoration strategies and actions at multiple geographic scales, which can be integrated with strategic frameworks of other resource managers in the Basin. Use of a sound strategic framework serves a critical role in identifying and prioritizing habitat protection and restoration projects and restoration methods from the reach to watershed scales.

The Program provides strategic guidance for habitat protection and restoration with ecosystem function core strategies, sub-strategies, and principles. The Program states that ecosystems that can respond to change can contribute to healthy processes and conditions that will support healthy species and human populations. Landscape perspectives and management approaches are necessary to maintain diversity so ecosystems can be resilient. The Program's Core Ecosystem Function Strategy is "*Protect and restore natural ecosystem functions, habitats, and biological diversity whenever feasible consistent with biological objectives of the program*." Principles that support the core strategy include 1) building from strength by protecting and restoring fish and wildlife habitat that supports existing populations that are relatively healthy and productive and 2) restore ecosystems not just single populations with a focus on restoring habitats and developing ecosystem functions and conditions that allow for expanding and maintaining diversity within and among species. Protecting existing high-quality habitat is as important as enhancing degraded habitat.

Not all habitat actions that should be implemented can be completed in the near term due to multiple constraints, including available funding, workforce capacity, and phasing with other potential actions. Prioritized actions lead to more timely and effective habitat improvement responses. Many of the habitat projects funded under the Program incorporate strategic level guidance in the process of identifying the highest priority protection and restoration areas as well as the implementation actions. The application of overarching strategic guidance in restoration project planning and selection has increased since the Program was first implemented. Numerous programs in the Columbia River Basin use strategic guidance for planning and prioritization, and these strategies are consistent with the Program guidance. To illustrate the role of strategic guidance, we highlight four major examples as case studies, which in combination represent the common elements and concepts contained in other programs.

2.1.5.1. The Upper Columbia River Biological Strategy

The identification, prioritization, and selection of fish habitat protection and restoration actions in the upper Columbia River Basin are guided by a Biological Strategy to Protect and Restore Salmonid Habitat (UCRTT 2021). The Biological Strategy was originally developed and applied in 2007 and has been updated repeatedly to incorporate new knowledge.

The Upper Columbia River Biological Strategy shares many elements with other strategic guidance. The three priorities are:

1. Protect existing natural watershed and stream processes

2. Restore natural processes that are impaired to the extent possible
3. Enhance degraded habitat

The strategy emphasizes the importance of a holistic approach that considers natural processes that operate at multiple spatial and temporal scales. Guidance includes priority on restoring watershed processes prior to or in parallel with process-based habitat enhancement actions.

The strategy specifies that "*the highest priority for protecting biological productivity should be to protect and allow natural geo-fluvial processes such as unrestricted stream channel migration and sediment transport, instream complexity, and floodplain function*." Protection of the highest functioning habitats at greatest risk of degradation along with protection of areas with the highest potential for maintaining geo-fluvial processes are emphasized. This highlights the importance of spatial information on landscape conditions, fluvial geomorphology, and riparian and floodplain vegetation for the major subbasins of the Columbia River.

The prioritization strategy is designed to "*provide a consistent, repeatable, systematic, and well documented approach for prioritizing restoration and protection action types and locations*." The prioritization strategy is supported by the Viable Salmonid Population (VSP) Framework and the Biological Strategy.

The process involves prioritizing and ranking assessment units and identifying priority life-stages within a subbasin. Metrics and scoring rules are used to rank assessment units (AU) into three tiers of high, medium, and low priority actions. Reaches within high priority AUs are then further prioritized based on ability to improve habitat conditions and function, address key limiting factors for critical life stages, and address migration barriers.

The Biological Strategy and Prioritization guidance provides a sound basis for the process to identify, prioritize, and select habitat protection and restoration actions as well as document important data and factors that are considered in the prioritization process.

2.1.5.2. The First Foods Framework

Habitat protection and restoration efforts conducted by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) throughout the subbasins within their ceded territory are guided by sound goals and strategies. The goal is to protect, enhance, and restore functional floodplain, channel, and watershed processes to provide sustainable and healthy habitat for First Foods species and support treaty reserved resources (Christian and Kelly 2021). The First Foods Framework (Quaempts et al. 2018) guides ecosystem management to supply traditional foods like salmon, deer, and huckleberries that are critical to sustaining traditional ceremonies and culture. The goal is to manage for both cultural and ecological sustainability. This unique framework explicitly emphasizes riparian terrestrial species in addition to salmonids, which are the traditional focus of restoration efforts and RM&E.

The habitat projects use a First Foods based strategy to guide aquatic ecosystem restoration efforts that are organized around the River Vision Functional Touchstones that include water quality and quantity, geomorphology, connectivity, riparian vegetation, and aquatic biota (Jones et al. 2008). The River Vision provides a description of processes and conditions necessary to protect and provide for production of riverine First Foods. The Upland Vision (Endress et al. 2019) links the upland to the riverine habitats to provide a ridgetop-to-ridgetop strategy similar to the riverscape concept.

The River Vision and Upland Vision prioritize protection and restoration of processes instead of targeting symptoms of habitat degradation. The Vision promotes process-based protection and restoration actions and prevents further degradation. A key objective of the habitat projects is to protect and conserve natural ecological processes that support the viability of fish populations and their primary life history strategies.

The strategic guidance provided by the First Foods, River Vision, and Upland Vision represents an integration of traditional ecological knowledge and "Western" science and has resulted in successful implementation of important protection and restoration actions.

2.1.5.3. Oregon Conservation and Recovery Plan for Middle Columbia River Steelhead

Many habitat protection and restoration projects implemented for Oregon's steelhead populations in the mid-Columbia River subbasins use strategic guidance for management actions provided in the Oregon Conservation and Recovery Plan for middle Columbia River Steelhead (Carmichael and Taylor 2010). The guidance is specified with goals, principles, and prioritization considerations.

Regarding habitat protection and restoration, the goals are to:

- Sustain ecosystem processes that currently support high quality habitats and their productive capacity and will continue to do so in the future.
- Enhance ecosystem processes that are impaired but are currently important to productive capacity.
- Restore habitat and ecosystem processes that were historically important but do not currently contribute to productive capacity.

These goals are grounded in several key principles adapted from Meffe and Carroll (1997) that include:

- Set aside or protect the highest quality habitat.
- Prevent any further habitat degradation.
- Maintain and restore critical ecological processes.
- Develop goals and objectives based on a thorough understanding of ecological processes and system properties.
- Conserve and restore evolutionary processes.
- Manage in an adaptive manner that is minimally intrusive.

Conservation of existing high-quality habitat that supports core production, primary life history types, and important migratory habitats is critical to sustainability and recovery. The highest priority actions for achieving the goals and conservation principles are those that:

- Provide long-term protection of habitat conditions and conservation of natural ecological processes that support viability of priority populations and their primary life history strategies.
- Protect and enhance viability of multiple populations.
- Support conservation of unique and rare functioning habitats, habitat diversity, life history and genetic attributes.
- Target key limiting factors that most affect long-term population productivity, spatial structure, and diversity rather than target short-term and small-scale solutions.
- Provide immediate benefits to enhancing viability where opportunity for success is high and the improvement is large.
- Provide critical information needed for assessing success and making adaptive management decisions.

2.1.5.4. Lower Columbia River Estuary

For over 20 years, the Columbia Estuary Ecosystem Restoration Program (CEERP) has supported the scientific review and implementation of site-specific estuary restoration actions and projects, together with long-term monitoring and research to assess effectiveness. CEERP is led by the Bonneville Power Administration (BPA) and the U.S. Army Corps of Engineers and advised by the National Oceanic and Atmospheric Administration. Developed to satisfy hydropower mitigation obligations and commitments under the Northwest Power and Conservation Act of 1980 and Biological Opinions (BiOps) on essential fish habitat response for operating and maintaining the Columbia River System, CEERP aims to understand, conserve, and restore ecosystems in the Columbia

River Estuary. In 2009, the Columbia Estuary Ecosystem Restoration Program (CEERP) developed an adaptive management program and uses the Expert Regional Technical Group (ERTG) to assess and score projects. Monitoring and evaluation informed the design of restoration and provided evidence of benefits to salmon that were used in subsequent project selection. More recently, ERTG produced the Landscape Planning Framework to apply landscape principles to project siting and design (ERTG 2020, Hood et al. 2022). After 2017, CEERP developed the Implementation Forecaster Tool to provide landscape maps and current information of implementation constraints, costs, and benefits to assist proponents, managers, and scientists in prioritizing and designing restoration actions. This contrasts with some tributary approaches like the Tucannon River Umbrella Project that conducts comprehensive evaluations of what is needed across the landscape and then finds partners to implement specific projects in priority areas. Major partners in the estuary include LCREP, Columbia Land Trust, Washington Department of Fish and Wildlife (WDFW), Columbia River Estuary Study Taskforce (CREST), and the Cowlitz Tribe.

ERTG was a significant development in the review and selection of restoration actions in the lower Columbia River estuary. Estuary restoration actions are initially reviewed by the Estuary Partnership's Science Work Group, undergo a second technical review, and are then assigned mitigation credit scores for the Landscape-Scale Elements factor and a Site-Scale Elements Project Benefit Units (PBU) (ERTG 2020). The Landscape Scale factor is based on landscape features such as connectivity for juvenile salmon, distance to other natural and restored patches, distance to a large tributary or hydrogeomorphic reach boundary, and location within a priority reach (ERTG 2019). Prior to 2021, ERTG assigned scores for salmon Survival Benefit Units (SBUs), which were based on potential improvement in salmon survival (Krueger et al. 2017). PBUs are based on restored habitat area, potential salmon densities, habitat access, and habitat capacity for ocean- and stream-type fish (ERTG 2021). The project prioritization and selection processes, especially the SBU process, have been reviewed by the ISRP and ISAB. Given the current focus on meeting the goals of the FCRPS BiOp, project prioritization and selection ultimately depend on the adequacy of the Landscape Elements and PBU approach and the ability of partners to independently identify the most productive projects. Recently, ERTG has been developing new guidance and tools to include biological metrics to complement their use of PBUs and other landscape principles in project planning, design, and assessment.

In summary, these four examples of strategic guidance share many concepts and priorities and have helped to incorporate habitat protection and restoration ecological principles into project planning, prioritization, and implementation decisions. At least in some basins, practitioners are developing approaches to counter the criticism that "*We are not doing the right things in the right places at the right times*", which was one of the five key factors that Bilby et al. (2024) report as contributing to "*why salmon aren't responding to habitat restoration in the PNW*." The use of strategic guidance can be beneficial for the planning of all habitat projects and is highly recommended.

2.2. Conclusions and Moving Forward

Conclusions

- Improving habitat conditions and increasing fish populations in the Basin require both protection and restoration of tributary habitats. Planning and prioritizing habitat actions should determine the benefits of protecting critical habitat before assessing possible restoration of degraded habitat.

Spatial Perspectives

- Initially, the Program focused on the mainstem Columbia River, and early habitat restoration projects targeted a few specific reaches of tributary streams but later recognized that larger-scale projects were needed.
- Larger projects lacked coordination and integration to achieve Program goals and objectives without a landscape framework for habitat restoration. A major advance was the Council's decision to develop subbasin plans.
- Initially, limiting factors were identified for local sites or reach conditions; as the Program evolved, analytical approaches were developed to identify limiting factors and guide habitat restoration for watersheds and large subbasins. Analysis of limiting factors has been and continues to be a foundation of restoration planning.
- Life-cycle models and habitat suitability analyses are important quantitative tools for identifying limiting factors and expected responses for planning and selection of habitat restoration.
- A major challenge for subbasin planning is maintaining up-to-date information on fish abundances, habitat conditions, changing land uses, and climate. Since the Subbasin Plans were developed, new watershed assessments take advantage of new technology, link directly to RM&E data, and incorporate life cycle models to guide restoration planning, design, and implementation.
- The landscape and coastal dynamics of the lower Columba River and its estuary require attention to unique

processes and challenges for habitat restoration. Changes in the hydrology of the Columbia River, largely caused by the hydrosystem, also contribute to habitat loss and degradation in the estuary.

- An important strategic advance in the Program's efforts to restore tributary habitats has been the evolution toward more complex and integrated restoration actions within individual projects or in multiple coordinated projects.
- Watershed assessments and life cycle models create valuable contexts for planning and prioritizing habitat restoration that encompass larger spatial scales and the full life history of salmon and steelhead to guide habitat restoration.
- Analysis of density dependence is a critical component of habitat restoration planning and prioritization. Improving local freshwater habitat may not increase carrying capacity if factors outside the tributaries limit survival at other life stages.

Process-based restoration versus structural restoration

- Few habitat restoration projects in the Program meet the full description of process-based restoration; however, the proportion of projects designed to restore impaired processes has increased.
- Watershed coordination and assessment programs and IMWs are rigorous approaches for incorporating process-based restoration and a major future direction in habitat restoration in the Program.

Strategic frameworks for guidance

- Sound strategic frameworks, such as landscape conceptual frameworks and recovery plans, serve a critical role in identifying and prioritizing habitat protection and restoration.
- Overarching strategic guidance has been used increasingly in project planning and selection.

Recommendations

- The ISRP recommends that analyses of limiting factors and density dependence continue to be critical components of habitat restoration planning and prioritization.
- For projects that lack necessary information or support for detailed site-specific modeling, the ISRP recommends exploring the potential use of habitat and life-cycle models for strategic analyses and general restoration planning. Strategic analyses would include coarse screening of different habitat restoration options to then explore promising approaches more closely. One approach would be to develop a generic Columbia River Basin template or library of templates for the

existing models and software. With some modifications for each application, these could be implemented for planning purposes, while recognizing their limitations.

- The ISRP recommends more explicit incorporation of process-based restoration and the assessments necessary to support it in planning and prioritization.
- Differences in watershed- and landscape-level assessments for restoration planning and prioritization provide test cases for alternative approaches and new lessons for future planning. The ISRP recommends the Program determine where watershed-level assessment and coordination approaches are effectively guiding restoration and develop additional subbasin assessments to better represent the diversity of landscape types and ecoregions in the Basin.
- Projects that are not part of a larger integrated landscape program and do not have the capacity to use planning tools like Atlas are often at a disadvantage. The Program should develop enhanced planning tools and strategic guidance to support these projects.

3. Methods of Habitat Restoration and Protection

3.1. Current Methods

Habitat protection and restoration projects vary greatly in the types of actions and their implementation, but several methods have been employed to address recognized limiting factors throughout the Columbia River Basin. In this chapter, we review eight common methods for restoring aquatic habitats: 1) barrier removal, 2) floodplain reconnection, 3) large wood addition, 4) riparian planting and fencing, 5) estuary habitat restoration, 6) flow augmentation, 7) cold-water habitat restoration, and 8) wildlife habitat restoration. We also discuss the evolution of process-based restoration over the history of the Program. We explore research and monitoring information on the effectiveness of the various methods conducted both inside and outside the Columbia River Basin, comment on statistical approaches, and identify lessons learned to apply to Program projects. This chapter of the report is more detailed and technical than the other chapters because one of our main objectives is to identify 1) where we know enough about particular restoration methods to de-emphasize monitoring efforts for that method in the future and 2) where information is lacking so continued or increased monitoring and evaluation are needed.

There are other methods used that contribute to the effectiveness of habitat restoration projects that are not covered in this review. In particular, we do not include an in-depth description or review of fish screens that protect migrating and moving resident and anadromous fish from being stranded by irrigation and other flow diversions. We view fish screens as fish protection not habitat restoration actions. However, the Program's fish screening projects have been an integral part of habitat restoration effectiveness, for example, ensuring that benefits from other restoration actions are not negated due to stranding, injury, or migration delay. We have commented on the need for more resources to be invested in these screening programs to ensure priority diversions are screened and screens are maintained in a timely manner. For example, we have highlighted the Idaho Fish Screening Improvement project (#1994-015-00) as an exemplary project (ISRP 2022-1).

Figure 3.1. Example of culvert replacement to remove a barrier to fish passage, Grande Ronde River/Buford Creek Fish Passage 2019 (Source: FWP project #2007-393-00, Nez Perce Tribe).

3.1.1. Barrier removal

Removal of barriers to upstream fish passage is believed to be one of the most successful types of habitat restoration actions (see Figure 3.1). Barriers have been a major focus of restoration efforts conducted by the Program since its inception and are generally considered high priority. There are many barriers (1,000s to 10,000s depending on the spatial scale considered) to salmonids at multiple life stages. Thus, given the numerous barriers and the need for removal to proceed sequentially from downstream to upstream, identifying which barriers to remove is critical. Several guidance documents and strategic approaches identify which barriers to remove and how (e.g., Washington Department of Fish and Wildlife 2024). These documents generally seek to restore hydrology and geomorphology so the stream channels both upstream and downstream near the barrier are similar after removal. An example is work by the Upper Columbia Salmon Recovery Board. By 2012, 93 barriers had been removed, opening 454 km (282 miles) of previously blocked habitat (UCSRB 2014), far more than was restored by all other types of habitat actions in the Upper Columbia program combined.

Hillman et al. (2016) reviewed 410 published studies of habitat restoration in tributaries of the Columbia River Basin, many of which were projects and studies implemented through the Program. Of these, 56 studies examined the effectiveness of removing fish passage barriers. They reported that studies evaluating the effectiveness of removing impassable culverts or dams, or that have installed structures to allow fish passage, have consistently shown rapid colonization of upstream habitat by fishes (e.g., Roni et al. 2008, 2013; Kiffney et al. 2009; Pess et al. 2012). However, a major finding of these and other studies is that the rate at which salmonids recolonize blocked habitats depends strongly on the amount and quality of habitat upstream and the size of the source population inhabiting downstream habitats or returning as anadromous fish.

Formal scientific evaluations of effects of removing fish passage barriers have been conducted at two scales – the reach and network scales, discussed below.

Reach-level investigations

Clark et al. (2020) evaluated effects of barrier removal at a reach scale for 32 sites selected from a potential pool of 100 sites in the Columbia River Basin where barrier removal had been funded by the Program since 2000. Few sites had coho or Chinook salmon, so analysis focused on juvenile steelhead and all anadromous salmonids combined but not resident salmonids.

The investigators assumed that if fish rapidly colonized upstream habitat, then no difference would be detected in densities between the upstream (treatment) versus downstream (control) sites after barrier removal. As predicted, they found no significant difference in densities of juvenile steelhead (P=0.44) or all anadromous salmonids combined (P=0.19), indicating that barrier removal successfully provided fish passage to upstream habitats, which were rapidly recolonized.[4]

Network-level investigation

Barriers affect distributions of anadromous and resident fishes throughout stream networks. For example, recolonization of habitat upstream after barrier removal can depend on the presence of impassable or partial barriers farther downstream, densities of fish downstream, numbers of returning adults, and the quantity and quality of habitat available upstream. Detection of fish in reaches downstream and upstream of barriers is invariably imperfect and depends on sampling

[4] Statistical note: Support for this hypothesis rests on accepting the null hypothesis of no difference between treatments and controls. One question is how much statistical power was available to detect this difference. Our understanding is that power must be calculated *a priori*, not after the fact. Despite this, one useful method can be to calculate what sample size would have been needed to detect treatment-control differences this small. If that sample size is rather large, this helps validate that the difference is small. Although it is not stated, the t-tests used are assumed to be two-sided.

methods and effort. In addition, persistence of resident fish in headwaters after disturbances like fire and debris flows can depend on periodic recolonization from downstream reaches, which is also affected by barriers.

Chelgren and Dunham (2015) developed a spatially balanced sampling design to assess 162 road crossings in 34 of 79 stream networks for small streams (4th order or smaller) in the Oregon coastal Siuslaw National Forest. In each network they sampled road crossings that had been replaced to U.S. Forest Service design standards to allow fish passage and compared these to road crossings that had not been replaced. They developed a sophisticated statistical model fit using Bayesian methods to evaluate species presence, abundance, and assemblage composition of anadromous and resident fish of all species. Modeling also included habitat covariates to project habitat availability for each species above replaced road crossings. Most Chinook salmon were fall-run ocean-type, so most juveniles had migrated before the summer sampling. Sculpins were the most abundant group, resident cutthroat trout were widespread, and rainbow trout/steelhead and juvenile coho salmon were common.

Replacing road crossings to design standards greatly increased access and use by fish. For example, salmonids were captured in at least one 30-m reach sampled above 43 of 49 replaced road crossings (88%) compared to only 23 of 61 that were not replaced (38%). The odds of access by fish at replaced versus non-replaced road crossings increased by more than 40 times (Bayesian posterior credible interval: 7.7 to 391.8 times) for the median species at median gradient, which is a huge effect.

Models fit for each species separately showed that the probability of access (given that the species was present downstream of the road crossing) was as high (or higher) for road crossings replaced to design standards as at locations with no road crossings, and much higher than the probability at non-replaced road crossings. However, in all cases this probability declined rapidly with stream gradient and declined more rapidly at non-replaced road crossings. As one example, the probability of access upstream for rainbow trout/steelhead at 10% slope was nearly 100% at replaced road crossings but was only about 50% at non-replaced road crossings.

Despite the increased likelihood of access for fish at road crossings replaced to design standards, fish habitat upstream was often too narrow and steep to be suitable for colonization. Improved access allowed fish of each species to colonize only 9% or less of the 187 km (116 miles) of habitat made available after fish passage was restored. Nevertheless, this habitat was likely the most important biologically, because it included the reaches that were widest and had the lowest gradient in these steep coastal watersheds. Finally, all these results were likely conservative, because managers prioritized barriers for replacement that were most likely to block movement, whereas some not replaced were not barriers to movement or were partial barriers to some life stages or at some flows.

Barrier removal is often successful, but several important project elements can increase uncertainty (e.g., size of source populations, width and gradient of upstream habitat, presence of other barriers upstream, and presence of invasive exotic and resident fishes). Effective restoration using barrier removal must address characteristics of the site, reach, watershed and fish populations in project planning, design, and monitoring. An important requirement is to replace barriers to design standards, which are described in several guidance documents (e.g., Washington Department of Fish and Wildlife 2024) and improve the likelihood of benefits to salmon, steelhead, and other fish species.

3.1.2. Reconnecting floodplains and off-channel habitat

As the spatial scale of habitat restoration has increased, there has been an increasing focus on reconnecting floodplains and off-channel habitats (see Figure 3.2). These are typically large, complex projects, but important because floodplain habitats are critical to rearing and overwinter survival of juvenile salmonids, especially juvenile Chinook salmon and steelhead (Nickelson et al. 1992, Sommer et al. 2001, Pess et al. 2005, Rosenfeld et al. 2008). Projects reconnecting floodplains and off-channel habitats made up 15% of all habitat restoration projects for salmonids in the Upper Columbia River conducted by the Upper Columbia Salmon Recovery Board (UCSRB 2014). From 1996 to 2012, these projects protected more than 11 km^2 (2,700 acres) of off-channel habitat, reconnected 0.5 more km^2 (117 acres), and restored 18 km (11 miles) of off-channel streams. In total, floodplain reconnection projects represented the second largest fraction of restoration projects after removing barriers.

In general, reconnecting floodplains and off-channel habitats allows rapid recolonization of the newly accessible habitat by salmonids (Roni et al. 2008, Hillman et al. 2016). For example, Desgroseillier and Albrecht (2016) and Grote and Desgroseillier (2016) reported higher densities of juvenile Chinook salmon in six off-channel habitats created or enhanced along the Entiat River compared to main channel habitats, indicating that fish colonized and used the newly accessible habitats.

Figure 3.2. Example of floodplain reconnection, Meacham Creek, Umatilla River subbasin, Oregon. (FWP project #1987-100-01, Confederated Tribes of the Umatilla Indian Reservation [CTUIR]). The top two photos are from the ISRP site tour in 2013 with CTUIR staff describing their vision for river restoration, and the bottom two aerial photos show the pre-restoration creek in 2005 and floodplain reconnection and added piles of large wood post-restoration in 2020. (Sources: top photos from the ISRP; bottom photos from CTUIR webpage Meacham Creek Restoration Projects Before and After – click link to use slide bar showing area pre- and post-restoration).

Research during the past 15 years has shown the importance of floodplain habitats to food webs that support juvenile salmonids in the Columbia River Basin. Floodplain sites with upwelling groundwater in the Methow River were warmer after salmon emergence in spring and had more nutrients, thereby producing more periphyton and benthic invertebrates than downwelling reaches (Meija et al. 2015). This resulted in faster growth rates of both hatchery juvenile Chinook salmon in enclosures and wild free-ranging Chinook in the reaches with upwelling.

Additional research showed that floodplains provide more of the food production that supports juvenile Chinook and steelhead than do main channels, and that restoring these habitats provides more benefit to native fishes than adding salmon carcasses or restoring riparian vegetation. Extensive sampling and analysis of fish and their invertebrate prey across habitats of the Methow River showed that 95% of the total prey biomass consumed by fish in the main channel supported two other native fishes, mountain whitefish and sculpin (Bellmore et al. 2013). In contrast, production of prey available to anadromous salmonids in floodplain side channels was more than 2.5 times the production in the main channel, even though the low densities of these salmonids prevented much of it from being used. A model of this ecosystem showed that reconnecting side channels could potentially increase native fish biomass by 31%, much more than either carcass addition (18%) or restoring riparian vegetation (2%; Bellmore et al. 2017).

As part of the Action Effectiveness Monitoring project (AEM), Roni et al. (2023a, 2025) measured the effects of 17 projects focused on levee setback and removal, floodplain reconnection, and channel re-meandering. Many projects included side channel creation and large wood placement. They measured paired treatment and control sites 2 to 14 years after floodplain reconnection (median: 4 years), using topographic surveys, drones to measure topography with LiDAR, and snorkeling to measure abundances of juvenile coho and Chinook salmon, steelhead, and whitefish. The results for fish of this Extensive Post-treatment Design were evaluated using two-tailed paired *t*-tests with alpha=0.10, to increase power to detect differences. One site was excluded because no salmonids were observed.[5]

Counts of large wood per 100 m were 6.5 times higher in treatment reaches where floodplains had been reconnected than in adjacent control reaches ($P<0.01$ by paired Wilcoxon signed rank test), and pool frequency was 1.4 times higher

[5] Statistical Note: Doubling the alpha level (to 0.10 vs. the traditional 0.05) greatly increases the chances (power) of detecting a significant difference, but with the tradeoff of also greatly increasing chances of claiming a difference when there is none (Type I error). This increase in alpha level is typically justified when the consequences of failing to find a difference are dire, such as when a treatment such as cattle grazing could cause resource damage.

(P=0.04). Counts of fish were highly variable, but juvenile steelhead and all juvenile salmonids combined were 1.6-1.7 times greater in treatment than control reaches ($P \leq 0.01$ for each by two-tailed paired *t*-test). However, in many cases fewer fish of several species were counted in the treatment versus control sections (7 of 13 sites for Chinook, 5 of 16 for steelhead, 5 of 11 for whitefish). Nevertheless, effects for juvenile steelhead and all salmonids combined were strong and positive, even for the modest sample size of sites that could be measured for these large-scale restoration projects.

Replicates of large-scale habitat restoration projects like floodplain reconnection are difficult to find and evaluate, and it may take years to decades for fluvial processes to play out and restoration to reach its full effect. Likewise, such projects do not necessarily address overarching issues at the watershed scale, such as water withdrawals or increased sediment loads. Several habitat metrics that increased significantly are those directly affected by management actions, such as adding large wood that creates pools.

Detection of fish responses was hampered by the small number of sites, and because some species were absent at some sites (e.g., Chinook at 13 sites, coho at 6 sites). In addition, numerical responses could have been affected by the short times between restoration and response (typically 4 years), variability in intensity and types of restoration among sites, and differences in ability to count fish in treatment versus control sites (e.g., lower detection probability in treatment sites owing to more complex habitat). Finally, fish surveys were done at low flows in summer, but floodplains may be especially important to fish at high flows and in winter, a topic for future assessment.

Floodplain restoration projects have increased in size and complexity since the inception of the AEM program in 2014, making adequate control sites nearly impossible to locate. Current monitoring focuses on remotely sensed metrics coupled with field data, and a Before-After study design to detect differences in habitat after restoration (see Roni et al. 2023a, 2025). An Extensive Post-treatment Design may still be useful for comparing fish abundances at points in time after restoration has influenced fluvial processes and had fuller effects on fish populations.

Results of monitoring indicate that floodplain reconnection projects are often successful with respect to fish recolonization, food production, and several habitat metrics. The Columbia Basin Tributary Habitat RME Strategy (2022) recommends that floodplain reconnection projects should be the focus of monitoring because of high uncertainty. Uncertainty results from a lack of suitable controls in monitoring efforts, the long timeframes required for habitat to develop, diversity of stream and watershed characteristics, and lack of winter monitoring. In winter, reconnection projects may be especially beneficial as refuges for fish during higher flows. While the ISRP believes that increased monitoring effort is a reasonable recommendation, we suggest that periodic synthesis using appropriate meta-analyses of monitoring results will be warranted to better address uncertainties (see 4.8. Synthesizing information across multiple projects).

3.1.3. Large wood

The history of logging, clearing for agriculture and residential land, stream and river cleaning for navigation, and road and bridge maintenance reduced wood density in many Pacific Northwest channels and wood's function as habitat in aquatic ecosystems (Wohl 2014). Structures made of large wood (see Figure 3.3) have been placed in streams to enhance habitat for salmonids since the 1930s (Hubbs et al. 1932, Needham 1938) but gained much wider and complex application following the recognition of the important role of large wood in stream ecosystems starting in the late 1970s (Swanson et al. 2021). In the Columbia River Basin, this approach has also been used since the inception of the Fish and Wildlife Program. The general hypothesis behind such efforts is that large wood creates pools and increases habitat complexity, thereby reducing inter-specific and intra-specific competition, and increasing foraging sites, protection from predators, and survival by providing low-velocity locations during floods and winter conditions.

This hypothesis about the importance to fish of habitat created by wood is based, in part, on studies of microhabitat selection by juvenile salmonids in streams. For example, juvenile steelhead selected positions with overhead cover, visual isolation, and velocity refuges during summer (Fausch 1993), and juvenile coho selected locations with low velocities in deeper water close to large wood structures during winter (Tullos and Walter 2015). Wall et al. (2017) calculated the profitability (net rate of energy intake, NREI) of foraging locations before and six months after four Post-Assisted Log Structures (PALS) were placed in a 40-m reach of Asotin Creek, Washington. They reported a doubling of microhabitat area that provided energetically favorable foraging locations for juvenile steelhead, increasing the estimated carrying capacity of the reach by 32%. Further improvements to microhabitat may be expected after more high flow events occur that create scour around the structures.

Figure 3.3. Example of large wood restoration in various locations in the Yakima River subbasin, Washington. Bottom photos of before and after large wood placement (FWP project #1997-051-00, Confederated Tribes and Bands of the Yakama Nation) (Source: Yakama Nation and Mid-Columbia Fisheries Enhancement Group; "Wood Fiesta" presentation to NPCC 2021).

Methods for restoring wood in streams have evolved over time. Initially, small amounts of wood were placed in streams, but often many of these pieces were washed downstream by high flows. Movement of wood in streams is a fundamental geomorphic process and is a critical component of wood restoration (Wohl et al. 2019), but the success of wood restoration can be reduced if transport from upstream has been reduced. More recently, engineered log jams, typically with at least some pieces anchored in place, have been used in large rivers, so the habitat feature remains in place. In addition, recent approaches to wood involve the addition of large amounts of wood (up to 1000s of pieces) in the active channel and adjacent to it. This allows the wood to a) create complex accumulations that are expected to be much less mobile than isolated pieces or small accumulations; b) trap additional wood in transport; and c) increase channel complexity with respect to hydraulics, substrate, hyporheic exchange flows, and overhead cover.

Since the 1980s, more than 2,000 wood placement projects have been installed in the Columbia River Basin (Clark et al. 2019). For example, instream structures such as engineered log jams were among the most common type of habitat restoration carried out by the Upper Columbia Salmon Recovery Board, making up a fifth of all projects (UCSRB 2014). By 2012, these projects added 518 structures, created 180 pools, and enhanced 35 km (22 miles) of streams in this region.

The effectiveness of wood habitat structures has received significant scrutiny from river restoration scientists, who question whether they actually increase fish numbers or biomass. Most credible reviews of such structures,[6] across many regions worldwide, report positive results overall (e.g., Whiteway et al. 2010; Roni et al. 2015). For example, Hillman et al. (2016) reported that about 90% of the 83 studies that they reviewed showed positive effects of placing habitat structures made of large wood on physical habitat, and about 70-80% reported positive effects on juvenile or adult salmonids (N=67 and 33 studies, respectively; Figure 3.4). Fewer than 3% of studies reported negative effects in any of these cases (the rest were equivocal). Even with a likely publication bias against negative results (i.e., investigators finding no effect, or a negative effect, are unlikely to attempt publication or successfully publish results), these results are biologically significant. Nevertheless, results are expected to vary across species and regions, owing to different responses to such structures by different salmonids at different life stages (cf. Fausch 1993; Roni and Quinn 2001a, 2001b; Quinn 2018).

A key study reporting effectiveness of large wood structures in Columbia River tributaries stemmed from the AEM project. Clark et al. (2019) analyzed 29 sites where large wood structures had been placed 2 to 18 years previously, using an Extensive Post-treatment design.

[6] A review by Stewart et al. (2009) was shown by Whiteway et al. (2010) to include mistakes that produced flawed results.

Physical habitat was measured and fish abundance counted by snorkeling during summer in treatment reaches (where wood was added) and control reaches (without added wood). Results showed that large wood (total, and functional pieces that created habitat in the low-flow channel) was 4.5 to 6.1 times higher in treatment than control reaches, and habitat complexity, number of pools, and proportion of pool area were 1.2 to 1.4 times higher in treatment reaches. All these effects were statistically significant ($P < 0.01$).

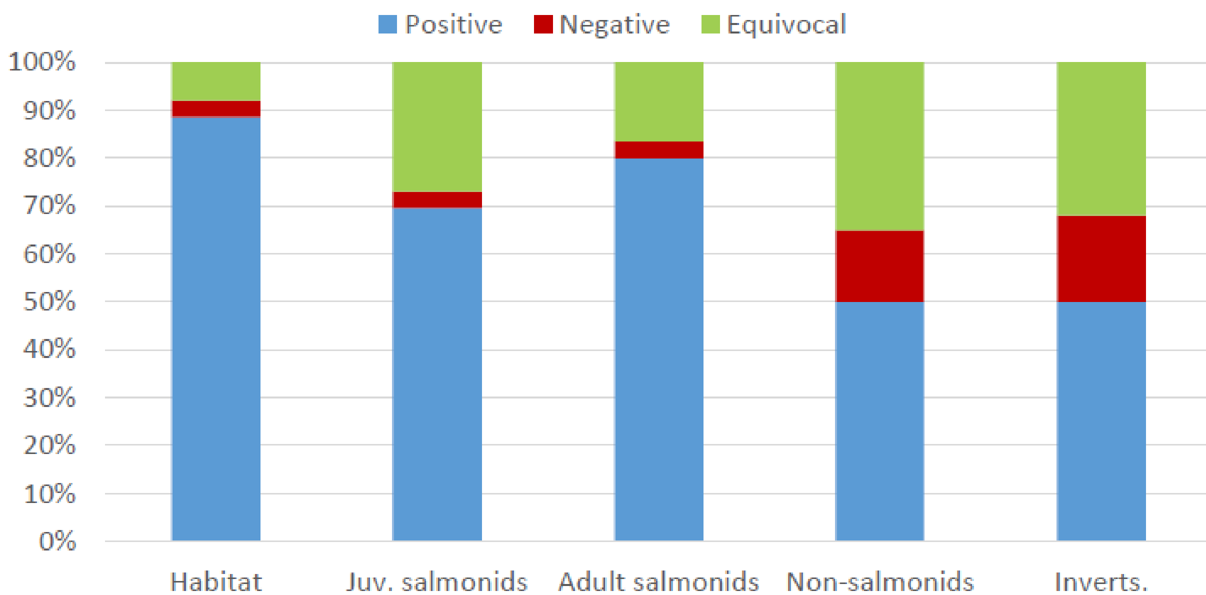

Figure 3.4. Proportion of published studies of installed large wood structures that reported positive effects, negative effects, or no change (equivocal) in physical habitat, fish (juvenile and adult salmonids, or non-salmonids), or macroinvertebrate density or diversity (Inverts.). The number of studies (n) was 83, 67, 33, 17, and 21 for each case, from left to right. Some studies reported responses for several categories (from ISAB 2018-1; after Roni et al. 2015 and Hillman et al. 2016).

Counts of juvenile Chinook and coho salmon, and steelhead, were 2.3 to 2.8 times higher in treatment compared to control reaches (i.e., more than doubled), and counts of cutthroat trout were 1.6 times higher (all effects were significant at $P \leq 0.02$ by paired *t*-test after log transformation; Clark et al. 2019). Responses by Chinook and coho salmon were positively correlated with the proportion of pool area ($P < 0.02$) and the response of Chinook was also positively correlated with functional large wood ($P = 0.03$). Extrapolation from this latter relationship yields the prediction that increasing functional large wood by 10 times would increase juvenile Chinook salmon abundance by about 3 times. No significant difference was detected in the responses of either habitat or salmonids across three major regions of the Columbia River Basin ($P \geq 0.20$), indicating that the responses were relatively uniform across these environments.

Beaver dam analogs and post-assisted log structures

Over the last decade, restoration projects applied novel installations of wood to mimic beaver dams (Beaver Dam Analogs or BDAs) or wood accumulations (Post-assisted Log Structures or PALS; Shahverdian et al. 2019). Similar low-tech methods using wood have been used in stream restoration projects over the last century, but specific applications have been developed recently in the Basin for BDAs (Pollock 2014) and PALS (Bennett and Bouwes 2009). The BDAs are channel-spanning wood structures installed to resemble and function like natural beaver dams (see Figure 3.5). They trap wood in transport, pond water, store sediment and organic matter, and may attract beavers to create additional dams or augment the BDAs. The PALS are collections of wood anchored by posts driven into the streambed to mimic natural wood accumulations. They trap additional wood and organic matter and modify channel structure similar to wood jams. Installation of BDAs and PALS requires no large equipment, thereby avoiding major equipment damage to streams and riparian areas. Relatively small crews can install these structures, even in remote locations.

The use of BDAs and PALS in the Program and region are relatively recent, and monitoring studies are limited but encouraging for small stream restoration. Two IMWs conducted watershed analyses to determine limiting factors and design the location, number, and types of structures. Monitoring and evaluation of BDAs installed in the Bridge Creek IMW determined that abundance of juvenile steelhead increased by 168% and their production (g/100 m/120 d) increased by 175% (Bouwes et al. 2016). Juvenile steelhead survival was 52% greater than the period before installation of the BDAs. PALS were installed in the Asotin Creek IMW in 2011. By 2017, pool habitat and large wood abundance increased significantly, and fish abundance increased by 26% (Asotin IMW Accomplishment Report 2017).

Figure 3.5. Example of beaver dam analogs in Bridge Creek, John Day River subbasin, Oregon. The BDA structures facilitated development of beaver complexes and habitat responses, resulting in increased juvenile steelhead survival and productivity. (FWP project #2003-017-00, NOAA Fisheries, completed) (Sources: aerial photos from PNAMP Bridge Creek IMW Accomplishment Report; BDA photo from the ISRP).

Additional studies of the geomorphic, riparian, fish, and other aquatic community responses to BDAs and PALs are needed to better understand their effectiveness and design requirements. As with all wood restoration, floods, fire, and other disturbances can affect their performance. Restoring wood in steep, high-gradient reaches is challenging. The small sized wood used to construct BDAs and PALS can initiate the channel and riparian changes desired, but the wood decomposes over several decades and the function of the structures will change. Where objectives for BDAs and PALS include riparian plant or forest restoration, factors such as native wildlife herbivory, livestock, drought, and site conditions will influence the rate and type of riparian recovery.

Spatial scale and outcomes of wood restoration

The responses to wood restoration measured at the reach scale during summer contrast with those measured at the basin scale for whole populations throughout their life cycles. Several IMWs reported variable responses to additions of large wood. Changes to habitat ranged from positive to negative, and responses by fish required many years to decades to evaluate.

For example, Bilby et al. (2022) evaluated responses for 11 IMWs where large wood or engineered log jams were placed to increase instream habitat complexity and connect streams to lateral floodplain habitats. Responses of these habitat metrics ranged from positive (7 IMWs) to equivocal (3), and one IMW had not yet evaluated the response. Of these 11 cases, 5 IMWs reported an increase in juvenile salmonid abundance, 6 reported an increase in juvenile salmonid survival and smolt production, and 2 reported an increase in abundance of adults. Hence, a bit more than half the IMWs reported increases in habitat complexity, and about half or fewer reported increases in juvenile salmonids or smolts, whereas few reported increases in adult fish returns. A more detailed analysis of five IMWs of this set supported by the Salmon Recovery Funding Board reported similarly variable responses (Anderson et al. 2023).

Although these results at large scales contrast markedly with those at reach scales described above, the differences are likely explained by factors that vary across scales of space and time. For example, fish may use complex habitat created by large wood structures at reach scales during summer to enhance foraging opportunities and protection from predators, and reduce intraspecific competition, increasing their abundance there (Clark et al. 2019). Despite this, the addition of structures in restricted reaches may be insufficient to increase abundance, growth, and survival of juveniles, the production of smolts, and the return of adults when measured at the watershed scale and given high variability in flow and ocean conditions.

One of the main sources of uncertainty in large wood restoration is the amount of time required to cause effects and detect them. The addition of sufficient large wood to cause substantial changes to habitat may take a decade or more to achieve. Moreover, the effects of this habitat enhancement on the fluvial processes and habitat conditions that affect the freshwater life cycle of fish populations may take another decade to fully manifest (Bilby et al. 2024; Bisson et al. unpublished). Overall, although additions of large wood can increase the summer abundance of juvenile salmonids at reach scales, whether they will have positive effects over the entire life cycle and at watershed scales depends on many factors that play out at larger spatial scales over longer time spans and are much more difficult to measure.

The addition of wood to stream channels to provide habitat for fish and other aquatic organisms without restoring riparian forests is an example of structural restoration rather than process restoration. If the causes of low wood abundance and reduced wood delivery in streams in forested landscapes are a result of timber harvest, or if decreased wood volumes are a result of channel clearing after logging, wood addition will provide only short-term benefits. Process-based approaches (Beechie et al. 2010) should include restoration of the riparian forest as a long term strategy as well as addition of large wood to streams as a short term strategy, to restore both stream and riparian ecosystem function.

3.1.4. Riparian areas

Restoration of riparian forests, meadows, and wetlands is a fundamental component of habitat restoration in the Columbia River Basin (see Figure 3.6). Loss of riparian forests is one of the major causes of stream warming, and stream temperature is the major water quality impairment in the Pacific Northwest. Even in meadows and wetlands along small streams, communities of willows and riparian shrubs can provide shade and reduce rates of warming (Kaufman 2002). Riparian plant communities influence other physical and ecological processes in addition to shade and stream temperature, including food inputs of terrestrial organic matter and terrestrial invertebrates, dissolved nutrient inputs, delivery of large wood, bank stability, and sediment input (Gregory et al. 1991, Baxter et al. 2005). Riparian plant communities also provide important habitat and migration corridors for terrestrial wildlife but can be degraded by grazing livestock.

As with large wood additions, a major challenge for assessing the effectiveness of riparian plantings and livestock exclosures for riparian restoration is the time required to restore the characteristics of mature riparian vegetation and the limited age of most riparian restoration projects. Short-term changes do not reflect the ecological objectives for restoration. Bank stabilization and reduction of lateral sediment input requires 10 to 20 years. Reestablishment of canopy cover to provide shade often requires 25 to 50 years, depending on stream size and forest type (Justice et al. 2017, Pess and Jordan 2019). Inputs of large wood take even longer to recover, requiring 50 to 100 years for restored riparian zones to begin to deliver substantial wood volumes and more than 200 years for them to provide wood delivery similar to old-growth forests (Meleason et al. 2003, Wohl et al. 2019).

Most available research and monitoring assess only the initial stages of recovery of riparian-related physical and ecological processes. The studies cited here are all limited to short-term responses, highlighting the need for coordinated long-term studies of riparian restoration. A study of 109 riparian restoration sites in oak woodlands and grasslands of the north coast of California found that recovery of riparian vegetation and aquatic habitat objectives was related to the age of the project, which ranged from 4 to 39 years (Lennox 2011). Significant increases with time since restoration were reported for vegetation abundance, total canopy, and native trees, with decreases in cover of annual forbs. Aquatic habitat, large and small wood, stream shade, and longitudinal shade also increased significantly through time. Bank stability and percent pool habitat also increased with time since restoration, although the relationships were weaker than for wood and shade. Although this study is not from the Columbia River Basin, it demonstrates the importance of response time, long-term evaluation of riparian restoration, and the need for future studies in the Columbia River Basin.

Riparian plantings

An analysis of nine riparian planting projects in Washington and Oregon demonstrated increased woody vegetation and high rates of survival of plantings after 5 to 10 years, but there were no significant differences in ground cover, canopy cover or bank erosion (O'Neal et al. 2016). The AEM Project measured characteristics of riparian vegetation in 31 riparian planting sites and 10 sites with both riparian planting and invasive plant removals across the interior Columbia River Basin, ranging in age from 2 to 24 years (Roni et al. 2023a, Burgess et al. 2023). Plant species richness and abundance of woody plants were significantly greater in restored reaches than in reference reaches.

A challenge for riparian plantings is the availability of water in areas with lowered water tables. A study of deep planting in an incised reach of Bridge Creek, Oregon found that cottonwood and willow pole cuttings planted in augured holes that penetrated water tables up to 1.9 m below the surface survived at seven times the rate of plants that were not planted to the depth of the water table, a significant difference (Hall et al. 2015).

A study in the Middle Fork of the John Day River used high-resolution fiber optic monitoring and a temperature model to assess the effects of riparian and channel restoration on stream temperatures (Hall and Selker 2021). The influence on stream temperature was a function of the change in water surface area and percentage of effective shade. The model results demonstrated that the benefits of riparian shade restoration required decades of growth to begin to mitigate for temperature increases, reducing temperature during the day and increasing temperatures at night. Less time is likely required for shade recovery of smaller, narrow streams than wider streams.

Figure 3.6. Example of riparian restoration, Trout Creek, Nye reach, Oregon, showing growth of riparian vegetation plantings (trees, shrubs, native grass and forbs) from 2005 to 2021 (Source: FWP projects #1998-028-00, Jefferson County Soil and Water Conservation District and #1994-042-00, ODFW)

Animal exclosures

Published studies of the effectiveness of livestock exclosures are more numerous than studies of riparian plantings alone, reflecting the greater use of fencing to restore riparian plant communities (Hillman et al. 2016). However, the results of using animal exclosures to restore riparian vegetation and aquatic habitat are mixed. Projects with exclosures differ greatly in type of fencing, age of the exclosure, differences in animals and history of grazing, locations of exclosures relative to reference sites, local environmental conditions, stream discharge and size, entry by native ungulates, and the extent to which they fully excluded livestock. Despite these challenges, several general outcomes have been observed in most studies described below.

The study of deep planting cottonwood and willow cuttings in Bridge Creek also examined the benefit of using plastic tree shelters and 1-m circular fencing around plantings. Use of plastic tree shelters resulted in over 50% higher survival after 3 years compared to unprotected and fence-caged plants, although higher fencing protected upper branches and buds, with 25% lower browse rates after three years.

Kauffman (2002) measured responses of riparian vegetation, stream geomorphology, and fish populations to livestock exclusion in paired reaches in 11 streams in Northeast Oregon. Plant species diversity and richness were higher in exclosed stream reaches. Cover, composition, and structure of forbs, shrubs, and sedges were significantly greater in the majority of exclosed reaches, and bare ground was more extensive in grazed reaches. Composition of streamside vegetation shifted to more mesic wetland riparian vegetation in livestock exclosures. Cover of willows, alder, and riparian shrubs was greater in 88% of the exclosures than in the paired grazed sites, and differences were greater in older exclosures, demonstrating that outcomes of riparian restoration reflect the age of the project. Stream channels in the exclosed reaches were significantly narrower, deeper, and contained greater proportions of pool habitat than the grazed reaches, although pool depth did not differ. Densities of age-0 redband trout were significantly greater in exclosed reaches than in grazed reaches, but densities of juvenile and adult trout did not differ. Warmwater fishes (redside shiners and speckled dace) were more abundant in the grazed reaches.

Bayley and Li (2008) compared fish communities and stream habitat in exclosures and unfenced, grazed reaches in eight second-order streams in the John Day River, Grande Ronde River, and Great Basin catchments in northeastern Oregon. Estimates of densities of age-0 redband trout in pools were 2.5 times greater in exclosed reaches whereas densities of warmwater fishes (e.g., speckled dace) were greater in grazed reaches. The authors attributed the greater density of age-0 trout in exclosures to the potential food supply and cover. The 7-d means of daily maximum or minimum stream temperatures in exclosures and grazed reaches were not significantly different.

The AEM Project measured responses to livestock exclusion in paired treatment and control reaches of 12 streams in Washington and Oregon (Krall et al. 2021). Sites were monitored for 1 year before installation of the exclosures and 1, 3, 5, and 10 years after to assess bank erosion, bank canopy cover, riparian vegetation structure, and fine sediment in the tails of pools. Livestock exclusion significantly reduced bank erosion from 44% prior to restoration to 11% by year 10, and bare ground was significantly lower after exclosure. Canopy cover and cover of woody and non-woody vegetation was not affected by livestock exclosure. Proportion of fine sediments did not differ significantly between treatments and controls.

A study of riparian restoration using livestock fencing exclosures in14 streams of the John Day Basin compared livestock exclosures to grazed sites (Archibald 2015). Wetland indicator values for understory plant communities increased in the older exclosures as compared to paired grazed reaches. Shrub density did not differ between treatments and controls but was greater in older exclosed sites than the paired grazed reaches. Shading was greater in the exclosed reaches and the difference increased with exclosure age, similar to the effects of age described above. Despite greater shading, water temperatures did not differ significantly between exclosed and grazed reaches, possibly reflecting the relatively short channel length exclosed. Fish densities also did not differ between the exclosure and grazed reaches.

Two studies examined the effects of large-scale elimination of livestock in riparian areas at Hart Mountain National Antelope Refuge in southeastern Oregon (Dobkin et al. 1998, Batchelor et al. 2015). The first study compared the structure of plant and avian communities on 1.5-ha plots inside a long-term (ca. 30-year) livestock exclosure with adjacent plots outside the exclosure (open plots) for 4 years following removal of livestock from open plots (Dobkin et al. 1998). Sedge cover, forb cover, and foliage height diversity of herbs were greater on exclosure plots. Bare ground, litter cover, shrub cover, and shrub foliage height diversity were greater on open plots. Forb, rush, and cryptogamic cover increased on open plots after livestock were removed but not on exclosure plots. Grass cover increased on all plots in conjunction with increased moisture. Sedge cover did not change. Avian species richness and relative abundances were greater on exclosure plots. Wetland and riparian birds were more abundant on the exclosure plots, whereas open plots were dominated by upland species. The subsequent study compared photographs of open sites 23 years after the removal of cattle grazing with 64 photos taken before grazing was removed (Batchelor et al. 2015). Stream channel widths decreased in 64% of the sites and eroding banks decreased in 73% of the sites. Cover of grasses/sedges/forbs increased by 15%, rushes increased by 389%, and willow increased by 388%, 23 years after livestock removal.

Responses of riparian wetland plant communities to livestock exclusion were investigated in a wetland dominated by invasive reed canary grass in the Lower Columbia River Basin (Kidd and Yeakley 2015). Two restoration sites, 3 and 13 years following livestock exclusion, were compared with a site with continued livestock grazing. Total species richness in the grazed wetland was twice that in the exclusion sites. Non-native species richness was significantly greater in the wetlands where livestock were excluded. Species richness did not differ between the two exclusion sites of different ages. Cover of native species was significantly lower in the older exclusion site. Reed canary grass was the dominant plant cover at all sites and was most abundant at the oldest exclusion site. The authors concluded that livestock exclusion may be ineffective for restoring riparian plant communities where aggressive invasive vegetation is present.

Finally, research in the central Rocky Mountains showed that riparian vegetation and inputs of terrestrial invertebrates that feed trout were higher under progressive livestock grazing practices versus season-long grazing and were associated with higher fish abundances (Saunders and Fausch 2007, 2012). Conserving woody riparian shrub vegetation that is degraded by long-term season-long cattle grazing is especially important as a source of terrestrial invertebrates that fall into streams and feed fish (Saunders and Fausch 2018).

Modeling

The Pacific Northwest has a long history of empirical studies of stream temperature and riparian vegetation, largely from "effects of logging" studies, and the physics is well known (e.g., Brown and Krieger 1970). Several major models of riparian effects on stream temperature have been developed in the region. Models of relationships between riparian vegetation and stream temperature, and between stream temperature and spring Chinook salmon, were used to explore the potential benefits of riparian restoration to salmon and possible effects of climate change (Justice et al. 2017). Basin maps of land cover under scenarios of riparian restoration were used to estimate stream narrowing and temperature responses to restoration. These estimates for the stream network were compared to stream temperature predicted by climate change models. The model predicted that a combination of riparian restoration and channel narrowing would reduce maximum summer water temperatures by an average of 6.5°C (11.7°F) in the Upper Grande Ronde River and 3.0°C (5.4°F) in Catherine Creek. These lower temperatures potentially would increase parr abundances of Chinook salmon by 590% and 67%, respectively, in the two streams. The authors concluded that temperature reductions owing to riparian restoration would potentially offset the increases projected for regional warming by 2080 (median increase of 2.7°C [4.9°F] in the Upper Grande Ronde and 1.5°C [2.7°F] in Catherine Creek).

Mechanistic stream temperature models and spatial stream models for the Middle Fork John Day River, Oregon, and Wind River and South Fork Nooksack River, Washington, were used to evaluate the potential effectiveness of stream restoration practices (i.e., riparian plant restoration, channel narrowing, increasing flow by restricting irrigation withdrawals, and combined applications; Fuller et al. 2025). Riparian vegetation restoration consistently was most effective in reducing temperatures throughout the watersheds. The study emphasized that regulations focused on specific locations (e.g., monitoring sites, river mouths) can overlook restoration potential in headwaters and the value of potential cold-water refuges throughout the river network.

In contrast to the two modeling examples above, an economic model of return on investment for restoration interventions in the Wenatchee River Basin concluded that riparian forest restoration would not be effective at increasing salmon production (Fonner et al. 2021). This analysis was based on earlier models of the Wenatchee watershed that predicted that prespawning and summer temperatures would decrease only slightly from current conditions in response to full implementation of proposed restoration actions (Jorgensen et al. 2009). In contrast, a companion analysis showed that temperatures would be warmer and smolt and adult Chinook production would decrease substantially under a scenario of continued degradation (Honea et al. 2009). The lack of positive response in the model possibly was because the temperature benefits of riparian restoration were predicted to be slight.

In conclusion, our review of using riparian plantings and livestock exclosures to restore riparian conditions suggests that riparian restoration primarily helps improve stream temperature but can also enhance food supply and stabilize banks. The empirical data on riparian restoration are limited or largely inadequate to measure responses to restoration because most projects in the Columbia River Basin are too recent to show a substantial response. Nonetheless, some monitoring projects (e.g., Asotin, Middle Fork John Day, Grande Ronde) showed changes in channel structure and sediments even in less than a decade.

Monitoring of 25 years or more is needed to fully evaluate results of riparian restoration. Although it seems unreasonable to expect a project sponsor to monitor that long, we recommend that the Program provide a mechanism for periodic monitoring of riparian restoration efforts where the important effects take many years to develop. For more than 75 years, long-term watershed studies have been conducted in the Pacific Northwest (e.g., Alsea Watershed Study, Carnation Creek Study, H.J. Andrews Experimental Forest, Wind River Experimental Forest) and are still part of ongoing research, including in the Columbia River Basin. A 200-year log decomposition experiment has been established in H.J. Andrews Experimental Forest in the McKenzie River basin (Harmon 2021). We recommend the Program develop an *a priori* experimental design to evaluate long-term effectiveness and improve power of future analyses to rigorously determine environmental, physical, ecological responses to riparian restoration (See Section 4.8 on Sampling and Experimental Designs).

3.1.5. Dike breaching and tide gate management in estuaries

Since estuarine restoration in the Estuary began in the early 2000's, most projects have focused on restoring hydrologic connectivity by breaching or eliminating dikes and berms (see Figure 3.7). Some restoration projects have also added fully functional or modified tide gates. Restoring connectivity of tidal wetlands is a primary approach used throughout the West Coast to restore estuary functions (Souder et al. 2018). While tidal action is being restored, efforts may be undertaken to also adjust the elevation of the wetland to facilitate recolonization by native vegetation. Excavation may also help restore channels in marshlands, which are critical habitat for salmon and other fish. Channel reformation depends on elevation of the recovering marsh area, amount of flow entering the marsh, extant salinity, and availability and delivery of sediment. As estuaries are restored, they will typically evolve as some type of wetland with channels, but this process may take decades.

Figure 3.7. Example of dike breaching and tide gate management in the Wallooskee-Youngs estuary restoration project, Astoria, Oregon (FWP project #2012-015-00). This project lowered or removed over a mile of levee and in the process removed 5 tidegates. The project also recreated nearly 10 miles of interior channels from historical data and enhanced LiDAR imagery. The former dairy farm is inundated twice daily providing access to, and organic import from, about 190 acres of tidal marsh. Native plants have germinated, although the vegetation community is still evolving. Top left: Construction in 2017, facing southwest (credit Cowlitz Indian Tribe). Top right: Five years after construction, the largest channel, facing southeast (credit Lower Columbia Estuary Partnership).

An example of restoring hydrology by breaching dikes is in the estuary of the Salmon River, Oregon, not far south of the Columbia River Basin. Restoration projects removed dikes in three locations in 1978, 1987, and 1996 and recovery of marsh vegetation was compared to an adjacent reference marsh that had never been diked (Gray et al. 2002). In addition, changes in out-migrant fish density, food availability, and diet composition for juvenile Chinook salmon in the marshes also were measured to determine the effectiveness of dike removal for fish populations.

Marsh vegetation reflected differences in subsidence due to the previous dikes as well as site variation in elevation, but the marsh where the dike had been recently removed was patchy and channels were wider and more open, reflecting the limited recolonization of the inundated surfaces over the short time since dike removal. By 2007, deposition of sediments in the restored marshes created marsh elevations and deepened tidal channels that were similar to the reference marsh (Flitcroft et al. 2016).

Abundances of Chinook salmon and staghorn sculpins peaked in the first 2-3 years after dike removal (Gray et al. 2002). Chinook and coho salmon occupied the restored marshes, but geographic position in the estuary influenced their distribution more than the time since restoration (Flitcroft et al. 2016). Juvenile salmon more consistently occupied the marsh closest to freshwater habitat as they entered the estuary from upstream. Invertebrate densities were dominated by chironomid insect larvae during this period as well, indicating increased food availability for fish in the newly inundated marshes (Gray et al. 2002).

A key finding was that restoration of the Salmon River estuary allowed Chinook and coho salmon to re-express their full life-history diversity. Removing the dikes resulted in each species recreating four different life-history types, each of which used the estuary for different but overlapping portions of their life cycles. For example, one life-history type of coho reared in freshwater streams through autumn, then emigrated to the estuary to spend the winter and outmigrated in spring. Another type emigrated to the estuary as fry and remained there until autumn but then moved upstream into small freshwater tributaries of the estuary to spend the winter before outmigrating the next spring (Flitcroft et al. 2016). This diverse portfolio of eight life-history types displayed by the two species improves productivity and lends resilience in the face of disturbances like droughts, floods, and tsunamis that affect only certain portions of the watershed. Other life-history types that use habitats less affected can thrive despite the disturbances.

The basic principles of estuary restoration, such as breaching dikes and eliminating tide gates, have changed little over the last several decades. Early projects often focused on the lower (i.e., more saline) parts of the estuary. A major shift in the restoration paradigms was the recognition that the estuary extended to the base of Bonneville Dam and that restoration efforts should extend to this point, because listed fish populations were found in all parts of the estuary not just the most saline and tidal portion. Another paradigm shift was the realization that horizontal position of a site relative to the main channel could be important because fish use tended to decrease with distance from the main channel.

Production of hatchery-origin salmon upstream in the Columbia River potentially limits the benefits of estuary habitat restoration associated with dike and tide gate removal for natural origin fish (Bottom and Krueger 2022). The concentration of higher numbers of migrating hatchery-origin smolts within a shorter time period can increase competition with natural-origin fish and the greater size of hatchery fish can give them even greater competitive advantage. Hatchery salmonids migrating in the main channel feed along the margins and feed in the same areas as natural–origin fish in the marsh as they move to the river margins during tidal outflow (David et al. 2015, Jones et al. 2018).

There are complications and uncertainties associated with removing or breaching a dike. First, a major issue is whether dikes/berms should be removed or breached in one or more locations. The two approaches differ in cost (total removal of levees is more expensive), and how they restore hydrology. Second, if restoration sites are privately owned then property acquisition is required at the same time as restoration. One significant difference between estuary lands and tributary/mainstem lands is that there are relatively few public (e.g., national forests) or tribal reservation lands in the estuary. Third, large projects are more desirable than small ones because of the cost and complications of removing roads and construction of new levees. Invasive plant and water quality issues can also develop as the site restores.

3.1.6. Environmental flows

Flow augmentation and habitat restoration

Flow augmentation, or the provision of instream river flows (i.e., environmental flows), is intended to improve aquatic habitat and fish survival by enhancing juvenile and adult fish survival as they live in and move through the hydrosystem and tributary rivers and streams. These efforts are designed to restore lateral (i.e., with floodplains) and longitudinal connectivity of aquatic habitats, and to mitigate negative effects of poor water quality at critical periods during the water year. Conservation agreements provide enhanced flow at key times in the life cycle of salmon and steelhead, usually during summer months when water temperature is high and dissolved oxygen is low (see Figure 3.8). Seasonal flow augmentation can be integrated with structural restoration like large wood addition and riparian fencing to improve conditions for fish. Here, we focus primarily on restoration actions to augment flow in tributaries and subbasins of the Columbia River. We do not address flow management in the mainstem Columbia River, which is a major effort to reduce the negative effects of the hydrosystem on fish passage and survival. Examples of representative types of flow augmentation for restoration of fish and wildlife resources and their intended outcomes are provided in Table 3.1.

Figure 3.8. Example of instream flow in Racetrack Creek before and after flow protection through a conservation agreement, Clark Fork River subbasin, Montana (FWP project #2002-013-01, Columbia Basin Water Transaction Program) (Source: Clark Fork Coalition).

Table 3.1. Representative project locations, actions, and outcomes where flow augmentation was employed solely or in addition to other habitat restoration actions. Project descriptions are summarized in ISRP (2008-4) and Homel and Bach (2024). The references listed provide more detail about outcomes determined by monitoring and evaluation. These are summarized in ISRP (2013-2), Hillman et al. (2016), Bilby et al. (2022), and the Columbia Basin Tributary Habitat RM&E Strategy (BPA/BOR 2022). IMW = Intensively Monitored Watershed. CBWTP=Columbia Basin Water Transactions Program.

Location	Action	Outcomes	References
Columbia River and Snake River Mainstem Augmentation and Dam Operations	Water budgets to allocate specific volumes of water during critical periods for juvenile salmon	Lower mortality associated with fish passage through turbines. Lower transport time of smolts through the hydrosystem. "Engineered resilience" to climate change through temperature mitigation.	ISAB 2001-5, Zabel et al. 2002, ISAB 2003-1, Hatcher and Jones 2013 Skalski et al. 2021
Hanford Reach below Priest Rapids Dam	Vernita Bar Agreement/Dam Operations	Mitigated river-level fluctuations resulting from dam operations, reduced stranding of eggs and provided juvenile rearing habitat. Large increase in fall Chinook productivity.	ISAB 1998-5, Harnish et al. 2014
Libby and Hungry Horse Dams	Modification of dam operations to augment flows during critical periods for salmonids and other species	Variable (VAR) outflow (Q) during the spring for listed species that preserves adequate flood control for the lower Columbia River. Other operations are designed to simulate a spring freshet to assist endangered Kootenai River white sturgeon spawning.	ISAB 2004-2, Muhlfeld et al. 2012 , ISRP 2016-10
Hungry Horse/Flathead Lake	Seasonal flow releases from the Hungry Horse Dam	Reduced temperature extremes and improved spawning and rearing conditions for bull trout. Releases stabilized flows downstream to prevent habitat degradation and avoid stranding juvenile fish.	ISAB 2004-2, ISRP 2008-4, Muhlfeld et al. 2012, Kovach et al. 2018
Umatilla Basin	Integrated instream flow conservation and habitat restoration enabled by water exchange programs	Structural habitat restoration like large-wood additions and riparian fencing integrated	Confederated Tribes of the Umatilla Indian Reservation 2023

		with flow management to optimize conditions for natural and artificial production goals.	
Catherine Creek	Upper Grande Ronde Subbasin Restoration Projects; instream water leases	Integrated habitat restoration and water provision during low flows provides deep, cool pool refuges during late summer and early fall.	ISRP 2018-11, Childs et al. 2023
Salmon Creek	Restoration of connection of Okanogan River and Salmon Creek via CBWTP and Washington Water Trust water lease	Monitoring indicated increases in steelhead returns and recruitment of sockeye and steelhead following flow augmentation.	Alexander et al. 2024
Teanaway River	Restoration of instream flow targets (12 - 20 cfs) in this Yakima River tributary during low flow periods via CBWTP water agreements	Improved fish passage for small- and medium-bodied salmonids during the late summer and fall.	McCaulou et al. 2015. See NPCC blog on Columbia Basin Water Transactions Program
Whychus Creek	Upper Deschutes Watershed Council of Deschutes River Conservancy secured water leases for flow restoration	Enhance organic matter retention and hyporheic exchange, resulting in increased nutrient availability, improved nutrient cycling, and greater primary productivity. Fish productivity unchanged compared to reference conditions.	Edwards et al. 2024
Lemhi River (IMW)	Agreements bringing water rights and point-of-use into legal compliance, thereby preserving instream flows	Reconnects small tributaries with main streams; manages high water temperatures in summer; provides critical rearing habitat and residence time for juvenile salmonids enhancing abundance and survival.	Bilby et al. 2022, Meyer et al. 2024
Potlatch River (IMW)	Flow augmentation	Increased juvenile steelhead growth, survival, and density. Moderated stream temperatures and dissolved oxygen. Improved longitudinal connectivity. Pilot flow study lasted only two years.	Bilby et al. 2022, Meyer et al. 2024

Methow River (IMW)	Instream flow, habitat enhancement	Side channel reconnections increased salmonid carrying capacity by 251% compared to the main channel	Bellmore et al. 2013, U.S. Bureau of Reclamation 2019

Flow augmentation can enhance restoration of riparian habitats, although landscape and social constraints can limit its benefits for fish. Augmentation from reservoirs is most effective where upstream storage and downstream water delivery are possible (U.S. Bureau of Reclamation 2007). The position of the restoration site within the watershed network can therefore limit the ability to provide instream flows, especially in upstream-most sites like headwater tributaries. Competing demands for water, including agricultural and municipal use, can limit water availability for flow augmentation. Acquiring water rights can be time consuming and expensive, particularly in overallocated basins.

Planning frameworks and environmental modeling have identified the need for flow augmentation to enhance fish survival in the Columbia River Basin and provide a basis for prioritization. Subbasin modeling based on the Ecological Limits of Hydrological Alteration (ELOHA) framework (Poff et al. 2010) identified systems that are particularly susceptible to poor water quality and lack of thermal refuges in hot and dry summers (Reidy Lierman et al. 2012). Analysis of four subbasins in Washington using the Water Evaluation and Planning system (WEAP) identified the Yakima River, a watershed with extensive agricultural withdrawals, as most flow limited and therefore most sensitive to loss of longitudinal and lateral connectivity (Donley et al. 2012). The Yakima and Okanogan subbasins were reported to be most responsive to flow augmentation through policy change, including reservoir releases during warm summer months (Mantua et al. 2009, 2010), and reducing stream withdrawals during the dry season.

Flow augmentation is intended to improve survival of juvenile salmonids, ultimately increasing fish productivity within the drainage. An Idaho Department of Fish and Game flow augmentation pilot project on Spring Valley/Little Bear Creek reported significant increases in juvenile rearing habitat, pool density and connectivity, as well as moderated stream temperatures and dissolved oxygen levels (Bilby et al. 2022). It also documented positive responses in juvenile steelhead growth, survival, and density in response to the augmentation efforts.

Instream flow transactions protect and enhance flows through water acquisitions and leases. For example, the Bonneville

Power Administration (BPA) and other agencies secured 397,636 acre-feet (490.5 million m^3) of water, increasing stream flows by 2,410 cfs (68 m^3/s) across various tributaries from 2005–2015. For example, changes to dam operations at Libby and Hungry Horse dams improved spawning and survival of resident species such as kokanee and bull trout while considering the needs of other native species, like the Kootenai River white sturgeon. Modified flood control at Libby and Hungry Horse dams used variable outflow during the spring to provide habitat for listed species while preserving adequate flood control for the lower Columbia River. Seasonal flow releases from the Hungry Horse Dam were regulated to reduce temperature extremes and improve spawning and rearing conditions for bull trout and westslope cutthroat trout, prevent habitat degradation, and avoid stranding juvenile fish. Many water budget and flow agreements are part of the Federal Columbia River Power System Biological Opinion (BiOp) and include input from federal, state, and tribal entities to ensure compliance with Endangered Species Act (ESA) requirements.

Much of the provision and preservation of instream flow in subbasins and tributaries, including Intensively Monitored Watersheds (IMWs), comes from water transfer and conservation agreements. An example is the Columbia Basin Water Transactions Program (CBWTP) that provided instream flow for the Salmon, Teanaway, and Whychus projects in collaboration with tribes, community partners, agricultural interests, and other stakeholders beginning in 2002 (Table 1). The CBWTP supported reintroduction of flows in Salmon Creek, historically dewatered due to irrigation withdrawals. This effort included a 12-year water lease to secure a minimum annual volume of 700 acre-feet (863,000 m^3) of water and the construction of a low-flow channel. These flows reconnected the creek to the Okanogan River, allowing steelhead to access critical spawning and rearing habitats. Habitat improvements and flow restoration in Salmon Creek led to measurable increases in fish populations and habitat connectivity, macroinvertebrate indices, and redd counts following flow restoration. Furthermore, monitoring showed increases in steelhead returns and recruitment of natural-origin steelhead following flow augmentation.

The CBWTP also secured flows in the lower Teanaway River (a Yakima River tributary) through water transaction agreements to achieve an instream flow target of 12 to 20 cfs during low-flow periods. These flows improved fish passage, particularly for small- and medium-bodied salmonids, during the late summer and fall. Studies of critical riffles demonstrated that augmented flows enhanced habitat availability and connectivity for native salmonids. CBWTP-supported water transactions also increased instream flows in streams such as Catherine Creek and Whychus Creek, addressing dewatering issues and improving riparian habitats. Habitat improvements included better fish passage and spawning conditions, enhanced macroinvertebrate communities, and increased detection of fish (via PIT tagging) in augmented reaches.

The Umatilla Initiative incorporates water exchange programs to improve habitat conditions for salmon and steelhead and upgrade irrigation diversions for better fish passage. Habitat restoration efforts such as large-wood additions and riparian fencing are directly supported by flow management to optimize conditions for natural and hatchery production goals. Water releases from storage and exchange agreements were implemented to enhance instream flows for fish passage and habitat restoration. These efforts aimed to mimic natural flow regimes and maintain adequate flow levels during critical life stages of salmon and steelhead. The water exchange program involved purchasing (or otherwise conserving) water used for irrigated agriculture and providing it to maintain streamflows. Collaboration between the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), Oregon Department of Fish and Wildlife (ODFW), and local stakeholders ensured agreement on these flow adjustments.

Intensively Monitored Watersheds (IMWs) - Targeted flow releases were coordinated in IMWs to assess the effects of flow restoration on habitat and fish population responses. These activities often involved strategically timed flows to promote riparian recovery or mimic natural hydrological conditions. Managed flows improved habitat complexity by creating pools and improving sediment deposition. For example, Methow River side channel reconnections increased salmonid carrying capacity by 251% compared to the main channel. The work resulted in immediate benefits for salmonid habitat and long-term resiliency. In another IMW, flow stabilization and barrier removal improved hydrological connectivity and provided access to tributaries for 275 km (171 miles) of the Lemhi River.

Fish Returns lag Habitat Restoration and Flow Augmentation - Despite improvements in physical habitat, fish population responses are often not immediate. For instance, riparian fencing and flow adjustments showed little short-term benefit for Chinook salmon and steelhead populations in the Lemhi IMW. The time required for ecological recovery and the potential influence of other limiting factors (e.g., predation, food availability) may have delayed observable benefits.

Long-term ecological responses to flow augmentation remain difficult to measure, particularly for fish populations influenced by multiple factors such as the hydrosystem, ocean conditions, and predation. In addition, short-term monitoring is frequently insufficient to capture long-term effects, and many projects lacked adequate duration or scope to observe meaningful population-scale outcomes. IMW projects highlighted the challenge of establishing clear cause-and-effect relationships between flow management and fish population recovery. Ecosystem recovery is influenced by multiple factors, and flow management alone may not be sufficient to overcome all habitat and population bottlenecks.

Flow stabilization and dam operations tailored for salmonids occasionally led to habitat changes that negatively affected other aquatic or riparian species. Flow regimes designed to produce specific habitat changes may not align with the needs of all species, highlighting the need for ecosystem-based approaches. Flow management alone was insufficient to counteract sedimentation impacts in some areas, reducing the effectiveness of restoration actions.

Limited population responses in some tributaries, such as the Teanaway River, showed less-than-expected increases in fish populations due to other limiting factors like habitat degradation and predation. Determining the optimal flow levels for fish productivity remains complex, as flows must balance ecological needs with legal and social constraints.

3.1.7. Cold-water refuges

Stream temperatures are altered by hydrosystem operations and increasingly by climate change. Water temperatures are one of the most widespread and increasingly dominant limiting factors for salmon, steelhead, and other cold-water and cool-water native fish species in the Columbia River Basin. Annual averaged water temperature in the lower Columbia River has increased by 2.2°C (4°F) since the 1850s (Scott et al. 2023), and increases have occurred primarily during July to December. The number of days with water temperatures over 20°C (68°F), a threshold similar to regional temperature standards for survival of salmon and steelhead, increased from 5 to 60 days per year during this period. The authors concluded that hydrosystem management by mainstem dams was responsible for 57% of the temperature increase, warming air temperatures 29%, and altered river discharge 14%.

Several major restoration actions aim to reduce stream warming or protect existing cold-water habitat, such as restoration of riparian plant communities to provide shade, and flow augmentation (see Section 3.1.6. Environmental Flows). Another strategy to create more favorable conditions for anadromous salmonids and resident cold-water species is protection and restoration of cold-water refuges. The two major sources of coldwater refuges in river networks are hyporheic or subsurface exchange and junctions with cooler tributaries. Both are important for fish communities in the Columbia River Basin, but restoration of hyporheic exchange generally is more feasible than creating cold tributary mouths.

Hyporheic flow occurs when surface water enters the subsurface channel bed and riverbanks to re-emerge downstream (Poole et al. 2022). The length of the flow path and its permeability determine the residence time in the subsurface environment where thermal exchange occurs. Water that enters the subsurface may be substantially colder in summer or warmer in winter than the surface water when it returns weeks, months, or years later (e.g., in a floodplain of the Willamette River: Faulkner et al. 2012, 2020). Hyporheic exchange also promotes biochemical processes that are important for water quality and aquatic habitat. The hyporheic zone creates flow paths that transport cool water, take up nutrients through microbial processes, and provide critical habitat and refuge for early life history stages of aquatic biota.

A restoration project in the Umatilla River (FWP project #2007-252-00 - Hyporheic Flow Assessment in Columbia River Tributaries) attempted to restore natural channel and floodplain geomorphology to increase exchange of hyporheic flow from the subsurface and result in inputs of cold water. Jones et al. (2008) found that hyporheic exchange from the floodplain aquifer provided 87% of the flow in a spring channel during winter and 80% during summer, with the remainder coming from subsurface sources outside the floodplain. Arrigoni et al. (2008) found that locations with hyporheic input had similar daily mean temperatures compared to mainstem temperatures but smaller diel temperature ranges. In total, the mainstem, side channels, and spring channels created thermal diversity, even though mean temperatures were similar.

In contrast to their expected outcomes, the Meacham Creek Restoration Project resulted in increased warming through the restoration reach. The project leaders attributed this to removal of riparian shade to allow large equipment to realign the channel. Both shade and hyporheic exchange may influence stream temperatures, but the mechanisms for thermal effects are different. The project leaders subsequently developed models of the Nyack floodplain of the Middle Fork Flathead River in Montana and the Umatilla River in Oregon, the location of several hyporheic restoration projects in the Program. These models were used to compare the relative seasonal effects of hyporheic exchange and riparian shade (Fogg et al. 2023). Shade and hyporheic exchange both dampened diurnal temperature cycles, but they altered seasonal temperature cycles differently.

In winter, hyporheic exchange warmed surface water temperatures, but shade had little effect. In summer, both shade and hyporheic exchange resulted in cooler channel temperatures, although the effects of shade were more pronounced.

Cold-water habitats provide refuges for native salmonids, but responses vary among locations and species. Chinook salmon in the Yakima River using deep pools with cooler water exhibited core body temperatures 2.5˚C lower than the ambient river temperature (Berman and Quinn 1991). The study concluded that "*cool-water areas need to be abundant and available to the fish. The availability of suitable thermal refuges and appropriate holding habitat within mainstem rivers may affect long-term population survival.*" Torgersen et al (1999) compared the distribution of adult spring Chinook salmon to patterns of water temperature detected by thermal remote sensing of the Middle and North Forks of the John Day River. Distributions of Chinook salmon were strongly limited by temperatures above their upper tolerance limit (25°C) in the warmer Middle Fork, but not in the colder North Fork that never exceeded this level. Fish preferred deep pools in both subbasins. In northeast Oregon, steelhead and Chinook salmon were found primarily in deeper pools or tributary junctions with cooler temperatures (Ebersole et al. 2001, 2003). Barrett and Armstrong (2022) tracked coastal cutthroat trout in the Willamette River in summer and found that roughly 90% of the radio-tagged fish stayed in the mainstem and tolerated high temperatures, 6% were found in cool floodplain alcoves, and 4% moved upstream into the cooler McKenzie River. Larger fish generally used cold-water refuge habitats more than smaller fish. Hyporheic exchange can also create warmer water habitats in winter, which may be important for survival and growth of cold-water fishes (Armstrong et al. 2021).

Cold-water refuges also provide benefits to salmon and other fish species by reducing exposure to parasites and disease (Chiaramonte et al. 2016). Chinook and coho salmon in the Klamath River disproportionately used the mouths of colder tributaries as they migrated upstream. The abundance of spores of a major parasite, *Ceratonova shasta*, was lower in these locations than in fish occupying the mainstem. Laboratory studies demonstrated that temperatures within the range experienced by fish using thermal refuges alleviated thermal effects on disease progression.

Field studies of hyporheic exchange may show little effect on stream temperatures if the hyporheic zone is small relative to the volume of the surface water, hydrologic exchange rates are low, net heat exchange between the channel and streambed is low seasonally, or turbulence in the surface water causes rapid mixing. Several field studies (e.g., Wright et al. 2005, Burkholder et al. 2008) have found such low influences of hyporheic exchange, possibly for one or more of these reasons (Fogg et al. 2023). A study of hyporheic exchange at 10 sites in a 52-km (32 miles) reach of the Middle Fork John Day River found little evidence of hyporheic upwelling or cold-water refuges (Wright et al. 2005). They also found no evidence of differences in aquatic primary production or macroinvertebrates between the expected downwelling and upwelling locations. They suggested that geomorphic features of the reaches and history of habitat degradation in the basin may limit the development of hyporheic exchange. Burkholder et al. (2008) found more than 40 small patches of cold water in the Clackamas River in Oregon but concluded that hyporheic cold-water inputs account for only 1% of the mainstem discharge. While hyporheic exchange may not greatly influence the overall temperature of the surface water, they can still provide localized cold water refuges that are important to fishes.

Cold water refuges are also important in large rivers like the mainstem Columbia and Snake rivers. In the Pend Oreille River, monitoring of thermal patterns demonstrated that tributary junctions provide significant numbers and area of cold-water refuge and are the major source of thermal heterogeneity (Mejia et al. 2020). Groundwater modeling projected that floodplain restoration through levee setbacks in the Yakima River have increased subsurface flow paths and expanded the area for hyporheic flux exchange between surface and groundwater (Singh et al. 2018). The effects on flow path length were greater in drier summer months. A model of fall Chinook salmon and summer steelhead estimated that cold water refuges provide relief from exposure to high water temperatures but do not substantially contribute to conserving energy expenditures by migrating adults (Snyder et al. 2020, 2023).

Keefer et al. (2018) tracked adult Chinook salmon with archival temperature loggers as they migrated up the Columbia and Snake rivers. Spring and summer Chinook migrated before summer maximum temperatures, but fall Chinook and steelhead had maximum temperatures near their thermal tolerance limits (20-22°C; 68-72°F) in the lower Columbia River. During periods with high temperatures, Chinook and steelhead extensively used thermal refuges associated with tributary confluences, where body temperatures were 2 to 10°C (3.6 to 18°F) cooler than the adjacent migration corridor. Steelhead tended to use refuges for weeks or more, whereas salmon, which spawn earlier, used these areas for hours to days. A study of adult summer steelhead that used the Deschutes River as a thermal refuge found that out-of-basin fish from the Salmon and Grande Ronde that had migrated through the mainstem Columbia River when water temperatures exceeded

21°C (70°F) were disproportionately represented (Hess et al. 2016). Fish from other basins that migrated at cooler times were less frequently observed or not detected in the Deschutes River.

3.2. Process-based vs. Engineered Restoration

Over the last 15 years, researchers and practitioners have identified the need for process-based restoration to restore physical and ecological processes to recover ecosystem productivity and diversity. In contrast, structural-based or engineered restoration attempts to recreate the desired physical structure of stream channels, floodplains, and riparian zones without necessarily addressing the processes that limit populations. However, many habitat restoration projects have attempted to also restore critical physical and ecological processes. These include riparian plantings and fencing to restore shade and wood delivery to streams, increasing channel complexity and topography to restore floodplain and wetland inundation, and removal of natural and artificial barriers to restore fish migration and transport of sediment and wood. As mentioned early, the ISAB Landscape Report (ISAB 2011-4) emphasized the critical role of consideration of biophysical processes in conservation and restoration of ecosystems.

Beechie et al. (2010) defined process-based restoration as an approach designed "*to reestablish normative rates and magnitudes of physical, chemical, and biological processes that create and sustain river and floodplain ecosystems. Processes are typically measured as rates, and they involve the movement of or changes to ecosystem parts and features.*" Such restoration focuses on correcting anthropogenic disruptions to allow recovery of processes with minimal corrective intervention (Sear 1994, Wohl et al. 2005). Beechie et al. (2010) noted that, "*Despite an abundance of research describing the need to restore processes rather than create certain structures, most restoration actions continue to create structures or channel forms that are perceived to be good habitat.*" Rather than attempting to attain a desired future state, process-based restoration recognizes that natural and human-caused changes will occur and endeavors to restore critical processes to allow the ecosystem to shape future structure and function. Process-based restoration incorporates four fundamental steps: 1) targeting root causes of habitat and ecosystem change, 2) tailoring restoration actions to local potential, 3) matching the scale of restoration to the scale of the problem, and 4) explicitly identifying expected outcomes.

Throughout the Fish and Wildlife Program, habitat restoration projects have often pursued both structural and process-based restoration, by attempting to improve habitat while also identifying key processes that have been altered and allowing natural physical and ecological processes to recover. In Program and project reviews, the ISRP and ISAB have called for restoration of process as well as structure, and the proportion of habitat restoration projects that address biophysical process rather than solely structure has increased. However, most of these would not be considered process-based restoration because they do not fully evaluate the range of processes and consider restoration of multiple processes and their interactions.

As one example, the Program has implemented many projects to restore volumes and sizes of large wood in streams, but many of these projects do not include actions to restore disrupted hydrology, nor the riparian forests and hillslope delivery sources that will supply large wood naturally in the future. Even projects that include riparian plantings to provide future wood inputs will not restore those processes for more than 100 years. Other projects attempt to restore the connectivity of channels with floodplains without addressing the larger processes operating at the reach or watershed scale that led to the isolation of the channel from its floodplain in the first place.

The need to simultaneously address multiple processes responsible for the habitat degradation is even more challenging than addressing individual processes like large wood inputs. Beechie et al. (2010) considered these "*partial restoration actions*" intended to restore selected physical, chemical, or biological processes to be the most common class of restoration actions. For large rivers and watersheds that have been extensively altered, the greatest challenge is to match the scale of process-based restoration to the scale of the complex and spatially extensive habitat modification that has occurred over an extended period (Beechie et al. 2010).

As we describe in the Planning and Prioritization chapter, the complexity, spatial extent, and degree of attention to both process and structure have increased markedly since the 2000 Fish and Wildlife Program. The most complete examples of process-based habitat restoration in the Program are the spatially explicit watershed assessment programs for subbasin-scale restoration design and implementation (see previous chapter for discussion of programs in the Grande Ronde, Okanogan, Upper Columbia, and Umatilla watersheds and the Lower Columbia River Estuary). These watershed assessment programs are continuously updated with new data and information from multiple projects and are linked to recovery plans, technical recovery teams, and management plans of state and federal agencies in the subbasins (Roni et al. 2023b). These programs differ in their analytical tools, assessment and prioritization processes, synthesis of monitoring and evaluation information, and adaptive management processes, but all meet the four fundamental steps of process-based restoration identified by Beechie et al. (2010).

Stage Zero Restoration

Over the last decade, a form of process-based restoration known as Stage Zero (or Stage 0) restoration has increasingly gained attention for restoring channel complexity and floodplain connectivity at reach and valley scales. Stage Zero restoration is based on a theoretical conceptual framework developed by Cluer and Thorne (2014), which is itself based on previous geomorphic channel evolution models (Schumm et al. 1984). Stage Zero restoration focuses on resetting the geomorphic characteristics of the degraded channel and floodplain to allow physical and biological processes to shape a new channel and floodplain. Although the conceptual model primarily describes geomorphic change in streams and wetlands, the stages of channel evolution have been related to hypothetical biological responses (Castro and Thorne 2019, Powers et al. 2019).

Stage Zero restoration has been implemented in more than 20 locations in the Pacific Northwest as well as other sites around the world (Flitcroft et al. 2022; Stage Zero Information Hub). As a result, studies that document the effectiveness of Stage Zero restoration are scarce, especially for ecological outcomes. In general, the immediate geomorphic changes observed include increased wetted channel area, formation of multiple channels, increased inundation of the channel and floodplain at higher flows, and greater floodplain connectivity (Powers et al. 2019, Flitcroft et al. 2022). Stream temperatures were warmer in the summers after restoration in the South Fork McKenzie River (Flitcroft et al. 2022).

Most Stage Zero restoration projects include addition of large quantities of large wood, but long-term trajectories of wood volumes and distributions in Stage Zero restoration projects have not been studied, given the short time the approach has been implemented. When wood was added in Deer Creek, Oregon, it was redistributed in high flows over the subsequent 2 years and accumulated in aggregations (Scott 2023). Information on biological responses is much more limited. Initial responses in some sites reveal changes in macroinvertebrate composition, and overall abundance within reaches increases, at least as a response to increase wetted area (Flitcroft et al. 2022). Potential rearing area for juvenile salmonids and suitable habitat velocities and depth were greater after Stage Zero restoration at several sites, but changes in fish abundance have not been documented to date (Flitcroft et al. 2022). Stage Zero projects are intended to allow channel structure to be self-forming over the long term; therefore, several decades of monitoring will be required to evaluate the outcomes as the channels and riparian plant communities adjust to the initial site modifications, wood additions, and riparian planting.

The Fish and Wildlife Program has few examples of Stage Zero restoration because it has been applied in the region only within the last decade. Stage Zero designs have been implemented in Program projects in several subbasins, including Meadow Creek and Lookingglass Creek in the Grande Ronde River, Wilson-Haun Ranch in the Wallowa River, and the Lower Red River in the South Fork Clearwater River. The regional attention on the Stage Zero restoration approach, and its substantial potential for improving restoration, highlight the importance of rigorous monitoring and evaluation of future Stage Zero projects in the Program. This will require monitoring of many intended outcomes, such as channel and floodplain geomorphology, stream temperature, water tables and hyporheic exchange, riparian vegetation, aquatic biota, fish communities, and abundance of salmon and steelhead. Stage Zero is based on self-forming channel evolution and geomorphic adjustment at valley and reach scales after implementation; therefore, monitoring of Stage Zero projects will require extensive long-term monitoring, a factor to be considered in future Program development and implementation.

Intensively Monitored Watersheds

Another group of projects in the Fish and Wildlife Program that generally meet the criteria for process-based restoration are the Intensively Monitored Watersheds (See Chapter 5; Bilby et al. 2005, NMFS 2020b). The IMWs are designed to be watershed-scale monitoring programs rather than habitat restoration projects per se, but they coordinate multiple projects to create collective sets of restoration actions to implement and evaluate process-based restoration. Some IMWs focus on restoring and monitoring a limited number of processes, such as wood additions in the Asotin Creek IMW, beaver dam analogs in the Bridge Creek IMW, and pool habitat and channel conditions in the Fish Creek IMW. Other IMWs in the Columbia River Basin (Entiat, Lemhi, Methow, Potlach Creek, Wind River) developed integrated restoration actions to restore multiple processes to address several limiting factors within watersheds.

3.3. Resident Fishes

Much of the focus on habitat restoration in the Columbia River Basin is on anadromous salmon and steelhead, but the Basin also supports fishes classified as “resident” that are of conservation concern, including native rainbow trout, cutthroat trout, and bull trout, and non-salmonids like Kootenai white sturgeon, burbot, and Pacific lamprey. The Columbia Basin Tributary Habitat RM&E

Strategy (BPA/BOR 2022) states that habitat changes targeting anadromous fish have the potential to benefit resident salmonids like bull trout, and many projects supported by the Program in the inland portions of the basin specifically target these fish considered resident. We note that these “resident” fishes also include migratory forms that move 100 km (62 miles) or more to access habitats throughout entire watersheds for spawning, rearing, and overwintering (e.g., Starcevich et al. 2012; Pierce and Podner 2018). Hence, restoration of connectivity is as important for these fishes as it is for anadromous forms. Furthermore, removal of impassable dams constructed in formerly anadromous salmonid reaches has the promise of allowing isolated “resident” salmonids to re-express anadromy (Allen et al. 2016). Here we focus on salmonids considered resident. We do not address the comparatively few but important habitat projects that address white sturgeon and other non-salmonid species. The key question we address is whether habitat protection and restoration for resident salmonids are fundamentally different than that conducted for anadromous salmonids.

The Program has funded many projects in blocked areas above the mainstem dams to benefit resident salmonids. These were recently reviewed in the 2020 Category Review of Resident Fish and Sturgeon Projects (ISRP 2020-8). Projects almost always addressed multiple habitat problems, from fragmentation by culverts and dams to destructive land uses (e.g., riparian logging and grazing, roads), water withdrawals, flow modification, and channelization that disconnected streams from floodplains and removed large wood. For example, of the 44 projects reviewed for the 2020 Categorical Review, 12 included significant habitat restoration for resident salmonids, as did one for Kootenai River white sturgeon. Of the 12, all included a variety of habitat restoration actions, including removing barriers, adding large wood, and riparian plantings to restore ecological function. None of the projects conducted only one type of treatment, so the results of projects could not be used to evaluate a single habitat restoration action, such as large wood placement.

A 30-year basinwide habitat restoration project in the Blackfoot River Basin, Montana, a 6,008 km^2 (2,320 mi^2) subbasin within the upper Columbia River Basin, provides highly useful results for resident fish restoration (Pierce and Podner 2018, Pierce et al. 2019). After the State of Montana stopped stocking trout in streams in 1974, the state focused on managing wild trout for natural reproduction to sustain sport fisheries. By the mid-1980s, declining wild trout populations in the Blackfoot River, and specifically wild native cutthroat trout and bull trout, prompted evaluation and restoration of key habitats starting in

1990, including tributary spawning and rearing habitats for migratory westslope cutthroat trout and Threatened bull trout. Restoration actions were completed at 178 locations on 64 streams within the basin, including, for example, fish passage improvements on 32 streams, improved riparian grazing on 36 streams, and active channel restoration on 27 streams. Other projects screened irrigation diversions (18 streams) and improved instreams flows (17 streams).[7] The overall goal was to provide diverse and complex channels that convey flows and sediment, paired with improved land use to sustain ecological functions that support abundant wild trout populations.

Results for 18 restoration projects that were monitored for 5 or more years and compared to reference reaches showed that channels typically became narrower and deeper, and fine sediment was reduced. In most cases abundance of age-1 and older trout at least doubled, and approached abundances measured in reference reaches within 5 to 10 years (Figure 3.9; Pierce and Podner 2018). Results from one stream showed that abundances increased more in reaches with large volumes of wood compared to those with low amounts of wood (Figure 3.10).

Moreover, improved habitat, colder temperature regimes, and restored connectivity allowed native westslope cutthroat trout to rebound throughout the entire basin, from making up 5% or less of trout numbers before restoration to 20-40% of trout at four long-term monitoring stations measured during 1989 to 2016. Similarly, after catch-and-release regulations were instituted in 1990, bull trout redd counts in two major spawning tributaries (North Fork Blackfoot River and Clearwater River) increased substantially when Milltown Dam was removed that isolated the entire Blackfoot River (Figure 3.11), and another dam was removed that isolated a large portion of the Clearwater River. Projects in three spring streams produced colder water, creating a thermal refuge for bull trout in ESA-designated critical habitat (Pierce and Podner 2018). Coldwater refuges in headwater basins like the North Fork Blackfoot River are predicted to sustain key refugia for bull trout as the changing climate warms water temperatures (Isaak et al. 2016), and a segment above a natural waterfall is being considered for bull trout translocation and conservation.

[7] As for projects funded by the Fish and Wildlife Program, virtually every project in this basin involved more than one of these restoration actions.

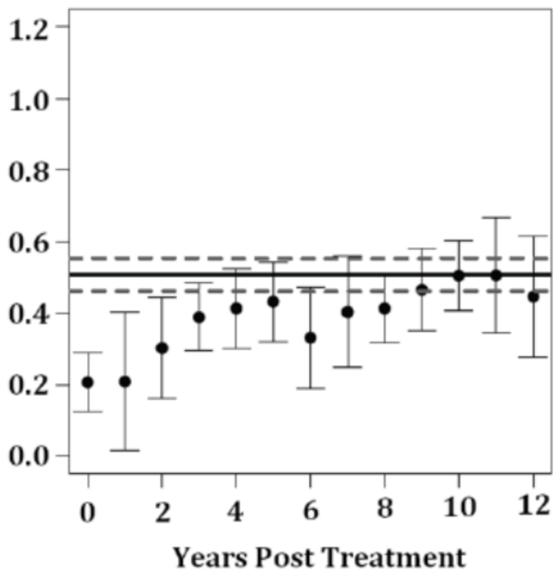

Figure 3.9. Mean abundance of age-1 and older trout (Ln trout/m + 95% confidence interval) by year post-treatment for habitat restoration projects in the Blackfoot River Basin, Montana (from Pierce and Podner 2018). The solid black line is the grand average trout abundance for all references sites including the 95% confidence interval (dashed lines). [Note: This report did not indicate how many habitat restoration projects or reference sites were included in these averages.]

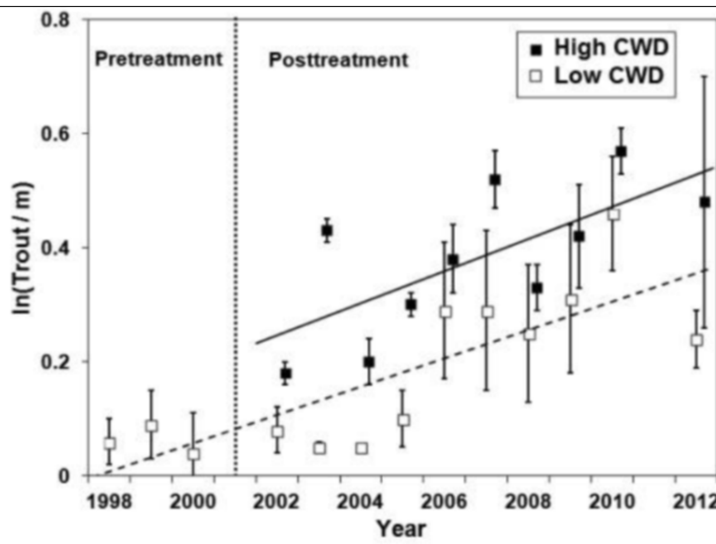

Figure 3.10. Abundance of age-1 and older trout in Kleinschmidt Creek, a tributary of the Blackfoot River, Montana, before (pretreatment) and after channel restoration (posttreatment). Results are presented separately for reaches with high and low amounts of large wood (here termed CWD; coarse woody debris). Lines show best fit linear regressions to the data (from Pierce and Podner 2018).

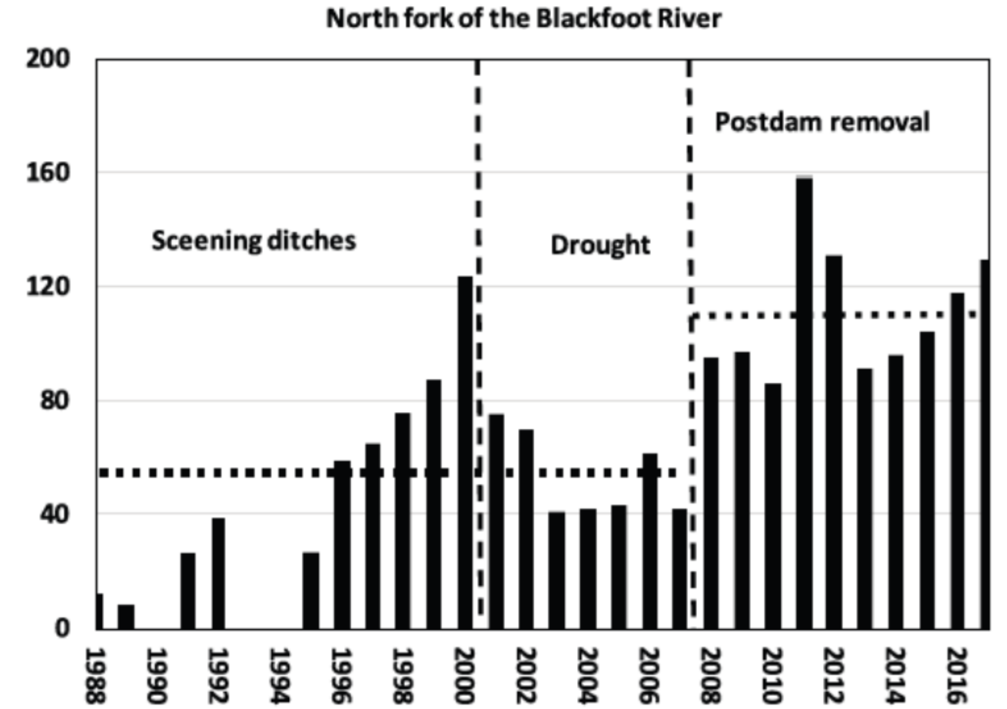

Figure 3.11. Bull trout redd counts in the North Fork Blackfoot River. Catch-and-release regulations were instituted in 1990, followed by screening irrigation ditches in the 1990s, 7 years of protracted drought (2001-2007), and the removal of Milltown Dam in 2008 that had isolated the Blackfoot River from the Clark Fork River. The horizontal dashed lines show the mean redd counts for the periods before and after dam removal (from Pierce et al. 2019).

As for anadromous salmonids, removal of barriers can open key habitats for spawning and rearing of migratory species like rainbow, cutthroat, and bull trout, such as in the Blackfoot River. In another example described previously, removal of 93 barriers in tributaries to the Upper Columbia River (i.e., Wenatchee, Entiat, and Methow rivers) opened 454 km (282 miles) of previously blocked habitat (UCSRB 2014), much of it suitable for bull trout. However, a key difference regarding this habitat restoration action for resident versus anadromous fish is the potential effect of providing access to these habitats by nonnative fishes, especially nonnative salmonids (Fausch et al. 2009, Tullos et al. 2016).

For example, nonnative brook trout threaten many populations of native cutthroat trout throughout the interior Columbia River Basin and other portions of the interior West. Peterson et al. (2008) developed a Bayesian Network model to assess the tradeoffs of removing barriers to connect populations and allow the full expression of cutthroat trout migratory life histories versus isolating the native cutthroat trout above barriers to prevent brook trout invasion. They found that the predicted probability of persistence of westslope cutthroat trout populations increased as the size of the stream network available increased. For populations with only resident life histories, persistence increased when a barrier was present that excluded brook trout, but persistence was similar with or without a barrier for populations with migratory life histories. Overall, more robust and resilient populations that include migratory life histories and are strongly connected to other populations are believed to resist displacement by brook trout in the northern Rocky Mountain watersheds for which this model was developed. Nevertheless, when only smaller resident cutthroat trout populations remain, such as in many other regions in the southern Rocky Mountains, isolation from brook trout is required to sustain the native trout (Peterson et al. 2004, Fausch 2008). Similarly, in the watershed of the Bonneville Pool of the Columbia River, density of coastal cutthroat trout was higher in streams isolated by barriers from downstream reaches accessible by anadromous and resident rainbow trout (Connolly and Sauter 2008).

Overall, there are likely to be more similarities than differences in the effects and outcomes of habitat protection and restoration for resident salmonids compared to anadromous salmonids. Many salmonids classified as resident, such as native rainbow, cutthroat, and bull trout, nevertheless include migratory life histories that require habitats dispersed throughout riverscapes (Fausch et al. 2002), often separated by distances up to 100 km (62 miles) or more (Starcevich et al. 2012). Sustaining robust populations of these large migratory fish can provide resilience that reduces effects of nonnative salmonids. Nevertheless, other populations of resident salmonids are hampered by nonnative fishes and can require isolation to allow persistence. Tradeoffs between isolating resident salmonids above barriers and thereby preventing migratory life histories from being expressed that contribute to their resilience will require careful analysis and consideration to select appropriate management strategies.

3.4. Wildlife

Approaches for mitigating effects of the hydrosystem on wildlife in the Columbia River Basin differ in many ways from the methods for planning, implementing, and monitoring mitigation actions for fish and aquatic ecosystems. Focal wildlife species in the Program include diverse taxa (e.g., mammals, birds, reptiles, and amphibians), differing greatly in mobility and habitat requirements. Wildlife projects are intended to mitigate for the habitats lost from inundation by reservoirs and altered by hydropower operations. As the ISRP identified in its 2017 Wildlife Project Review (ISRP 2017-7), the habitats lost owing to the hydrosystem were mostly continuous parcels of riparian wetlands, floodplains, and forests, much of which are now under water. Unlike restoration of fish habitats in the Basin, restored wildlife habitats primarily occur in different locations than the original habitat. Another difference is that although many wildlife acquisition and restoration projects were intended to protect or restore "in-kind" habitat types used by focal species that were impacted by the hydrosystem, many protected or restored wildlife habitats differ ecologically from the original lost habitat ("out-of-kind"), especially when upland habitats are substituted for lost riparian and wetland habitats.

One of the major challenges for wildlife habitat restoration in the Fish and Wildlife Program is spatial extent and connectivity of restored habitat. In many cases, habitat restoration is a substitution for lost habitat rather than restoration of existing degraded conditions in habitats. Many wildlife projects focus on acquiring land to either conserve or restore habitat conditions for wildlife communities and habitats inundated by the reservoirs. The approximately 30 wildlife projects in the Fish and Wildlife Program manage more than 800 parcels of land to mitigate for the hydrosystem effects. As a result, the patches of wildlife habitat tend to be fragmented and disconnected to a much greater degree than the fish habitat restoration projects connected by stream and river networks.

Although restoring connectivity is a major objective of both wildlife and fish habitat restoration, it is a far greater challenge in the fragmented wildlife parcels. Planning and design of restoration actions for wildlife habitats must consider fundamental ecological site characteristics, such as species-area relations, effective population sizes for long-term persistence, permeability of boundaries and barriers, and corridors and connectivity, which often differ greatly from the lost riparian and floodplain habitats. Each of these considerations also depends on the wildlife species of concern.

The small patches of restored wildlife habitat have extensive edges with unrestored lands, which often are in agricultural or production forestry land uses with extensive complicating factors such as fences, roads, machinery, and urbanization. This creates obvious limitations for the colonization and movement of desired species, and challenges associated with the invasion of non-native or undesired plant and animal species. Weed management is a major component of managing wildlife habitat parcels and requires ongoing, long-term site management. Weed management introduces additional risks associated with repeated annual herbicide applications and their effects on wildlife and the communities that support them. Monitoring of wildlife habitat restoration projects is frequently qualitative and limited, reflecting a "build it and they will come" approach. While this may have on-the-ground benefits, it limits the understanding of the Fish and Wildlife Program outcomes and reduces the lessons learned from the investment of funds to restore wildlife.

Wildlife habitat mitigation faces major challenges compared with fish habitat mitigation, but several aspects are more advantageous. For example, active migration by birds allows them to find restored habitats more easily than fish, which must surmount dams. Although both wildlife and fish habitat restoration often focus on target species, the nature of wildlife habitat management tends to address associated plant and animal communities to a greater degree than the more population-centered focus of fish habitat restoration. While the numerous parcels create problems of spatial extent and connectivity for many species, it is usually easier to establish independent treatment and control areas for experiments to assess restoration effectiveness. This offers an opportunity for the Fish and Wildlife Program to critically evaluate wildlife restoration methods and share the lessons learned among projects within the Basin and other regions.

Although wildlife habitat restoration and fish habitat restoration differ in many ways, the two approaches can have synergistic effects, enhancing their joint success. For example, riparian fencing and floodplain restoration described above for fish habitat restoration have major benefits for wildlife. Many wildlife projects are located within, adjacent to, and near fish habitat restoration projects and potentially contribute to the objectives for both. In many cases, those benefits are not explicitly quantified and documented as specific mitigation for the effects of the hydrosystem, but they contribute to the overall success of the Fish and Wildlife Program. Greater synergistic planning and implementation of fish and wildlife habitat restoration projects offers potential for the Program to invest in "win-win" opportunities.

3.5. Conclusions and Moving Forward

A major objective of this review is to identify 1) where we know enough about particular methods to de-emphasize monitoring in the future versus 2) where lack of information, risk, and uncertainty require continued or increased monitoring and evaluation. We reviewed eight major methods used to restore aquatic habitats in the Basin.

Barrier removal

Removing barriers to upstream fish passage is among the most successful types of habitat restoration projects. This conclusion is based on strong evidence that replacing road crossings to design standards increased access for fish, and that after barrier removal densities of salmon and steelhead upstream were similar to those downstream of removed barriers. However, despite the increased access, only limited fish habitat upstream from former barriers is often suitable for colonization because channels upstream are often narrow and steep. Overall, key factors influencing success of barrier removals include size of source populations, condition of upstream habitat (e.g., channel gradient), presence of other barriers upstream, and use of design standards.

Floodplain reconnection

As spatial scale of habitat restoration has increased, projects increasingly have focused on reconnecting floodplains and off-channel habitats. These are typically large and complex projects that require extensive planning and permitting.

In general, studies of reconnecting floodplains and off-channel habitats show rapid recolonization of the newly accessible habitat and other benefits such as higher food production than main-channel habitats, which supports faster growth of juvenile salmonids.

The greater size and complexity of floodplain restoration projects create challenges for assessing effectiveness because adequate control sites are scarce. Nevertheless, there is substantial evidence that within about a decade these projects can increase habitat features important to salmonids and increase abundances of juvenile salmon and steelhead.

Wood restoration

Addition of wood to streams to provide habitat for fish without restoring riparian forests or upslope sources of long-term input of wood is an example of structural restoration rather than process restoration. Over the last 40 years, restoration projects have greatly increased the amounts of wood added, included both the active channel and floodplain in wood restoration, increased complexity of wood accumulations, and conducted associated riparian restoration.

Studies of individual wood restoration structures show that they increase foraging locations for salmonids, and that fish use them. Results of wood restoration measured at the reach scale during summer, including those in the Columbia River Basin and elsewhere, show substantially increased abundances of anadromous and resident salmonids.

In contrast, studies of wood restoration in IMWs at the watershed scale for whole populations showed variable responses, with about half reporting increases in juvenile salmonids or smolts. A few reported increases in adult returns, although this metric is influenced by many factors beyond the watershed. These studies concluded that responses of fish require many years to decades to fully evaluate.

Riparian restoration

A major challenge for assessing the effectiveness of riparian restoration is the time required to restore mature riparian vegetation and the short durations (<10 years) of most projects. Short-term changes do not reflect the ecological objectives for restoration, and recovery of riparian vegetation and aquatic habitat is related to the age of the restoration project. Available studies highlight the need for coordinated long-term studies of riparian restoration.

Results of using animal exclosures to restore riparian and aquatic habitat are mixed, and maintaining exclusions is difficult. Livestock exclusion may successfully restore riparian plant cover and reduce bank erosion, but exclosures may not be effective for restoring native plant communities where restored reaches are short relative to adjacent degraded reaches or where aggressive invasive vegetation, such as reed canary grass, is present. Results from the central Rocky Mountains indicate that restoring riparian vegetation provides substantial inputs of terrestrial invertebrates that feed salmonids and can increase their abundance.

Several models in the Basin indicated that temperature benefits of riparian restoration owing to shading could offset increases projected for regional warming, but another model concluded that riparian restoration would not increase salmon production.

Dike breaching and tide gate management

Since restoration in the Columbia River Estuary began in the early 2000’s, most projects have focused on restoring hydrologic connectivity by breaching or eliminating dikes and berms. Removal of dikes in a coastal estuary resulted in recovery of marsh vegetation and wetland morphology. Chinook and coho juveniles occupied the restored marshes and each species re-expressed four different life-history types that enhanced population resilience. The abundance of insect prey also increased after restoration.

One of the main shifts in restoration paradigms was that the estuary extended to the base of Bonneville Dam and that restoration should also extend to this point, especially because listed populations were found in all parts of the estuary, not just the most saline and tidal portion. Changes in the hydrology and temperature regimes of the Columbia River and potential competition with hatchery salmonids are confounding factors for estuary restoration.

Flow augmentation

Many instream flow restoration projects in the Fish and Wildlife Program and IMWs are water transfer and conservation agreements, and several studies documented measurable increases in habitat connectivity, fish populations, and other measures of aquatic health. One study also showed increased returns and recruitment of natural-origin steelhead following flow augmentation.

Despite improvements in physical habitat, fish population responses often are not immediate. Time required for ecological recovery and the potential influence of other limiting factors may delay measurable benefits.

Many projects lacked adequate duration or scope to observe meaningful population-scale outcomes. Limited population responses in some tributaries also showed less-than-expected increases in fish populations due to other limiting factors like habitat degradation and predation.

Cold-water refuges

Cold-water habitats provide critical refuges for juvenile and adult native salmonids, but responses vary among locations and species.

Shade and hyporheic exchange dampen diurnal temperature cycles but alter seasonal temperature cycles differently. Models predicted that hyporheic exchange warmed surface water in winter, but shade would have little effect. In summer, both shade and hyporheic exchange would reduce channel temperatures, although the effects of shade are greater.

Hyporheic exchange may have little effect on stream temperatures if the hyporheic zone is small relative to the volume of the surface water, hydrologic exchange rates are low, net heat exchange between the channel and streambed is low seasonally, or turbulence in the surface water causes rapid mixing.

In addition to meeting thermal requirements of fish, cold-water refuges can reduce exposure to parasites and disease.

Process-based restoration

ISRP and ISAB reviews have called for restoration of processes as well as structure, and the proportion of habitat restoration projects that address biophysical and ecological processes rather than solely habitat structure has increased. However, most of these would not be considered process-based restoration because they do not fully evaluate the range of processes or consider restoration of multiple processes and their interactions.

Large rivers and watersheds that have been extensively altered are major restoration challenges because it is difficult to scale restoration to match the complex and spatially extensive habitat modifications made over an extended period.

Project complexity, spatial extent, and degree of attention to both process and structure have increased markedly since the 2000 Fish and Wildlife Program. The most complete examples of process-based habitat restoration in the Program are spatially explicit watershed assessment programs for subbasin-scale restoration.

Resident fish

Much habitat restoration in the Columbia River Basin focuses on anadromous salmon and steelhead, but resident fishes are an important component in the Program. The Program has funded many projects aimed at resident salmonids, many of which are in blocked areas above the mainstem dams.

Most projects funded by the program included multiple types of habitat restoration, preventing analysis of any one type. However, a 30-year basinwide project in an upper Columbia River subbasin (not funded by the program) showed that coordinated restoration of habitat complexity, connectivity, and flows increased abundance of native cutthroat trout and bull trout. Overall, there are likely more similarities than differences in the effects and outcomes of habitat protection and restoration for resident salmonids compared to anadromous salmonids.

Populations of resident salmonids that are hampered by nonnative fishes may require isolation to persist. Tradeoffs between the benefits of protecting resident salmonids from non-native species by isolating them above barriers and the risks of preventing migratory life histories from being expressed will require careful analysis and consideration to select appropriate management strategies.

Wildlife habitat restoration

Unlike restoration of fish habitats in the Basin, wildlife habitat restoration projects occur in different locations than the original lost habitats and differ in community types and landscape conditions. Restored wildlife habitats sometimes differ ecologically from the original habitats, and upland habitats often are substituted for riparian and wetland habitats.

A major challenge for wildlife habitat restoration is addressing spatial extent and connectivity of restored habitat. Restoration often substitutes smaller, fragmented parcels of habitat rather than the larger and more continuous riparian corridors that were lost.

Monitoring of wildlife habitat projects is frequently qualitative and limited, reflecting a “build it and they will come” approach. While this has local benefits, it limits the understanding of habitat restoration effectiveness. Greater identification and planning for synergistic outcomes of habitat restoration projects for both fish and wildlife could offer increased benefits for the Program.

Recommendations

- Although our focus in this chapter is on restoration methods, we emphasize that protection is important as well. Protection should be considered in tandem with restoration, as recommended in past ISRP and ISAB reports.

- We recommend that process-based restoration continue to be emphasized over structural-based approaches alone, which is also consistent with past ISAB and ISRP recommendations.
- Of the 8 restoration methods we reviewed, removing barriers to restore connectivity, and reconnecting side channels and floodplains, including in the estuary, have a strong likelihood of positive benefits for anadromous salmonids.
- Of the restoration methods we reviewed, barrier removal, flow augmentation, and some wood additions are likely to achieve their intended outcomes in a relatively short period of time (i.e., 5-10 years). There is substantial uncertainty about the time required for restoration of riparian forests, and connectivity and complexity of floodplains. In addition, the persistence of restored cold-water refuges is variable and highly uncertain. Current monitoring of these latter habitat restoration methods has been too short to determine the outcomes.
- The ISRP recommends that the Fish and Wildlife Program encourage synthesis by those conducting long-term experiments like Intensively Monitored Watersheds and continue to support those providing long-term data to answer key current questions, and unanticipated questions that will arise in the future.
- The ISRP recommends the Council develop a coordinated study to monitor and evaluate the long-term effectiveness of floodplain reconnection, riparian forest and meadow restoration, and creation and restoration of cold-water refuges.
- Consistent with language in the 2014 Fish and Wildlife Program, the ISRP recommends that the Council continue to pursue and support projects that increase connectivity between wildlife conservation areas, coordinate with fish restoration and protection projects to further promote terrestrial and aquatic habitat connectivity, and encourage RM&E of habitat and species responses to mitigation actions, especially to evaluate outcomes at larger scales than individual projects. Specifically, the ISRP recommends that the Council identify the major types of wildlife restoration actions that require effectiveness monitoring in the future and develop an approach to implement the monitoring as part of the Tributary Habitat RM&E Strategy.

4. Research, Monitoring, and Evaluation

4.1. A Brief History of Research, Monitoring, and Evaluation

Research, monitoring, and evaluation (RM&E) have been fundamental components of the Fish and Wildlife Program since it began in 1982. The 1987 Fish and Wildlife Program identified the importance of monitoring and evaluation for developing effective actions:

> "*To minimize the risks of management and enhancement decisions made against a background of biological uncertainty, actions must be accompanied by a monitoring and evaluation program to provide feedback to the Council, so that ineffective actions can be identified and management strategies modified accordingly*."

The 1996 Amendment to the Northwest Power Act specifically calls for the ISRP to evaluate whether the projects have provisions for monitoring and evaluation of results and benefits to fish and wildlife. In the 2000s, there was a shift from isolated restoration actions to more integrated actions that have continued to the present. Implementation of habitat restoration and protection actions is strengthened by rigorous monitoring and evaluation to assess the effectiveness of restoration methods, risks of unintended outcomes, and benefits for fish and wildlife. The Adaptive Management Strategy of the Program includes two primary categories of monitoring — status and trend monitoring and effectiveness monitoring (NPCC 2014).

Despite its importance, monitoring and evaluation have been problematic and inconsistent in the Fish and Wildlife Program. One issue has been the costs and time associated with monitoring and evaluation, which can reduce the available resources for actually restoring habitat. Another limitation is that monitoring efforts have often not been prioritized, designed, or funded at a level necessary to rigorously evaluate effectiveness. Organizations that sponsor monitoring programs have a wide array of protocols for habitat monitoring and analyses, and project proponents differ greatly in their technical expertise and analytical capacity.

Coordination and information sharing and application are major challenges in monitoring and evaluation of habitat protection and restoration projects. In the recent Anadromous Fish Habitat and Hatchery Projects Review (ISRP 2022-1), the ISRP found that approximately half of the habitat-related proposals did not adequately describe the monitoring and evaluation occurring in their project or subbasin. Often it was unclear what was being monitored, what monitoring information was provided by other projects, how information was shared, or how it supported project evaluation and management decisions. In the final review, the ISRP recommended that the Program develop a process or mechanisms to identify the multiple M&E activities within geographic areas and clearly describe collectively what is being monitored, how it is being evaluated, and how it is being reported. The ISAB's 2024 Review of the Fish and Wildlife Program (ISAB 2024-2) found that the Program currently lacks but would benefit from fundamental integration of monitoring and evaluation; and, although the Tributary Habitat RM&E Strategy provides useful guidance for RM&E at a site or reach scale, approaches for coordinated monitoring and evaluation for geographical areas or subbasins are needed.

After the 2000 Fish and Wildlife Program, a major addition to habitat monitoring and evaluation were the Integrated Status and Effectiveness Monitoring Program (ISEMP) in 2003 and the Columbia Habitat Monitoring Program (CHaMP) in 2011, created to conduct systematic monitoring for the Columbia River Basin. Although these programs did not directly monitor the effectiveness of habitat restoration, they provided rigorous systematic measures of major habitat components in representative locations in the Basin and were intended to be available for projects in those areas to use for habitat condition assessments. They also developed models for projecting habitat conditions across whole subbasin and basin scales, and the predicted effects of certain habitat features on fish populations (ISEMP/CHaMP 2018). Although these programs ended in 2019, they were a major step in developing consistent, systematic habitat monitoring and tools for predicting these conditions across basins. The Action Effectiveness Monitoring Project was developed in 2013 to assess the effectiveness of major types of habitat restoration, including barrier removal, riparian fencing, wood addition, and floodplain restoration. Results of these evaluations are reported above in Chapter 3. Methods of Habitat Restoration and Protection.

4.2. Guiding principles for RM&E

Tradeoffs between confidence and relevance in monitoring restoration

Restoration is typically monitored at three basic levels: Implementation, Intermediate, and Effectiveness monitoring (NAS 2017). Implementation Monitoring simply documents that the project was built, which can be done with high confidence (low uncertainty), but provides little information about the intended outcome. The Intermediate level of monitoring addresses how the project is functioning and so increases the relevance but often with lower (but still relatively high) confidence. Finally, Effectiveness Monitoring quantifies the responses of the habitat and target species (highly relevant) but often has the lowest confidence (highest uncertainty).

This tradeoff between relevance to management goals and the uncertainty of the results (confidence) is described in Figure 4.1.

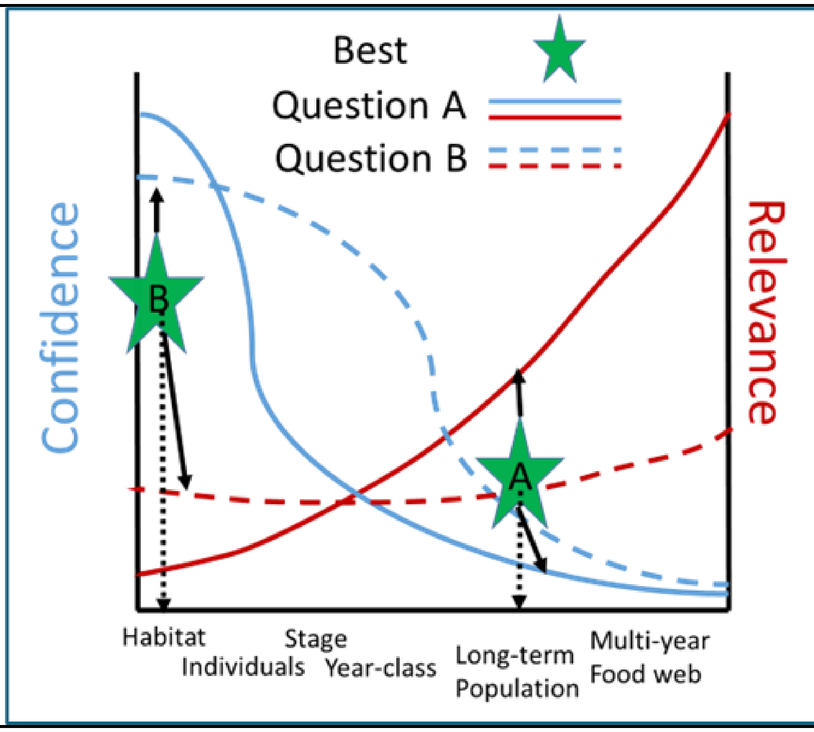

Figure 4.1. Hypothetical relationships between confidence and relevance to management with increasing biological scale of the response variable for two different questions. The two lines associated with each question (confidence and relevance) differ based on the feasibility of answering the specific question, the availability of information, and the planned monitoring design. The stars show the best biological scale for each question, as indicated with the dotted arrows. Note that the best scale is not necessarily indicated by where the solid and dashed lines cross. Some questions require a response variable with high confidence (e.g., Question B - blue dashed line) with the tradeoff being lower relevance (red dashed line). In contrast, other questions are best answered with a response variable with higher relevance (Question A - red solid line) with a tradeoff of lower confidence (blue solid line).

Within Effectiveness Monitoring, there is also a general tradeoff between relevance and uncertainty based on the response variables indicative of the target species that are used (Figure 4.1). Confidence decreases, while relevance increases, progressing from monitoring habitat to individual fish to stage-specific groups to year-class success (multiple stages) to population and food web responses. The lines describing the tradeoffs differ depending on the questions, availability of information, and planned monitoring design. Determining the best response variable to use is then a tradeoff between confidence and relevance. The two stars indicate that Question A would best be answered (optimal tradeoff of confidence and relevance) at the year-class level whereas Question B is better answered at the individual level. In practice, one would identify a desired level of confidence and relevance for a question, and then roughly estimate the two lines for different types of general monitoring designs and determine what response variable and design would be best. In many situations, these assessments would be qualitative or semi-quantitative and one would assess how confidence and relevance trade off among response variables and designs.

Finally, this progression of confidence and relevance with increasing biological scale is also a progression of increasing temporal and spatial scales. For example, assessing the response of a species to a restoration project at the population level requires sampling over longer time periods and over broader scales than answering questions about the local responses of individuals. Thus, different monitoring designs are required.

Although there are exceptions to this tradeoff pattern (Implementation to Effectiveness Monitoring, and measuring habitat to food webs within Effectiveness Monitoring), such as for certain types of complicated, large-scale restoration projects, the patterns are generally robust and applicable in many situations. The key is to carefully consider the tradeoffs when designing the monitoring for a specific project, even when quantitative information is not available to determine exact relationships.

Risk-uncertainty matrix in the 2014 Fish and Wildlife Program

Research, monitoring, and evaluation fundamentally are intended to reduce uncertainty. In the 2014 Fish and Wildlife Program, the Council developed a framework for assessing risk and uncertainty in the development of RM&E. The Program called for project sponsors to use a risk-uncertainty matrix to determine the level of effort to be dedicated to monitoring and evaluation in their adaptive management process (Figure 4.2).

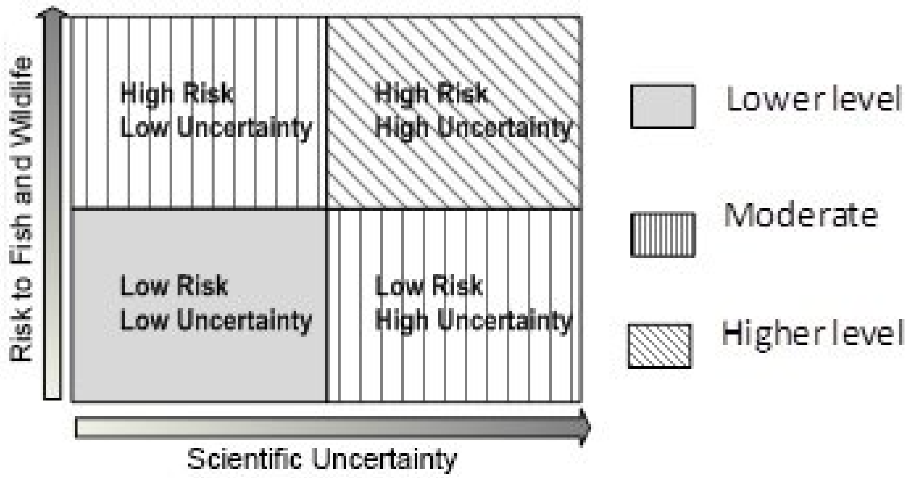

Figure 4.2. Risk-uncertainty matrix guiding level of monitoring efforts for a given action (hatchery, hydrosystem, habitat), and biological status. This guidance also applies to effectiveness assessments and research.

The ISRP and Council also are expected to use the risk uncertainty matrix in project review and decisions (see pages 102-104 of the 2014 Fish and Wildlife Program). The 2014 Program states that:

> "*This assessment should be guided by the risk uncertainty matrix, which states that the level of effort used to gather data should be commensurate with the risk and uncertainty associated with a given species, habitat, and action. In this approach, the intensity of monitoring associated with an action, environmental condition, or population characteristic aligns with the perceived risk of the activity to fish, wildlife and habitat and the level of certainty associated with the impact of the actions, environmental conditions, and population characteristics. This can also serve to guide the level of effort for effectiveness assessments and research. The risk-uncertainty matrix does not apply to baseline status and trend monitoring*."

Risk is defined as the likelihood that an unintended, undesirable outcome may occur. Uncertainty is associated with the level of evidence associated with a given action or biological status based on scientific support. Certainty is ranked in four categories, from strong peer-reviewed empirical evidence, strong weight of evidence, theoretical support, or speculative with little support. Uncertainty in the Fish and Wildlife Program's Risk/Uncertainty Framework is similar to Confidence in the conceptual framework for evaluating tradeoffs in monitoring described in the previous section, whereas Risk and Relevance in the two frameworks are related but not synonymous.

Following the adoption of the 2014 Fish and Wildlife Program, the Council asked the ISAB and ISRP to review and prioritize the critical uncertainties associated with the Program and use the 2 x 2 matrix where applicable (ISAB/ISRP 2016-1). The ISAB and ISRP found the matrix to be insufficient and modified it to include benefits to the Program goals if an uncertainty was resolved and the value of new information obtained from resolving an uncertainty. Costs were discussed as an important element but not considered in prioritizing the uncertainties. The ISAB developed an alternative matrix based on benefits, value of information, and costs (Appendix A of the ISAB/ISRP Critical Uncertainties Report 2016-1), but it too has not been useful in assessing the needs for research, monitoring, and evaluation. In the 2018 ISAB review of the 2014 Fish and Wildlife Program (ISAB 2018-3), the ISAB described the risk-uncertainty matrix as difficult to use based on its efforts to apply it in the Critical Uncertainties Report.

Though the Program calls for the Risk-Uncertainty Framework to guide RM&E, and other programs have developed similar frameworks, the utility of such frameworks as an explicit, detailed decision tool is limited. Consideration of risk, benefit, uncertainty, and relevance is conceptually logical and potentially valuable in developing RM&E programs. The ISRP does not discount the intent of such frameworks for guiding decisions about RM&E and adaptive management. Unfortunately, the complex aspects of risk, many ways to define benefits or relevance, wide array of types and sources of information, and multifaceted approaches for estimating cost make it difficult to apply any simple matrix to determine what needs to be monitored and how much effort is warranted.

Recent development of RM&E guidance and coordination

The Council and BPA have long recognized the ongoing problems with RM&E and have taken multiple steps to bring greater consistency to the habitat monitoring and evaluation process in the Columbia River Basin. The Council has made substantial improvements to monitoring and evaluation through coordinated programs such as the Coordinated Assessments Partnership, Columbia River Basin Coordinated Assessment Data Exchange, and MonitoringResources.org of the Pacific Northwest Aquatic Monitoring Program.

These programs and documents provide a basis for monitoring and evaluation in the Fish and Wildlife Program, but the ISAB review (2024-2) of the Program concluded that the Program still lacks an approach or process for expanding results from specific areas to the full Columbia River Basin. A basinwide monitoring approach would provide an important landscape context for protection and restoration efforts, and assessment and interpretation of the effectiveness of habitat restoration projects. Since the 2020 Addendum was developed, the Council, BPA, Tribes, and other partners finalized the Tributary Habitat RM&E Strategy, which is discussed later in this chapter of the report. The ISAB recommended that the Council should incorporate the recommendations from the ISRP's Anadromous Fish Habitat and Hatchery Projects Review (ISRP 2022-1) to establish the clearly defined RM&E relationships among projects within major subbasins and geographic areas, and ensure the transfer of information among those components in updates of the Fish and Wildlife Program and the Tributary Habitat RM&E Strategy (ISAB 2024-2).

4.3. Coordination

To be successful, the Program must integrate research, monitoring, and evaluation among projects and management agencies to assess habitat conditions, limiting factors, restoration effectiveness, status and trends of fish populations, and integrate information in life cycle models. Ultimately, learning and adaptation require sharing information across watersheds, regions, and cultures so each project contributes to a larger collective evaluation of successes and failures. Active networking across groups with common interests must be part of the process (Rieman et al. 2015).

Both the ISAB and ISRP have commented for several decades on the need for coordination and collaboration. For example, in 2011 the ISAB concluded that "*Effective conservation and restoration of the Columbia River Basin requires a broader, more comprehensive, and more coordinated approach*" (ISAB 2011-4). The ISRP identified coordination and reporting of M&E as an important issue in the 2022 review of Anadromous Fish Habitat and Hatchery Projects Review (ISRP 2022-1). In that review, the ISRP found that for many projects, monitoring and evaluation efforts for habitat restoration were implemented by the individual projects. However, in other cases, M&E projects address broader scale questions above the individual project level.

When conducted at large scales, monitoring and evaluation of protection and restoration provide better quantification and evidence that these restoration efforts lead to improvements in watershed processes, habitat conditions, and salmon and steelhead viability. Such an approach also allows monitoring to address watershed and population-level responses of actions. The solution to this has been development and implementation of basin or subbasin scale habitat planning, implementation, and monitoring that builds on coordination, cooperation, and integration of projects and their results. Umbrella Habitat Restoration Projects have been one of the more effective tactics used to provide effective large-scale restoration (ISRP 2017-2). These umbrella projects currently include the Estuary and Lower Columbia River, Willamette River, John Day River, Yakima River, Upper Columbia River, Lower Snake, Tucannon, and Asotin Rivers, Grande Ronde and Imnaha Rivers, Salmon River, and Pacific Lamprey Conservation Initiative.

Another approach is referred to as Intensively Monitored Watersheds (IMW). IMWs began in the early 2000s and are fundamentally large-scale field experiments in one or more catchments to determine watershed-scale fish and habitat responses to restoration actions with a well-designed, long-term monitoring program (Bennett et al. 2016). The IMW approach is considered an effective experimental design for evaluating watershed-scale salmon and steelhead responses to habitat restoration, although different basins vary in how they implement it (Bennett et al. 2016, Bilby et al. 2022). The IMWs bring together a wide range of stakeholders, which may include state and federal agencies, academic institutions, tribal entities, ranchers and other private landowners, environmental and community groups, and recreationists. Several IMW programs were funded through the Fish and Wildlife Program to coordinate and collaborate on all phases of restoration. Although projects associated with IMWs are still funded, the coordination programs themselves are not. Within the Columbia River Basin there are eight IMWs (see section 4.4.3 below), of which we describe the John Day IMW in greater detail in Chapter 7 on Exemplary Projects.

4.4. Implementation and Compliance Monitoring

The Columbia Basin Tributary Habitat RM&E Strategy (BPA/BOR 2022) requires implementation and compliance monitoring for all habitat restoration projects. Reporting and tracking of implementation and compliance became a major component of tributary restoration work in 2007 when CBFish.org was initiated as the project tracking system for projects funded by BPA.

Implementation monitoring determines whether habitat restoration actions were implemented as planned. The goal is to describe the action, where it took place, and whether it was completed as planned, while collecting basic information on conditions before and afterwards. Typically, implementation monitoring occurs before, during, and for a few years after the action. It is a basic level of monitoring that provides data to project proponents, managers, funders, and regulators as to whether project actions were completed as planned and whether the actions were as durable as projected, while documenting any changes that occurred between project planning and project execution.

Compliance monitoring tracks whether the project has met milestones, such as engineering blueprints and start of construction, and has met appropriate permit requirements. The main purpose of compliance monitoring is to ensure compliance with appropriate regulations, statutes, and permits, and specifically levels of take defined in ESA permits. Compliance monitoring also assesses whether the project remained functional over the life of the monitoring, and whether all legal and mandatory obligations (including environmental compliance requirements), as stipulated in consultations and biological opinions, were met.

The following questions listed in the Tributary Habitat RM&E Strategy are part of reporting of implementation and compliance. Responses are required to document whether project proponents are in compliance with the 2020 Biological Opinion:

1. What habitat restoration actions were implemented?
2. What habitat action categories were addressed by the implemented actions?
3. What were the objective and rationale for the actions?
4. What protocols and tools were used?
5. Where did the action occur?
6. What was the extent of the habitat action implemented?
7. When was the action initiated and how long did it take to be completed?
8. What percent of the originally proposed habitat length or area was restored to the desired condition because of the implemented actions?

The Tributary Habitat RME Strategy provides a useful list of implementation metrics associated with Action categories and types that projects can use. Various methods can be employed to provide data, including repeated photos at key locations (photo points), remote sensing, and field measurements (e.g., counting boulders or pools or habitat structures). Implementation monitoring usually does not require extensive field data and does not attempt to evaluate the larger-scale and longer-term benefits of habitat improvement actions. The implementation metrics are mostly quantitative and are needed to evaluate the extent (size) and intensity (amount) of the habitat restoration action. Implementation monitoring allows funding entities to evaluate whether projects meet their stated targets for numbers and types of actions.

4.5. Effectiveness Monitoring

Effectiveness monitoring measures the responses of habitat and fish populations to restoration. This monitoring must define the scales of space, time, and biological hierarchy over which these responses will be measured, which adds complexity. Here we focus on monitoring fish populations at the spatial scale of watersheds that encompass the entire freshwater life cycle of fish populations, and contrast this with monitoring at the scale of stream reaches where movements of fish influence the response. At each scale we also discuss the biological metrics that may be appropriate to measure.

4.5.1. Physical Habitat and Whole Fish Populations

Measuring responses of whole fish populations to habitat restoration is most tractable in watersheds or subwatersheds that encompass the entire freshwater life history of a relatively well-defined population of anadromous or resident fish. Examples include anadromous salmon and steelhead populations in three sets of three short coastal watersheds in the Lower Columbia, Puget Sound, and Strait of Juan de Fuca Intensively Monitored Watersheds (IMWs), as well as anadromous populations that home to subwatersheds like the Entiat River (mid-Columbia) and Asotin Creek (Snake River; see Table 1 in Chapter 5. Intensively Monitored Watersheds). Straying of fish among subwatersheds does occur but is expected to be low and can be measured to determine whether its effects are likely to confound results.

Although population boundaries are often well defined, methods for measuring whole-population responses must address three common problems. First, habitat restoration often takes many forms in treated watersheds, such as the combined additions of large wood, floodplain restoration, and barrier removals. These restorations often take place over years rather than during a short period and can require decades to reach their full effect in modifying habitat and influencing the multi-year life cycles of fish. Second, given these long-time scales, it is likely that unanticipated environmental disturbances will also occur, such as floods or fire-caused debris flows, confounding the fish response to habitat restoration (Anderson et al. 2023). Third, the natural annual variability of fish populations is often high, even without major disturbances, requiring long periods of measurement to ensure that data are sufficient to detect biologically important effects from habitat restoration.

A basic outline for measuring responses by a whole fish population

For populations of anadromous fish that migrate from sub-watersheds to the ocean, and later return, biologists have developed methods for what is termed "fish in, fish out" monitoring, to understand the basic population parameters of the entire life cycle. These relevant parameters typically consist of annual (or more frequent) measurement or estimation of:

- Adult spawners – measured at weirs or by redd counts.

- Eggs deposited – estimated from relationships of fecundity with length/weight of spawners.
- Juvenile parr density/abundance – estimated by electrofishing or trapping, which allows inserting PIT tags at this life stage. Length/weight can also be measured to estimate growth.
- Smolts produced – estimated using weirs or floating screw traps, and expanded to the entire flow volume.
- Returning adults – assigned to brood years based on scales, otoliths, coded-wire tags, or analysis of parental based genetic tags. Harvest must also be estimated and included to assess total production (ISAB 2025-1).

These measures are then used to derive parameters such as the following:

- Number of adults returning (including harvest) from each brood year of spawning adults, and numbers of eggs, juveniles, and smolts they produced.
- Density of juvenile parr in various rearing habitats.
- Survival from egg-to-parr, parr-to-smolt, and smolt-to-adult life stages.
    - For fish with multiple-year freshwater residency, such as steelhead and "resident" trout, sampling over a period of years (and perhaps in multiple seasons per year) allows estimating survival over these annual or seasonal intervals.
- Movement of parr and smolts during the freshwater life history (immigration and emigration among reaches, and permanent outmigration to the ocean), if the design includes active PIT-tag monitoring or passive monitoring using antennas (e.g., Bouwes et al. 2016).

Monitoring all life stages requires substantial effort over many years, at considerable cost. If suitable treatment and control/reference watersheds are monitored that are reasonably independent (i.e., few fish move among them), then a series of questions like the following can be addressed: in the treated watershed

- Is the density of juvenile salmonid parr higher in watersheds treated with a given suite of habitat restoration compared to untreated control watersheds?
    - Is there an increasing trend in fish densities through time in the treated watershed as restoration proceeds and modifies habitat?
    - Do fish densities in control watersheds become more variable or decline through time, such as owing to disturbances linked to a changing climate?

- Is survival during different intervals of the life stage (i.e., egg-to-parr, parr-to-smolt, smolt-to-adult [i.e., SAS and SAR]) higher for fish born in treated watersheds compared to controls?
- Did habitat restoration alter the distribution of parr among treated reaches within the watershed, or the outmigration timing of smolts, in the treated watershed compared to controls? Detecting this depends on the locations and scale of PIT-tag antennas deployed.
- Did habitat restoration increase the productivity of adults in the treated watershed, defined as the number of smolts produced per spawner, compared to the control watershed?
- Did habitat restoration increase production ($g/m^2/yr$) of fish in the treated watershed relative to the control? Production can be estimated from growth or length-frequency histograms.

In no case is the monitoring of fish at this whole population scale likely to be simple, owing to complexities of fish life histories and the likelihood of confounding factors. However, assembling these data over a well-designed long-term study has the best potential for assessing the net effects of watershed-wide habitat restoration. Further analysis and modeling often will be needed to work out what planned and unplanned factors caused the effects.

The Lower Columbia River IMW is a good example of a coordinated study of the response of fish populations to restoration at the watershed scale (Anderson et al. 2023). The project monitored three small contiguous watersheds draining directly to the Columbia River about 55 miles from its mouth, over >20 years (since 2001). Two are treatment watersheds (Abernathy and Germany Creeks) and one is a control (Mill Creek). Historical logging had depleted channels of large wood and its sources, and road crossings restricted passage of fish, wood, and substrates of all sizes.

Restoration projects (n=13 in Abernathy Creek) were completed in 2012 through 2021 to increase floodplain and stream connectivity, and habitat complexity. These consisted of adding large wood (as pieces and engineered log jams) and replacing undersized bridges and culverts. Restoration was aimed at increasing multi-thread channels with roughness elements (i.e., large wood) that produce more diverse depths and velocities and eventually promote reconnection of the channel with its floodplain. Four projects were also completed in Germany Creek before restoration was stopped there in 2016, and two culverts were replaced in Mill Creek to expand habitat for salmon. The projects in Abernathy Creek affected about 33% of accessible habitat (11.8 km [7 miles] of instream habitat) for coho and Chinook salmon and steelhead.

Biological metrics measured for the anadromous salmonids include:

- Abundance of adult spawners, summer rearing juveniles (parr), and out-migrating smolts
- Survival between life stages
- Body size and growth
- Spatial distribution of spawners

Although restoration treatments have been completed only recently (2015-2021), key findings so far include:

- Fish responded immediately to removal of barriers, and spawners built redds in the newly available habitats upstream.
- Abernathy Creek (treatment) produced fewer coho smolts than Mill Creek (control) before 2018, but since then it has switched and Abernathy Creek has produced more coho smolts.
- Although Germany Creek originally produced the most steelhead smolts, steelhead smolt output from Abernathy Creek has matched Germany Creek starting in 2017.
- Survival rates of juvenile coho salmon from parr to smolt declined sharply with summer parr abundance in all three streams, based on the >15 yrs of monitoring (brood years 2004-2019). This provides clear evidence that survival during this life stage is density-dependent and limited by freshwater habitat.
- The proportion of juvenile Chinook salmon that outmigrate as parr instead of fry also decreased with density, providing evidence that freshwater habitat is limiting this species also.
- Coho that reared in headwater reaches and tributaries were more likely to emigrate after a year of freshwater residency and at a larger size than those that reared farther downstream and emigrated earlier. Larger size is related to higher marine survival and returns as adults, so headwater restoration is likely effective for increasing coho salmon.

This example shows the complexity of responses across space and time, and the need for a comprehensive monitoring plan. Reponses to habitat restoration in the Lower Columbia River IMW have yet to be fully manifested owing to the short period since completion, were more prevalent in coho salmon habitat than in Chinook salmon or steelhead habitat, and were most effective for coho salmon when completed in headwater reaches. Responses by adult spawners to removal of barriers were immediate, whereas responses to added large wood are still playing out. Strong density-dependent juvenile survival for both coho and Chinook salmon indicates that both species should benefit from increased habitat over time.

4.5.2. Segment/Reach-Scale Fish Responses

Most habitat restoration has been evaluated by measuring fish density at the scale of reaches <500 m long and asking whether density is higher in restored reaches than in unrestored controls (e.g., Roni et al. 2008). Studies at this scale differ from those at the watershed scale regarding the metrics in the biological hierarchy that can be measured, the extent to which the key requirements of experimental design can be met, and the mechanisms that can be evaluated. Hence, each approach, whether at the watershed or reach scale, has pros and cons and can be complementary.

What metric(s) in the biological hierarchy are relevant to measure?

Metrics measured to assess responses to habitat restoration occur along a biological hierarchy from short-term measures at small spatial scales to the measurement of lifetime fitness at the spatial scale of all habitats used by a population. Metrics amenable to measurement typically include behavior (e.g., movement, habitat selection), physiology, growth, survival, and reproduction, as well as derived variables like production (survival times growth).

Some metrics are amenable to measurement at the reach scale, and may be relevant over single summer seasons, such as for life-history forms of juvenile Chinook salmon that spend only one summer rearing in Columbia River tributaries (Polivka 2022). Typical metrics for these fish include movement and habitat selection, growth, and density. Other metrics like smolt-to-adult survival, production, and reproduction are typically best measured at the watershed scale, because they must be measured over years and can be affected by other factors such as ocean conditions.

Tradeoffs in experimental design

Three key features—control, replication, and randomization—are required of field experiments to provide robust, unbiased results that can resolve hypotheses about the effectiveness of habitat restoration. These requirements create tradeoffs when designing studies at reach versus whole watershed scales.

Control – True experiments compare responses of fish in one or more watersheds or reaches where habitat has been restored (the treatment) to the responses in otherwise similar locations that are not restored (the control). A key problem is maintaining independence of treatment and control reaches or watersheds, because fish move among them. If investigators measure the leptokurtic distribution of fish movement distances (see Box 2 on stream fish movement), study reaches can be separated at distances that optimize independence among them.[8]

A useful strategy, if resources permit, is to include several control reaches or watersheds at different distances (see Bouwes et al. 2016). The tradeoff here is that streams are inherently different, so paired treatment and control reaches within the same streams are most efficient for detecting treatment effects. Locating treatment and control reaches in different streams results in confounding these random "stream effects" with the treatment effects of interest but may be necessary if, for example, effects on fish or habitat in treatment sections influence control sections (see Bouwes et al. 2016).

Replication – Replication is either low or not possible for studies at the watershed scale, whereas at least a reasonable level of replication is typically possible at the reach scale (n=4-6 treatment reaches, and an equal or slightly lower number of controls). Inferences from whole watershed studies that include only one treatment and one control rest on the strong assumptions that the two watersheds were similar initially, represent other similar watersheds, and that no other factor except the treatment affects the response of fish differently in one watershed than the other. For example, if a flood affects the treatment watershed more strongly than the control, then the effect of this on fish cannot be separated from the effect of the habitat restoration treatment. The two are confounded, and the negative effects of the flood may negate any positive effects of the restoration.

Randomization – In a true experiment, a set of similar reaches or watersheds chosen for study are assigned randomly *a priori* to receive the treatment or be selected as a control. This requirement can typically be met for either the watershed or reach scale if the experiment is planned well in advance, but often other constraints like access and ownership intervene. In many cases, habitat restoration has already been started before any experiment planning, so randomization is no longer possible. Such studies must then be considered either intensive (one treatment and control reach/watershed) or extensive (several of each) post-treatment designs (e.g., see Clark et al. 2019). This lack of randomization can cause unknown bias, especially if reaches chosen for the original habitat restoration were different in some respect from other reaches from which the controls are later chosen. For example, if the most degraded locations were selected to receive habitat restoration, then the treatment effect

[8] Compared to a normal distribution, a leptokurtic distribution has a higher peak around the mean, more observations in the tails, and a higher probability of extreme values.

could be overestimated when compared to the effect that would have occurred had a random subset been selected for restoration.

Sidebar 4.1. Stream fish movement and responses to habitat restoration

Movement is ubiquitous among fish in streams. Movements occur across nearly all life stages of fish and span a broad range of spatial scales. Movements include passive dispersal of fry, active dispersal of juveniles to rearing habitat, seasonal movements and migrations of juveniles and adults to seek refuges for overwintering, and anadromy from rivers to ocean and back (Gowan et al. 1994). A key indicator of the ubiquity of movement is the rapid response by stream fishes when barriers are removed (Clark et al. 2020), dry streams are rewatered (Erman and Hawthorne 1976), or weirs or other fish capture devices are placed in streams or rivers (Schmutz and Jungwirth 1999). Fish typically colonize or recolonize new habitats rapidly in both coastal and inland watersheds (e.g., after dam removal on the Elwha River; Duda et al. 2021).

Empirical data show that the most common pattern of movement distances displays a large peak at short distances, but with very long tails accounting for fish that move to many different distances up to long distances away (Figure 4.3; Radinger 2014). This pattern is called leptokurtic, and the entire function is termed the dispersal kernel.

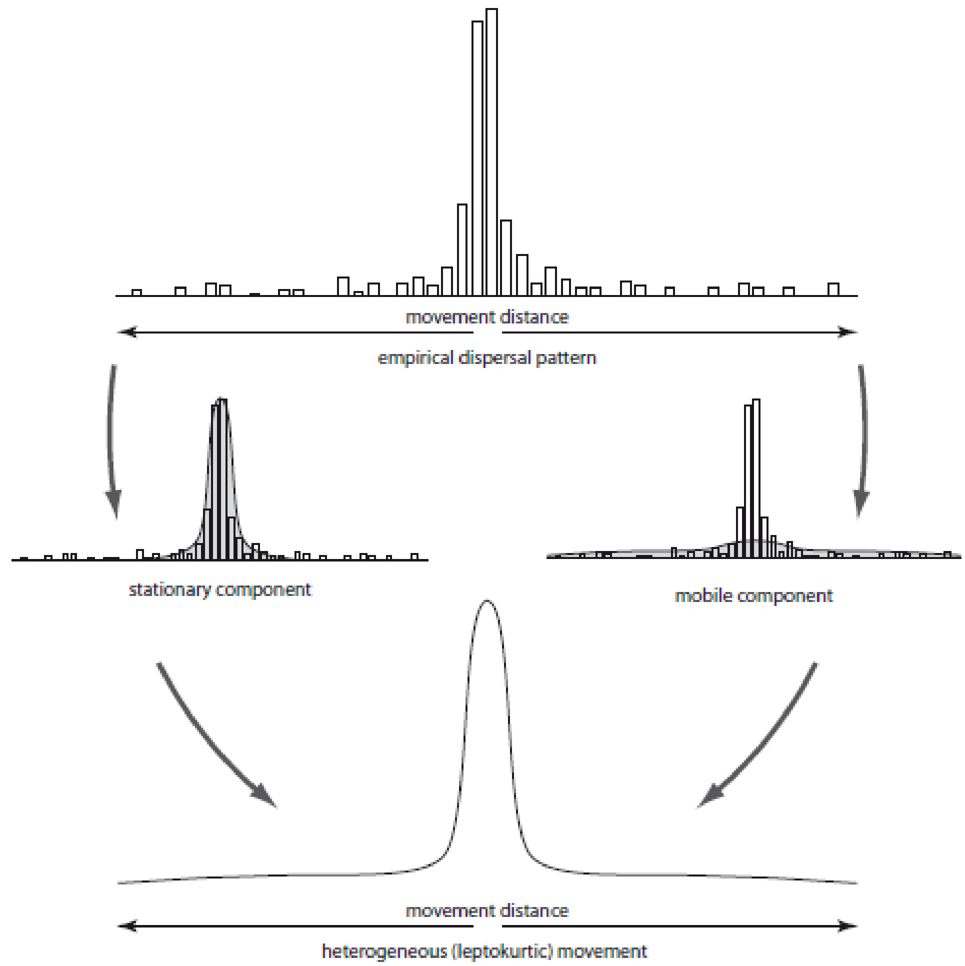

Figure 4.3. A typical pattern of movement distances in stream fish, best described by a leptokurtic distribution with a sharp peak and long tails. These distributions, termed dispersal kernels, are typically fit with a two-part model describing what investigators term stationary and mobile components (from Radinger 2014).

Early studies measured movement directly by tagging and recapturing fish or using radio telemetry. The most comprehensive studies that included relatively long study sections and repeated measurements over months to years show this leptokurtic distribution (Figures 4.4 and 4.5), both for fish considered resident (e.g., Gowan and Fausch 1996b; Gresswell and Hendricks 2007) and anadromous fish with freshwater life cycles (Heggenes et al. 1991).

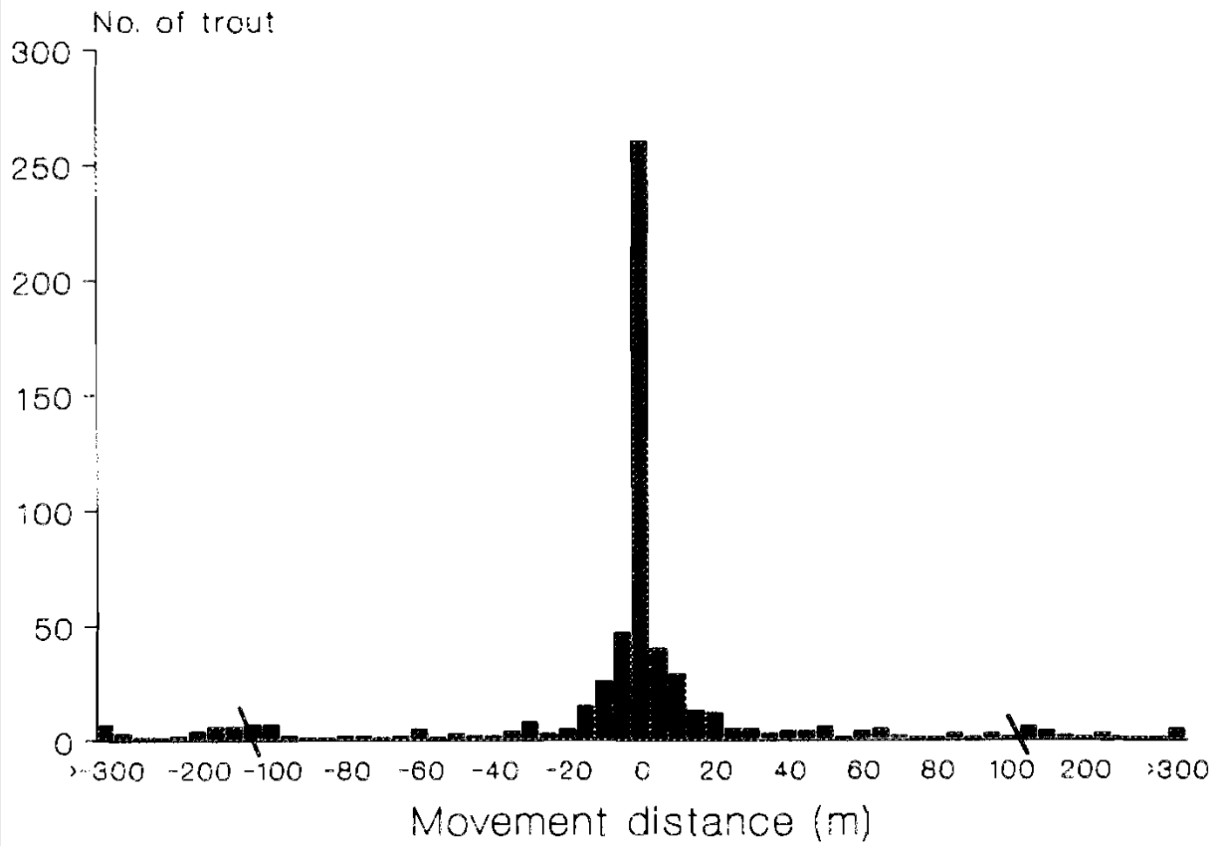

Figure 4.4. Distribution of movement distances of marked anadromous coastal cutthroat trout determined by sampling at 2-week intervals during January to August 1988 in Musqueam Creek, British Columbia. Bars represent 5-m intervals for distances to 100 m, and 25-m intervals at greater distances (total study area was 525 m; from Heggenes et al. 1991).

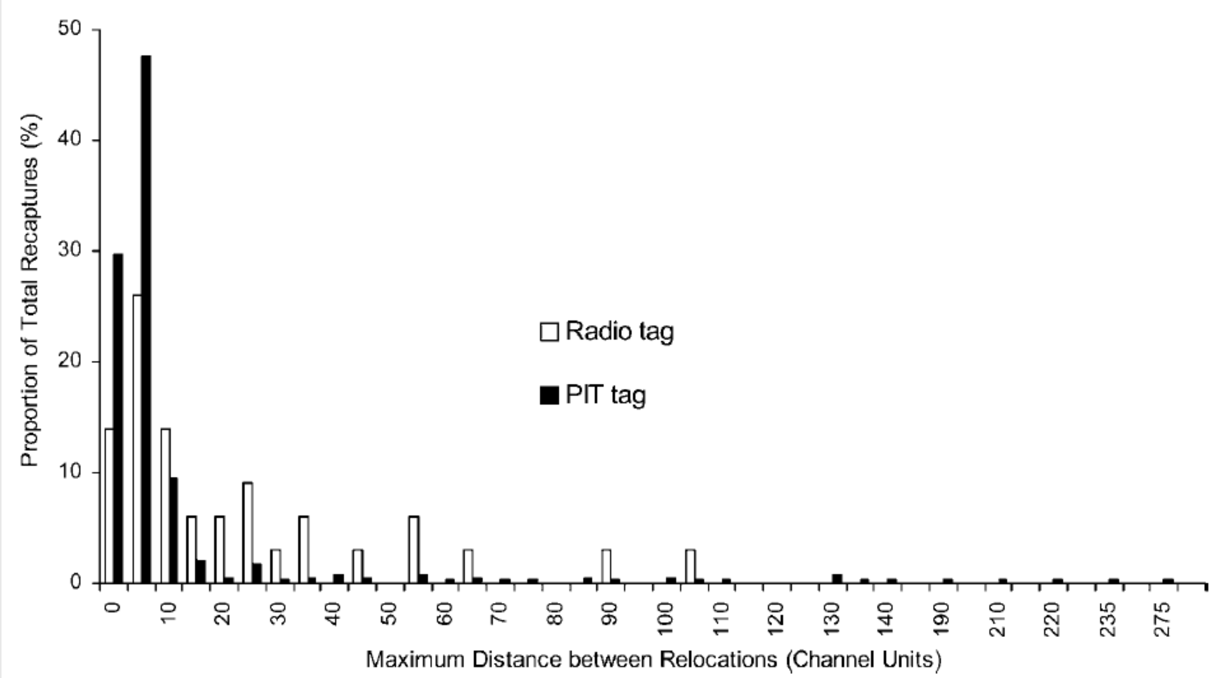

Figure 4.5. Maximum dispersal distance (in channel units) of resident coastal cutthroat trout in Camp Creek, Oregon, during a 14-month study (June 1999 to August 2000). Maximum distance is from the most upstream to the most downstream channel unit in which fish were captured and relocated. Intervals are 5 channel units, except for zero. Channel units averaged about 20 m long, so 50 channel units represent about 1 km (.62 miles), and 300 about 6 km (3.7 miles). Note that unlike the previous two figures, this one lacks direction (upstream, downstream), so all long distance movements are combined into one long tail.

A key problem is that movement measured using such direct methods is always underestimated, because fish that move the longest distances are routinely not detected and assumed to have died. Gowan et al. (1994) and Fausch and Young (1995) addressed this, showing that in most studies based on mark-and-recapture of fish, even though a large proportion of the recaptured fish were found in or near their "home" sections, a large proportion were never recaptured (e.g., see Gresswell and Hendricks 2007). As telemetry studies began to tag and track more fish, investigators found that long-distance movements were common, taking fish far beyond the limited study areas of hundreds of meters searched for marked fish in typical studies (e.g. see Young 1994, who detected brown trout maximum movement distances of 23 and 94 km [14 and 58 miles]).

Most studies of movement also have been conducted over relatively short periods, compared to the entire life cycles of fish. Three extensive surveys of hundreds of studies on stream fish movements reported that median durations of studies, or time between recaptures of individuals, were 77, 92, and 150 days (Rodriguez 2002, Radinger and Wolter 2013, Comte and Olden 2018), representing only 2 to 5 months of the entire life cycles of fish. All three studies reported that dispersal distances were positively correlated with study duration or time between recaptures, and with spatial extent of the study area, or both. For example, a model fit by Radinger and Wolter (2013) shows the spread of dispersal distances predicted for large brown trout in a third-order stream for one month versus an entire year (Figure 4.6).

Modeling distributions of stream fish movement distances and inferences drawn

Several investigators modeled the distribution of movement distances (the dispersal kernel) and used these models to draw inferences. Because the model is strongly leptokurtic (high peak and long tails), conventional models based on a single distribution do not fit well. Investigators postulated that fish populations consist of a sedentary or stationary fraction (“stayers”) and a mobile fraction ("movers”), and they used a two-compartment model to fit the function. They then estimated parameters such as the median movement distance, the spread of this distribution (standard deviation) as a measure of the routine home range over which fish move, and the proportion of fish that are sedentary or stationary. For example, Rodriguez (2002) used a two-group negative exponential model to estimate median movement distances and the proportion of sedentary individuals from 27 datasets for stream salmonids, primarily brown, brook, and rainbow trout and Atlantic salmon. It is notable that for a few studies he censored fish that moved long distances that were not quantified, and in another he deleted 5 of 110 fish that created an outlier (it is unclear whether these were long-distance movements).

Rodriguez (2002) reported that the median of all the 27 median movement distances was 28 m. The median was <50 m for 17 of the 27 populations, and <100 m for 24 populations. The median percentage of stationary individuals was 81%. However, several characteristics of this dataset suggest that it may not represent movement distances accurately. First, the studies reviewed ranged as short as 1 day, 8 of 27 were shorter than one month, only 4 were a year or longer, and the median duration was 3 months (92 days). Second, the median extent of study sections was only 430 m, and 10 of 27 were <250 m, so for many of the studies fish moving long distances could not be detected. Nevertheless, the conclusion from this study, that stream fish typically move <100 m, is widely used to assess how fish respond to habitat restoration (e.g., see Roni 2018).

Comte and Olden (2018) evaluated movement distances across many different species of stream fishes for about 200 case studies that used direct methods (mark-recapture or telemetry) and another 200 “indirect” studies that used genetic methods to estimate isolation by distance. To compare direct studies that averaged 77 days between relocations with genetic methods that measure movement over generations, they fit models that included time and estimated the parent-to-offspring dispersal distances over one generation. The average of the mean parent-to-offspring dispersal distance for case studies of salmonids (determined from their Figure 4) was 5 km (3.1 miles), and the average maximum dispersal distance was 8 km (5 miles). The standard deviation of the dispersal kernels showed that routine movements of the stationary component for salmonids was 200 m, whereas for the mobile component, routine movements were about 2 km (1.24 miles). Interestingly, Comte and Olden (2018) still reported these movements as "restricted," emphasizing a point made by Gowan et al. (1994) that this term is strictly relative and not defined compared to what movements might be considered "unrestricted."

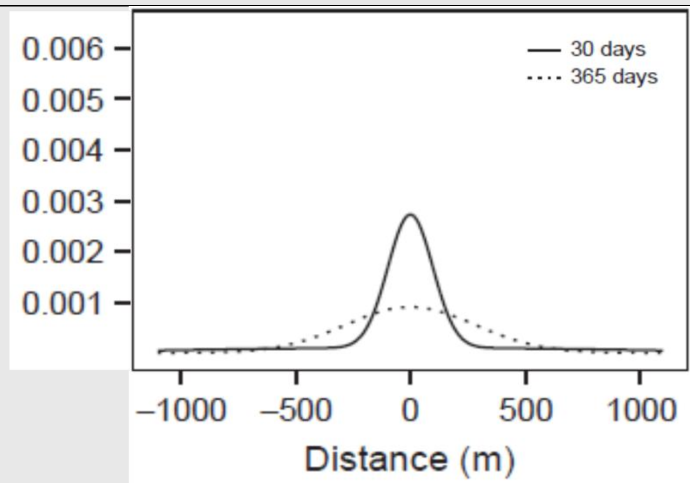

Figure 4.6. The distribution of movement distances (dispersal kernel) predicted for large brown trout (600 mm) in a third-order stream from a multiple regression model, showing the spread of dispersal distances with time, at 30 days and 1 year (from Radinger 2014).

The median isn't the message for the response of salmonids to habitat restoration[9]

A key controversy about the role of stream fish movements in response to habitat restoration revolves around whether fish are merely "attracted" to habitat structures, and hence whether they become "concentrated" around them (e.g., Roni 2018). An often-

[9] This idea is borrowed from a well-known article by evolutionary biologist Stephen Jay Gould, who when he was diagnosed with mesothelioma cancer and learned that the median time to mortality was only 8 months, decided to be hopeful because he deduced that his risk factors placed him in the 50% that lived longer than the median. He lived another 20 years (reprinted as Gould SJ. 2013. The median isn't the message. Virtual Mentor 15:77-81.)

unstated assumption (but see Polivka et al. 2015) is that such concentration must leave other habitats depleted of the fish that moved to use positions near the habitat structures. The worry is that if fish simply redistribute and use restored habitat, it may result in no net benefit.

Roni (2018) reviewed a large number of studies and concluded that some reported increases in fish abundance after habitat restoration owing to immigration (e.g., Gowan and Fausch 1996a), others found little evidence for immigration and assumed increases in habitat capacity or survival, and others reported that both mechanisms were responsible (e.g., Lonzarich and Quinn 1995). Despite this, Roni (2018) concluded (apparently based largely on Rodriguez 2002) that "*salmonids generally move less than 100 m during low-flow periods*" and "*there is little evidence to support the contention that instream restoration or river restoration techniques concentrate fish*." The evidence indicates that the first conclusion is often not true for salmonids in general, and the second is incomplete without addressing an unstated assumption. Moreover, fish movement can have clear benefits for effective habitat restoration.

A key problem is that these conclusions are based on median movement distances, estimated from data that typically missed the longest-distance movements and using models fit with two-part functions such as the negative exponential (e.g., Rodriguez 2002). In addition to excluding key long-distance movements, such statistical models may not estimate the distribution of these long-distance movements accurately.

A thought experiment can show the effects of basing conclusions on only the median movement distances. Consider a case where an investigator marks a high proportion of fish in a 50-m reach in a small stream, and samples a large spatial extent (e.g., perhaps 2 km [1.24 mi] both upstream and downstream) a year later to estimate distances fish have moved. The resulting data are likely to be leptokurtic, as in Figures 4.3 and 4.4. Now consider that they install habitat structures in this 50-m reach (the restored reach) and measure fish abundance for several years.

If one assumes the simple case in which fish in each adjacent 50-m reach also show the same distribution of movement distances over time, then during the next year the number of fish represented in this entire leptokurtic distribution would encounter the habitat restoration. That is, the 50-m reaches adjacent to the restored reach would send the number of fish in the 50-99-m intervals in each direction, the 50-m reaches that start 50-m away would send the number in the next 100-149-m intervals, and so on in both directions. As a result, even though on average about 2/3 of fish were reported to be "stationary" in the short-term studies reviewed by Rodriguez (2002) and Radinger and Wolter (2013), within a year a large number of fish would encounter the restored reach. Many of these are fish that moved beyond the median distance and come from long distances. Again, this fraction of fishes is also typically underestimated in studies of stream fish movement.

Another reason many fish will encounter the restored reach is that they range much farther throughout their life cycle than these key papers report. Roni (2018) concluded that fish move less than 100 m "during low-flow periods," but this may have little relevance to their response to habitat restoration over entire life cycles, and depends on their life history (which, in fairness, Roni acknowledges). If seasonal movements of fish to find refuge habitats from harsh winter or low flow periods bring them in contact with attractive restored habitat, it is likely they will use it. This behavior, of moving until suitable habitat is found is termed "ranging behavior" (Dingle 1996), and may be common among stream fishes (e.g., Kahler et al. 2001).

Is concentration of fish in restored reaches a problem?

Does this mechanism of fish response to habitat structures via immigration cause a problem for managers interested in effectiveness of restoration? If there is concern that habitat restoration "simply concentrates fish," this implies that movement from unrestored habitats to those restored will leave other habitats depleted of fish, resulting in no net increase in fish abundance streamwide. If such long-term depletion were the case, it seems that, at least for fish subject to sport fisheries, managers would be unlikely to let anglers catch and keep fish, since by this assumption they would never be replaced.

Like many animals, stream salmonids display density-dependent survival, whereby survival is lower at high density and increases as density is reduced (e.g., Elliott 1994). Adult salmonids produce hundreds to thousands of eggs, of which only two need to survive to adulthood for the population to be stable. Hence, mortality is high, especially at the egg, fry, and juvenile stages.

The key question is: When a fish moves to find better habitat (e.g., ranging behavior), will its position be filled by another (often juvenile) fish? The answer based on the first principles of population biology and density-dependent survival is very likely to be yes. Indeed, when Polivka and his collaborators (Polivka et al. 2015; Polivka and Claeson 2020) measured abundances of juvenile Chinook salmon and steelhead near habitat structures, adjacent to them, and at some distance away they found increased density near habitat structures but no evidence that abundances were depleted in adjacent or distant habitats not restored. Perhaps such depletion might be possible in cases where the number of spawning adults is severely limited, but these cases could not be considered the norm.

In summary, although the phrase "If you build it, they will come" has been used for some time by those concerned about this issue, increases in abundance via immigration have clear benefits for habitat restoration projects (Polivka 2020, Polivka et al. 2024). Immigration can increase abundance quickly. In many cases it is also likely to be accompanied by a short-term increase in density-dependent survival in the restored sites, as the fish population rapidly responds to the increased carrying capacity for a year or two. For example, Gowan and Fausch (1996a) reported that this increase in survival could be detected during the first year after habitat structures were placed in one of two streams where survival was measured in detail by mark-recapture of tagged fish.

Does stream fish movement confound field experiments?

A second issue is whether the movement of stream fish can invalidate field experiments by destroying the independence of treatment and control sections. For example, if a fish is first captured and marked in the control section, but then moves to an adjacent treatment section, this invalidates the fundamental design of the experiment. Control fish are not supposed to become treatment fish. Here, however, the leptokurtic movement distribution can be used to advantage, to estimate how far apart to locate study reaches to provide minimal confounding. For example, estimates of the median distances moved by the mobile fraction (about a third of the population, based on estimates) have been reported to be 329 m for stream salmonids (Rodriguez 2002) and 363 m among a broad set of stream fish species (Radinger and Wolter 2013). Hence, one might argue that study reaches placed about 1 km (0.6 mi) apart should minimize the number of individuals that move between them. Although given the long tails of dispersal kernels, it would not be possible to prevent all such exchange, a small amount is unlikely to swamp any but the most modest effects of restoration, which are not the effects managers are interested in.

Direct evidence for increased habitat capacity created by habitat restoration at the reach scale

As described above, when immigration is found to drive increases in fish density in response to habitat restoration, an implicit assumption often made is that this leaves other habitats vacant leading to no net increase in streamwide fish abundance or production. Carlos Polivka and his collaborators set out to test this idea directly in a series of integrated studies conducted on the Entiat River, Washington, an IMW that was terminated in 2017 (see review in Polivka 2022). Habitat structures were installed in reaches of about 300-800 m every three years, during 2008, 2011, and 2014, and the results for several biological metrics (habitat selection behavior, density, and growth) were measured across spatial scales ranging from habitat units (pools) to reaches. Because no pre-treatment data were measured, the studies are based on either intensive or extensive post-treatment designs. The target species were juveniles of Chinook salmon, which rear in the stream for one summer, and juvenile steelhead which typically rear for 2-3 years.

The Engineered Log Jams (ELJs) and small boulder structures (rock barbs) installed in the Entiat River were typically constructed at a density of about 5-10 per reach, and each created a small pool from about 15 m^2 (i.e., about 4 m X 4 m) to 55 m^2 (about 7.5 X 7.5 m) in area. Polivka and his collaborators hypothesized that if fish concentrated near structures and left other habitat vacant, this could be detected by comparing fish densities in pools around structures with those in natural small pools in areas without structures in the treatment reach. They also compared these with fish densities in similar pools in control reaches at some distance that were not restored (Polivka et al. 2015, 2019; Polivka 2020; Polivka and Claeson 2020).

In their extensive post-treatment design (n=8 treatment reaches, n=5 control reaches, divided among two longer segments), they found that densities of juvenile Chinook salmon were 2.9-13 times higher in pools created by ELJs compared to unrestored patches in the treatment reaches, and steelhead were at 1.7-6.8 X greater density. In contrast, there was no difference in density between the unrestored pools in treatment reaches and similar pools in control reaches at some distance. From these results, they inferred that habitat restoration had increased the carrying capacity of the habitat in restored reaches, rather than leaving habitat vacant as fish moved from adjacent locations and used habitat created by ELJ structures (Polivka and Claeson 2020; Polivka 2022). In addition, in the upstream segment, pools formed by ELJs had similar densities of the two species when compared to pools formed by natural jams of large wood, indicating that the structures installed were good analogs of natural structures.

In these and related studies, measurements at different scales of space and time revealed the inherent variability in fish responses to habitat restoration. For example, in more detailed studies of density-dependent movement and growth across years, Polivka (2020) and Polivka et al. (2020) found positive effects in at least half the years in most cases, but not every year. For example, juvenile Chinook showed a higher affinity for pools formed by ELJs versus those in unrestored areas in two of four years studied. They also reported that juvenile Chinook recaptured in pools created by ELJs grew larger earlier in the season than those not associated with habitat structures, but only in three of five years studied. Thus, owing to these variable responses, replication in time (across years) is as important as replication in space (multiple reaches). Important effects can be missed in single-year studies.

Regarding spatial scale, increases in density versus control locations were clear at the scale of habitat units (i.e., the small pools formed around ELJ structures), but disappeared when areas twice this size were sampled (Polivka et al. 2019). Hence, the relatively sparse spacing of habitat structures, affecting about 3.5% of the area in treatment reaches, did not increase fish densities sufficiently to be detectable at the entire reach or watershed scales. This does not negate the effectiveness of these structures, but when installed at this density their effectiveness must be measured at the appropriate spatial scale.

In summary, approaches at the reach scale and watershed scale have different strengths and weaknesses, and can be used to address different questions. Whole-watershed studies are useful to address results at the scale of whole populations, the scale at which managers make decisions. However, they require decades to complete and suffer from potential confounding of fish responses to habitat with responses to other environmental factors. Studies at the reach scale can meet the requirements of rigorous experiments, and address important mechanisms such as fish movement, habitat selection, and growth at the scale of habitat structures or reaches, but results may be difficult or impossible to scale up to entire fish populations in whole watersheds (Polivka 2022).

4.5.3. Estuary Monitoring

Monitoring and evaluation in the estuary inform the Program and the Biological Opinion (BiOp) for the Columbia River System (CRS, previously referred to as Federal Columbia River Power System or FCRPS). A research, monitoring, and evaluation (RM&E) plan for the Columbia River estuary and plume was developed by Johnson et al. (2003) to fulfill certain requirements of Reasonable and Prudent Alternatives of the 2000 Biological Opinion on the Operation of the Federal Columbia River Power System (NMFS 2000). From 2004 to 2007, BPA and the COE worked with NOAA Fisheries (also referred to as the National Marine Fisheries Service [NMFS]) to develop a plan called the Research, Monitoring, and Evaluation for the Federal Columbia River Estuary Program which developed specific research, monitoring, and evaluation objectives that were incorporated into the 2008 FCRPS BiOp (Johnson et al. 2008). CEERP was formed to implement federal ecosystem restoration actions and research, monitoring, and evaluation RM&E in the estuary.

The main focus of restoration monitoring in the lower Columbia River and estuary has been on effectiveness monitoring (e.g., Roegner et al. 2009). A stated goal of effectiveness monitoring is to have some monitoring occurring at all estuary restoration sites. Since 2010, the Lower Columbia Estuary Partnership (LCEP), along with partners, has managed a number of distinctive monitoring and evaluation programs. The LCEP collects data and guides or directs data collection by others.

One monitoring program managed by LCEP is the Ecosystem Monitoring Program that collects baseline information on habitats used by migrating salmon and provides data on Status and Trends. Work began in 2011 and focuses on five minimally disturbed tidal wetland sites in the lower Columbia River: Ilwaco Slough, Welch Island, Whites Island, Campbell Slough, and Franz Lake (left). More specifically, this program aims to:

1. Inventory different types of habitats.
2. Track ecosystem and hydrology trends in these habitats.
3. Monitor reference sites, to provide ideal end points for habitat restoration projects.
4. Analyze how management actions impact the broader Lower Columbia ecosystem.

Data are collected on fish and fish prey, habitat, hydrology, food webs, abiotic site conditions, and mainstem river conditions.

Arguably, the most significant monitoring program is the Action Effectiveness Monitoring and Research program (AEMR) of the Lower Columbia Estuary Program. The purpose of AEMR is to determine the success of restoration actions at site, landscape, and estuary-wide scales in terms of improved ecosystem functionality, especially as it relates to juvenile salmon performance and the CEERP objectives. The goal of AEMR is to provide some monitoring at all restoration sites, but not all types of monitoring are collected at all sites. Reference sites are also monitored.

Estuary monitoring for the CEERP Program was originally guided by protocols published by Roegner et al. (2009) which defined "core metrics," "higher-order" indicators, and sampling designs for AEMR of habitat restoration projects. AEMR methods depend on the attendant restoration actions. This critical work laid the foundation for the development and refinement of future monitoring protocols.

In 2023, the Estuary Partnership released new protocols for monitoring juvenile salmonid habitat in the lower Columbia River (Kidd et al. 2023) that refined the methods of Roegner et al. (2009). Factors to monitor include hydrology, water quality, elevation, remote sensing, plant communities, vegetation plantings, and fish communities. Updated methods integrate changes based on new knowledge and advancements in the field. This document, prepared by the LCEP, extends beyond the scope of the CEERP, and serves as a guiding monitoring protocol supporting diverse programs and research efforts in the estuary.

4.6. Columbia Basin Tributary Habitat RM&E Strategy

The Columbia Basin Tributary Habitat RM&E Strategy (BPA/BOR 2022) represents the most recent and arguably the most significant step in developing, organizing, strategizing, evaluating, and reporting M&E of tributary restoration for the Fish and Wildlife Program. The framework and guidance were developed to meet the needs of varied parties involved in tributary habitat projects across the Columbia River Basin. The Strategy describes a consistent and logical approach to tributary habitat RM&E to assess the physical and biological benefits of restoration actions. It also supports the goal of targeted restoration work to better address habitat, species, and population-specific ecological concerns in tributaries. The Strategy deals only with Columbia River Basin tributaries, does not include estuaries and lakes, and is focused on Chinook salmon and steelhead.

The Strategy is built around five key management questions (KMQ's). The KMQs represents the three major themes of the RM&E Framework: ensuring project implementation, evaluating habitat response, and measuring biological change. It supports targeted restoration work to address population-specific ecological concerns and facilitates the collection of physical and biological indicators that can be used to assess outcomes and inform future habitat restoration projects. These KMQ's are consistent with the Council's Fish and Wildlife Program, the Action Agencies' proposed action (BPA et al. 2020) in the NMFS and USFWS 2020 CRS BiOps (NMFS 2020a and USFWS 2020), and the NMFS and USFWS Habitat Improvement Project Biological Opinions (HIP BiOps; NMFS 2013, USFWS 2013). The Strategy was developed in collaboration with most tribes and government entities in the Columbia River Basin. It is a broad, collaborative, and inclusive approach to articulating and advancing priority RM&E to meet many purposes and scales for tributary habitat projects across the Columbia River Basin. This collaborative development process reduces surprises because many entities monitoring restoration in the Basin will know the elements of the Strategy and should be familiar with how to implement it.

The Strategy could be best described as an enhanced logic path that guides investigators through the major steps of restoration RM&E, helps identify significant issues, and provides resources to assist in developing and implementing an M&E program. It is noteworthy that the logic path fits within the feedback loop of an adaptive management process, from planning/project selection to implementation, to monitoring, to reporting and then back to planning/project selection. The ISRP and ISAB have consistently identified the importance of adaptive management in their project reviews. The 2014 Fish and Wildlife Program also emphasizes the importance of its Adaptive Management Strategy. The Tributary Habitat RM&E Strategy primarily deals with RM&E rather than project planning or implementation, but results from any RM&E effort should fit within an adaptive management process and provide direction for future project planning and implementation.

The Tributary Habitat RM&E Strategy emphasizes project or reach level monitoring to measure project implementation, compliance, habitat response, and biological response. The importance of scaling up and monitoring at watershed scales is discussed because population-level effects can be understood only at larger spatial scales. If feasible, the Strategy recommends that monitoring programs be designed so that information collected at the project or reach scale can be extrapolated to larger spatial scales. However, there is limited guidance provided on how to do this. Scaling up is not a simple compilation of the project and reach data and requires a sound sample site selection and experimental and analytical design. As the Strategy is implemented, more specific guidance will be needed for project proponents to ensure that the data collected are scalable, comparable, and can be used in a broader analytical framework.

Many details associated with RM&E are clearly beyond the scope of the Strategy to specify, in large part because RM&E depends on project-specific variables such as type of project, size, location, and limiting factors. For example, key questions include what indicators should be selected, how to measure them, what experimental design should be selected, location and number of control reaches, how often to monitor, and what statistical analysis should be implemented. Many of these issues are important, complicated, and require specialized expertise. Such details can make the difference between producing monitoring data that is useful or not. To help investigators, the Strategy includes references and data resources, tools, and models available to help with RM&E planning. For example, the Pacific Northwest Aquatic Monitoring Partnership (PNAMP)'s Monitoring Resources tools identify and describe methods for measuring habitat indicators identified in Table 3 of the Strategy. A literature survey to identify and describe methods for measuring habitat restoration (Beechie et al. 2017) included most of the indicators identified in that table. Roni et al. (2019) and White et al. (2021) also identify methods for measuring habitat indicators.

The Strategy proposes that many actions should not require effectiveness monitoring and justifies this assertion by citing available literature for major types of restoration. They state, however, that implementation monitoring is required for all projects. The Strategy's evaluation of restoration literature concluded that evidence was sufficient to conclude that most types of projects "worked" and that further verification of this with "more" monitoring was not warranted, a conclusion the ISRP does not fully support. The greatest uncertainty is associated with effectiveness of floodplain reconnection/enhancement, riparian restoration, and restoration of cold-water refuges (see Section 3.5 on conclusions for methods of habitat restoration), so these projects have the highest priority for effectiveness monitoring.

To determine whether effectiveness monitoring is required for a particular project, the Strategy provides five criteria:

1. Fish Species Status—ESA-listed fish species and focal species will be prioritized
2. Region—Project lies within the Columbia River Basin.
3. Degree of Knowledge/Uncertainty—If little is known about the proposed action or actions, effectiveness monitoring may be justified.
4. Degree of Acuteness of Impact—Habitat restoration actions that address a specific, acute condition limiting the survival of a specific life stage (e.g., bottleneck) will be prioritized for monitoring
5. Degree of Risk—Habitat restoration actions that might have unintended, undesirable outcomes in ecological conditions or biological response will be prioritized

Data handling is an important theme throughout the Strategy. Most major elements of the Strategy (Implementation, Effectiveness Monitoring for Habitat and Biological Response) include a discussion of data management, analysis, and reporting as key parts of any monitoring program. Data handling includes data management, setting standards, infrastructure and sharing, curation, sharing, management of raw data, meta data, and quality control and assurance. One essential element of data handling not included in the Strategy is data analysis. We refer readers to Sections 4.7 and 4.8 below, which address certain aspects of design and analysis of such data.

The Tributary Habitat RM&E Strategy relies on consistent, scientifically rigorous habitat data and reporting to address the Action Agencies' RM&E priorities and data gaps, while allowing flexibility in monitoring methods. We concur that data management is an important element in this Strategy because consistent data reporting and data management standards help facilitate adaptive management and promote evaluation at the scale of the Columbia River Basin. However, data management requires high-level coordination and management. For example, processes for handling, storing, and accessing data and metadata vary considerably, especially when several entities are contributing to a common database. The Coordinated Assessments Partnership provides a good example of the magnitude of effort, coordination, and cooperation required to build and support a sound data management and sharing program. A similar effort may be needed to meet the data management and data sharing objectives of the Strategy.

A major benefit of the Strategy has been to develop a list of habitat and biological indicators to help standardize data collected, although not all indicators need to be measured by a project. As the Strategy is implemented, it would be helpful if users described the major pros and cons of the indicators, such as measurement error, reliance on established methods, cost effectiveness, and information content. There is some guidance in CBFish.org as well as guidance in the literature on how to measure many of these habitat variables (Beechie et al. 2017).

The Strategy treats limiting factors fairly simply, and some important aspects are not addressed. Based on best available information, the Strategy asks what are the priority ecological concerns for focal species that tributary habitat actions are intended to address, including the freshwater habitat life stages that limit focal species and populations and the habitat factors that limit those life stages. Even within one life stage, there can be multiple limiting factors, as well as confounding factors that affect how a limiting factor operates and how it needs to be restored (see Chapter 5). For example, density dependence (ISAB 2015-1) can occur, even under low densities, and affect the success of a restoration effort.

Finally, the Tributary Habitat RM&E Strategy does not describe how it would be staged and implemented. For example, will there be seminars or training on the Strategy? It is also unclear how progress and effectiveness will be tracked once the Strategy is fully implemented. Will periodic surveys or evaluations of information in CBFish.org determine how the strategy is being used? How will the information generated by the projects be assessed and shared to build a broader understanding of the most effective restoration strategies and methods?

4.7. Sampling and Experimental Designs and Statistical Approaches to Enhance RM&E

Monitoring and evaluation of habitat restoration rests on 1) careful design of sampling or field experiments to ensure they can evaluate the questions posed and 2) appropriate statistical analysis that can support robust inferences. In this section, we first present fundamental principles of designing restoration monitoring, followed by information on experimental designs shown to be optimal, methods of measuring response to restoration across large spatial scales, and new techniques for synthesizing information across multiple projects.

4.7.1. Key steps in designing a program to monitor habitat restoration

Ensuring that the questions managers ask about the effectiveness of habitat restoration can be answered with confidence rests on the fundamental design of the monitoring program.

There are several useful reviews of best practices and step-by-step guides for designing a monitoring program (Block et al. 2001; Machmer and Steeger 2002; Roni et al. 2005, 2013, 2018; England et al. 2021). Implementation monitoring is typically straightforward, so step-by-step guides focus on effectiveness monitoring. As described in other sections, challenges of effectiveness monitoring include measuring the responses of target species that are 1) highly mobile within a dynamic environment (England et al. 2021), 2) subject to large intra-annual and inter-annual variation in timing and spatial dynamics, and 3) whose vital rates (survival, growth, and reproduction) are often influenced by many factors outside the influence of the project. There continue to be calls for a standardized framework for effectiveness monitoring and reporting of results (Eger et al. 2022). We show one example (Figure 4.7) from Roni et al (2005), and others share similar steps.

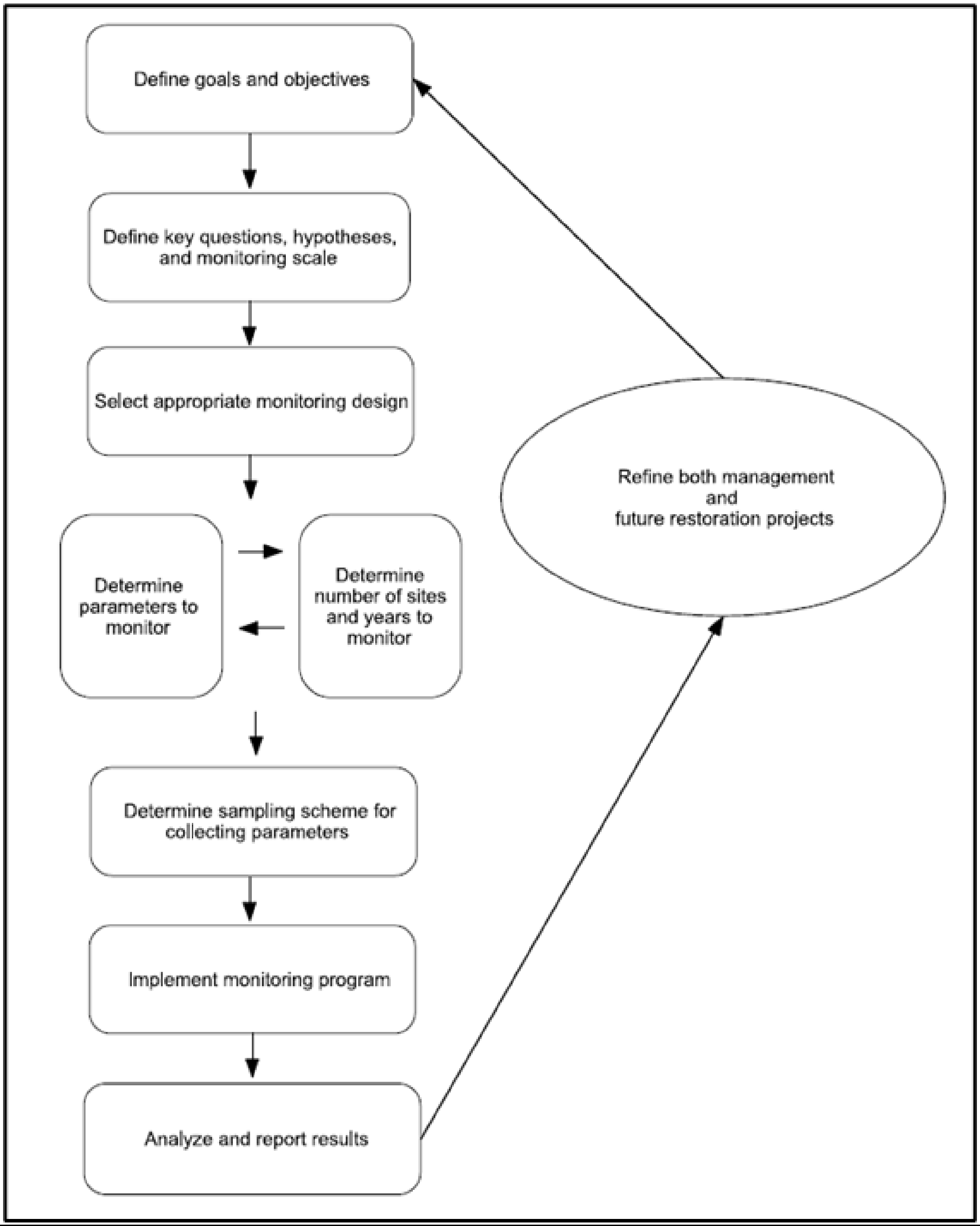

Figure 4.7. A step-by-step approach to designing an effectiveness monitoring program (from Roni et al. 2005). Other step-by-step schemes have been proposed and generally follow the same steps.

Specifying questions and defining scales of monitoring

A key first step that determines the usefulness of monitoring is specification of the questions, which must flow logically from the goals and objectives of the restoration project (Roni et al. 2005). The more specific and testable the questions, the more straightforward is the process of designing monitoring (Chapman 1999). With all monitoring, and especially effectiveness monitoring, consensus can be more easily reached for vague questions than specific ones because vague questions leave open the interpretation of success or not. Managers, other researchers, and stakeholders often have different understanding of terms such as "habitat." Without clear specification, people attach their own ideas and expectations to the term "habitat," which strongly affects attempts to determine whether it increased and was effective at producing increases in target species. Hence, questions need to be clear and definitions specific.

Another consideration is whether it is sufficient to show the target species responded to the project or whether it is also important to know *why* this response occurred (cause and effect). Information on why a project did or did not perform as expected is crucial if the results are also intended to inform adaptive management. Using an example of floodplain reconnection and restoration, it might be easier to determine whether more juvenile salmonids are present during summer rearing but more difficult to assess whether this is owing to favorable water temperatures, greater habitat complexity, or more food resources (e.g., see Bellmore et al. 2013, 2017).

Another key consideration is the appropriate temporal and spatial scales for monitoring. As described above (Section 4.5.2), sampling over a short period and limited spatial domain generates detailed information about fish responses but can be strongly influenced by fish movement. The opposite approach of sampling over a broad spatial domain reduces the influence of movement across boundaries but at the cost of requiring more samples to cover the broader area and often sacrificing the details (resolution) of each observation. The biological scale and the dictated temporal and spatial scales are determined together because the design (e.g., number of surveys, samples, locations, layout of receivers) and physical and biological analyses must generate results with sufficient confidence and be feasible.

Design of monitoring, and important statistical attributes

Once specific questions have been defined, the next major steps comprise designing the monitoring. These steps include the selection of response variables, and explanatory variables (if needed), and the design of the sampling scheme itself. Defining the response variables is generally known for a specific project and location. Although the data from many designs can be analyzed in native units (e.g., density of fish), more often differences or ratios between treated versus untreated measurements are used as the response variables (Connor et al. 2016). How to measure the response variables (and associated variability) can be challenging. A logic chain or conceptual model that shows how the measurements are related and fit with the other important factors to answer the question is critical (Michener 1997).

Sampling design, a component of monitoring design, is the specification of the number and spatial distribution of stations or the locations where measurements are made (e.g., PIT-tag antennas), and the temporal distribution of surveys. Sampling theory has a long and proven history, and basic sampling strategies and layouts for monitoring living resources, habitat, and environmental data are well-documented (EPA 2002, Noble-James et al. 2018, Williams and Brown 2019). There are alternative designs, but the key is to use a well-planned design.

There are several important concepts and practices to consider when designing monitoring programs. Control, randomization, and replication, the hallmarks of experiments, have been discussed above (see Section 4.5.2), but may be modified for monitoring schemes. For example, when monitoring restoration there is a distinction between control and reference sites, although the terms are often used interchangeably (Chapman 1999, Roni et al. 2005). As for true experiments, control sites are similar to the sites to be restored but are not treated or influenced by nearby restoration. Control sites attempt to show what would have happened to the restored sites if they had not been restored. In contrast, reference sites are relatively undisturbed sites, also not influenced by restoration, and represent what it is hoped restored sites will trend towards and eventually resemble (White and Walker 1997, Stoddard et al. 2006). Both control and reference sites are ways to account for natural variability unrelated to the restoration and both greatly strengthen a BACI-type analysis (Chapman 1999, Roni et al. 2018b). Some have proposed selection of sites and analyses using dynamic reference sites to accommodate the “moving target” inherent in highly variable locations with trending environmental conditions (Hiers et al. 2012).

Unlike laboratory experiments, true randomization is often not possible with restoration because in most cases treatments (restoration) cannot be randomly assigned to locations owing to practical considerations that limit options for sampling. Nevertheless, it is important to choose sites representative of those suitable for restoration, and where possible, randomly select sites for restoration and those to be controls. Sites chosen should also be periodically re-evaluated to ensure they are still representative. The lack of true randomization means classical statistics must be used with caution (Michener 1997). Non-random sampling (systematic, transect) designs are useful, but involve more sophisticated statistical analyses. Replication, the third key ingredient, is critical for separating restoration responses from other factors that cause random variation (Michener 1997, Block et al. 2001).

Other important concepts to monitoring design and analyses are interactions, stratification, power, timescale of responses, and statistical significance versus effect size. Often, the response to restoration is based on the importance of the treatment-by-time interaction (Block et al. 2001, Connor et al. 2016). Conceptually, this involves comparing the responses of treated sites relative to untreated sites before restoration (when responses such as fish abundance are expected to be similar) versus after restoration (when restoration is expected to have caused an increase in the treated site). Stratification (or blocking) is a way to control for variability (Block et al. 2001), whereby strata are selected that have lower within-strata variability versus among-strata variability.

Statistical power refers to the probability of detecting a true effect (or trend) when it exists (as opposed to falsely concluding that there was no effect). Calculations of power are based on prior or simulated data that include the variation expected, and they are used to test the appropriateness of different designs and plan needed sample sizes (e.g., Roni et al. 2005, Vaudor et al. 2015). The time scale of target species responses to restoration is often longer than most monitoring of projects (England et al. 2021), so monitoring of project implementation, intermediate processes that support target species, and improvements in habitat suitability measured using effectiveness monitoring (Figure 4.7) can provide evidence of project performance.

There is often too much reliance on reporting statistical significance, which is the probability (typically 0.05 is selected, a 5% chance) of falsely claiming an effect of restoration. However, an effect that is statistically significant may, nevertheless, be very small, so more important is the size of the effect detected (e.g., a 20% increase in smolt production after restoration), which should always be estimated and reported (Smith 2020). An inadequate design or improper analysis diminishes the chance that a true effect that is important biologically will be detected, leading to potentially false conclusions that the restoration was either effective (owing to statistically significant but small and biologically unimportant effect size), or ineffective (owing to low power to detect even a substantial and biologically important effect). Effort and money can be expended on carrying out inadequate designs that ultimately do not allow accurate assessment of the response.

Selecting and testing alternative designs

There are many possible sampling designs (Roni et al. 2018b), and several reviews describe the advantages and challenges of alternative designs (Noble-James et al. 2018, Loughlin et al. 2021). In selecting an alternative, it is critical that the details of the design are specified and then tested before sampling occurs with data representative of the project effects and location. These data can be prior data from the location or from other similar projects and systems or can be data simulated to have similar mean and variance.

Some projects occur where there is ongoing sampling, so the design is inherited and should be evaluated, and augmented, if necessary, to answer the new questions posed. This leveraging can maintain the integrity of the existing monitoring while also enabling analysis of the response to the project actions. Any changes should be examined to ensure the purpose and continuity of the original monitoring are maintained. Other projects may involve response variables rarely quantified in the project area because of limited study or a relatively new measurement method. Gathering pre-treatment data is imperative for the new monitoring.

A common situation is that pre-restoration data are not available, requiring use of post-treatment designs based on a space-for-time substitution (Roni et al. 2003, 2005). Intensive post-treatment designs use multiple years of data collected at one or a few paired control (or reference) and treatment sites. In contrast, extensive post-treatment designs use many paired treated and untreated sites each sampled once over 1-3 years. The intensive design is essentially a BACI design without pre-project data and low replication, and is generally less informative than an extensive design for quantifying responses to restoration actions.

Sometimes, especially with large projects, there is an opportunity to set up a design specifically for the project. In this case, a version of a BACI design is often the preferred and recommended approach (see Section 4.7.2 below; Conner et al. 2016, Hale et al. 2019, England et al. 2021). Baldigo and Warren (2008) compared power with BACI designs that differed in the statistical test to detect restoration effects and the number of years, number of treatment reaches, and replication.

Whether an existing design is being augmented or a new design is being planned, testing the design beforehand is critical to ensure the results are capable of evaluating the hypotheses posed. Testing involves using available data plus reasonable assumptions to fill in missing data to generate a hypothetical dataset that would likely result from the proposed design. One then analyzes the dataset to "test" whether there will be sufficient power to detect biologically important effects, and how well the data from the design can answer each question. Testing to inform designs should occur before data are collected, and confirmed after the initial set of data (e.g., year 1) is obtained. This provides an opportunity to revise the design before there is a large investment in collected data and strong inertia to continue the same monitoring. It also offers an opportunity to achieve a balance between confidence, relevance, and cost (see Figure 4.7). Testing ensures effective integration of results, especially across response variables.

Monitoring and data analysis over time

Effectiveness monitoring will likely require multiple surveys over multiple years. There is a transition period when the habitat or restoration action achieves the design specifications and use of habitat by the target species reaches a dynamic equilibrium. Thus, the term "before and after" is an oversimplification, as restoration projects are not like flipping a switch and going from dark to light. Moreover, not all features of the habitat will progress at the same pace, so care must be used when interpreting the years immediately after project completion. These features of a before-after design were detailed by Holtby and Scrivener (1989) in their very insightful paper on the effects of logging in the Carnation Creek, British Columbia, watershed. Although habitat use will not be the same every year (e.g., owing to different flows, hydro-system operations, population sizes), dynamic equilibrium is reached when the variation in responses is bounded.

Data analyses should be done throughout the project evaluation. Initially, results are used to ensure the design can generate information to answer questions. After that, preliminary results can inform adaptive management and eventually, as added data increase confidence, form the basis of an assessment of performance. Data management – including QA/QC, metadata documentation, and accessibility – is needed to ensure the integrity of the analyses and the continued availability of the information (Michener 1997). Clear and accessible reporting and communication are essential to the success of any assessment (Roni et al. 2005). While protocols are often well documented, an implementation plan that presents the questions, rationale for the design, conceptual or logic model, how the data will be analyzed, and communication is also required.

4.7.2. For Monitoring and Evaluation, what experimental/ sampling designs are optimal?

As described above (Section 4.5.2), scientific experiments incorporate three elements: randomization, replication, and controls. Meeting these requirements becomes increasingly difficult as the experimental units become larger and more diverse, and responses to treatments become more protracted and variable through time. Responses of fish to habitat restoration include all these constraints, because experimental units are typically long stream segments or whole streams, and responses of fish populations are inherently variable across years and may take years to manifest, as has been found for the IMWs (Anderson et al. 2023; Bilby et al. 2024; Bisson et al. unpublished) and studies of disturbance (e.g., Holtby and Scrivener 1989).

Before-After, Control-Impact (BACI) designs

The most commonly prescribed design for measuring effects of environmental impacts such as habitat restoration is a before-after, control-impact (BACI) design

(Stewart-Oaten et al. 1986, 1992*)*. In this design, for example, a stream segment (or whole stream) receiving large wood placements is compared to a control not subject to this treatment and both are measured before and after the treatment. Afterwards, fish in the treated segment are expected to show a positive response (e.g., increased growth, abundance, or survival) compared to the three other cases (beforehand in the treatment, and in the control segment before and after). This effect is represented as the interaction of Treatment X Time in the statistical model.

The original BACI design included only one replicate each of the “impact” location and a control or reference location (Stewart-Oaten et al. 1986) and hence does not include either replication or randomization. In contrast, in a classic experiment a set of replicate streams or stream segments would be chosen for study, and some would be randomly selected to receive the treatment and the others would be controls. Such Multiple BACI designs (mBACI; Downes et al. 2002) offer more power to detect effects.

For example, Gowan et al. (1996a) used an mBACI design to measure the response by resident trout to addition of log structures that created pools. Treatment sections with 10 log structures were compared to adjacent paired control sections in six replicate Rocky Mountain streams, before and after installing the logs, and measured a total of 8 years. The treatment and control sections were randomly assigned to upstream vs. downstream positions, altogether satisfying the three elements of experimental design (but see below for further comments). The paired treatment-control design in each stream had the additional advantage of accounting for effects unique to each stream (see below).

Another option is to compare an “impact” location to multiple control sites, referred to as an asymmetric BACI (aBACI; Underwood 1994). This also provides more power than the simple BACI and protects the experiment from controls that may not be independent of the treatment segment, discussed further below.

Staircase designs to account for unplanned environmental perturbations

Key characteristics revealed during long-term data collection for the Intensively Monitored Watersheds include high interannual variability of the response by fish populations to habitat restoration, and the strong effects of random environmental perturbations such as floods and wildfires (Anderson et al. 2023; Bilby et al. 2024). As described above, if the experimental units are whole streams, and only one stream is selected as the treatment stream, then the effect of any perturbation that happens to coincide with the habitat restoration cannot be separated from the effect of the treatment.

Walters et al. (1988) proposed staircase experimental designs that can account for these “time-treatment” interactions. For habitat restoration projects, the fundamental idea is to apply restoration to replicate streams in different successive years, reducing or eliminating the chance that a single unplanned environmental perturbation that occurs region-wide, or in a particular stream, will influence the effect of the planned habitat restoration. Instead, each replicate is exposed to a different sequence of random environmental effects before and after the treatment (Loughin et al. 2021).

Loughlin et al. (2021) tested the effectiveness of two asymmetrical BACI designs, and two staircase designs for detecting effects of adding large wood to Asotin Creek on density of juvenile steelhead during summer. They developed a simulation model and used data on juvenile steelhead abundance collected over 24 years, as well as 2 years of more recent data from the Asotin IMW, to estimate variance components over time and space. They tested several "effect sizes" of the large wood treatment (i.e., a 5% to 40% increase in steelhead density). They also tested several levels of variability across space and time, including the variability expected based on historical data as well as the "worst-case" of high variability (i.e., the upper 95% confidence limit on the spatial and temporal variance component estimates).

Under the expected level of variation in steelhead density across space and time, all four experimental designs (BACI and staircase) detected a 25% change owing to adding large wood (in the simulation model) with nearly perfect statistical power (i.e., 1.00, or in 100% of the simulations). However, under the worst-case level of variation, the best staircase design was far superior, detecting a 25% difference in density in 77% of the 5000 simulations (i.e., power of 0.77). In contrast, the two aBACI designs detected this 25% difference in only 41% and 3% of simulations, a large decrease in statistical power to detect effects when variation was high.

The staircase design achieving the highest power incorporated one treatment and two control sections in each of three streams, where the treatment was applied at different successive times in each stream (Figure 4.8). This has the practical advantage of allowing investigators to stage habitat restoration across multiple years, because logistical constraints typically prevent all work being done in one year or over a short period. This design is similar to the idea of statistical blocking, where each stream is a block in which the experiment is replicated with its own internal controls, but with staggered start times. These internal controls are also important because streams are not identical and tend to respond differently to habitat treatments.

One caveat for any experimental design is that fish movement may prevent treatment and control segments from being independent, especially if they are nearby (see Sidebar 4.1. Stream fish movement and responses to habitat restoration). However, if fish movements are measured (e.g., their leptokurtic dispersal kernels), then control segments can be located at sufficient distances that effects on responses in the treatment segments (i.e., control fish becoming treatment fish) are minimal. For example, Gowan et al. (1996a) placed 250-m treatment and control segments adjacent to each other and found rapid increases in trout density that were driven by fish movement (Gowan et al. 1994). However, marked fish revealed that relatively few immigrants came from the adjacent control (only 2-5% bore marks from the control section, even though 97% of age-1+ and older fish were captured and marked during each sampling occasion), and instead were unmarked fish that came from many different distances up to long distances away (Gowan and Fausch 1996b).

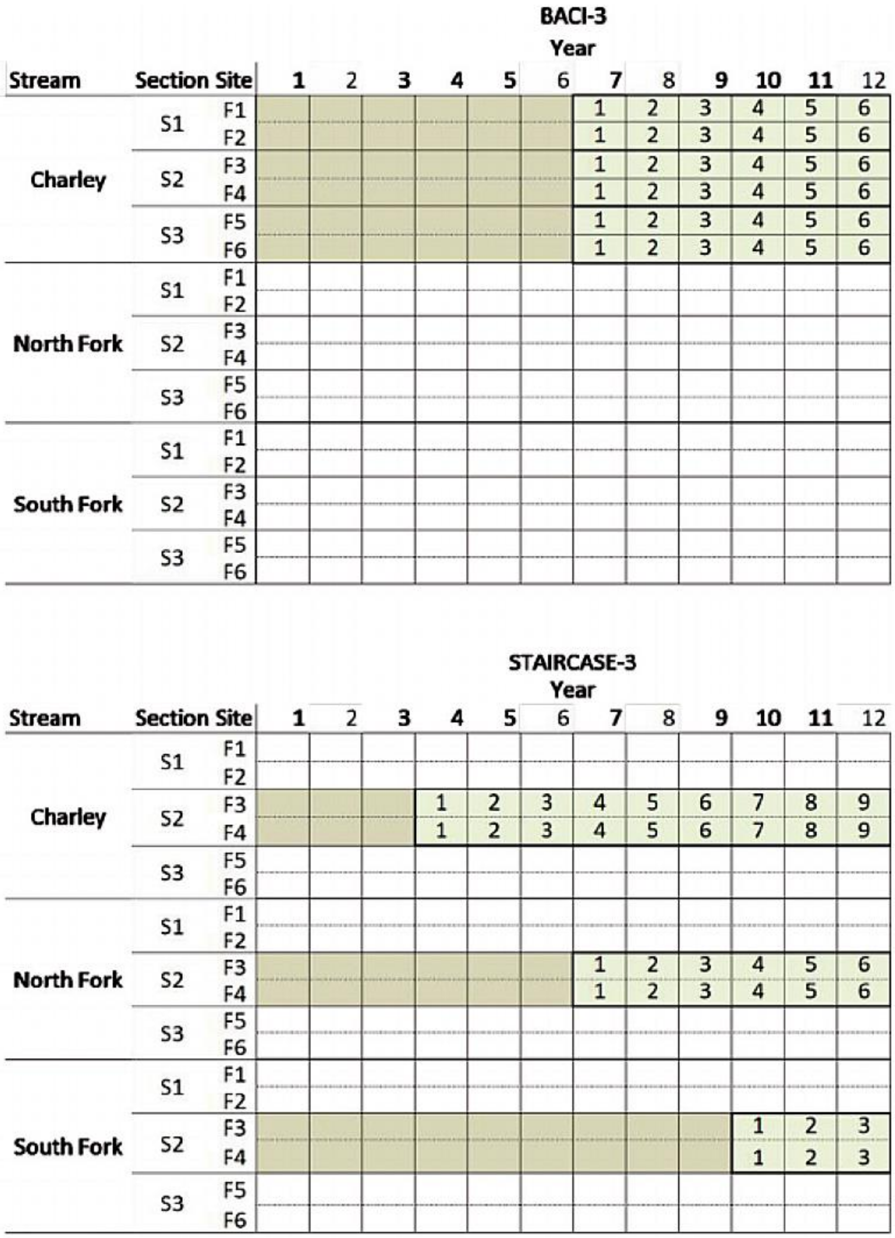

Figure 4.8. Two experimental designs for detecting effects of habitat restoration on fish populations (from Loughlin et al. 2021). The **top diagram** shows an asymmetrical BACI design (labeled BACI-3) where habitat is manipulated in year 7 of a 12-year study in three separate sections (S1 to S3) of Charley Creek, and fish are measured in each with two subsections (e.g., F1 and F2). Two other streams (North and South Fork) serve as unmanipulated controls. The **bottom diagram** shows a staircase design (Staircase-3) where habitat is manipulated in one section (S2) of each stream, but with staggered start years (4, 7, and 10). Adjacent unmanipulated sections (S1, S3) serve as independent controls in each stream. Fish are measured in two subsections of each section (e.g., F3 and F4). When variation is substantial, the staircase design has greater power to detect

effects, the strength of which may vary among streams and be affected by unplanned environmental perturbations that coincide with the habitat manipulation.

4.7.3. What methods of analysis can be used to assess responses of fish populations across large spatial scales?

Responses of fish to habitat restoration in tributaries of the Columbia River Basin occur at the large spatial scales over which entire fish populations carry out their life cycles. For anadromous fish, even the freshwater portion of their life cycles can encompass whole sub-watersheds. Likewise, many species considered "resident," such as bull trout and cutthroat trout, include fluvial and adfluvial life history forms that range over tens of kilometers and up to 100 km (62 miles) or more to complete their life cycles (e.g., Starcevich et al. 2012).

Unlike studies focused on mainstem habitats where juvenile salmon are typically tagged during outmigrations and detected at dams as they move downstream, juvenile salmonids residing in tributaries for at least some of their life cycle, like steelhead and cutthroat trout, are encountered at different times and locations using different methods. For example, juvenile steelhead may be captured by electrofishing in rearing areas and PIT-tagged, encountered again during surveys with mobile antennas, and then later detected passing PIT-tag antennas as smolts or adults (e.g., Bouwes et al. 2016).

Ideally, a statistical model for estimating abundance, survival, and movement would account for immigration and emigration among segments and incorporate these different sources of data. Although open-population models such as the Cormack-Jolly-Seber (CJS) model, which can account for immigration/emigration, have been available for many decades, they cannot incorporate the additional encounters of fish outside of regular sampling bouts (Conner et al. 2015). In contrast, the more recently developed Barker model can include all encounters of fish, during regular sampling and at additional locations (e.g., via fixed and mobile PIT-tag antennas).

Simulations have shown that estimates of survival and movement using the Barker model are more precise and less biased than those from the CJS model under most conditions of sampling intensity (i.e., number of fish tagged) and recapture/detection probability (Conner et al. 2015). Tattam et al. (2013) used realistic ranges in parameters for their simulations, based on data measured for juvenile steelhead in a tributary of the John Day River Basin. They developed several scenarios simulating typical movements by steelhead, where some fish are resident in the tributary, some reside multiple years and then emigrate, and some emigrate within a year of hatching. These simulations showed that survival estimates using the Barker model were 17% to 35% more precise than those using the CJS model. Results from the Barker model also averaged about half the bias compared to the CJS model, across a range of scenarios.

Bouwes et al. (2016) used the Barker model to good advantage for measuring the response of steelhead to Beaver Dam Analogs in Bridge Creek, Oregon. They designed a large-scale field experiment with replicate treatment and control reaches, including additional control reaches in an entirely separate control watershed, and measured responses of habitat and fish before and after treatments using a mBACI design. The estimates from the Barker model showed that juvenile steelhead density increased substantially, survival increased 52%, and production (g/m2/year) increased 175% in sections of the treatment watershed compared to the control watershed. After treatment, beavers built dams throughout the watershed where BDAs were constructed, confounding the comparison of treatment with control reaches there and requiring comparisons to be made to reaches in the separate control watershed.

4.8. Synthesizing information across multiple projects

An additional frontier in the analysis of habitat restoration is the opportunity to synthesize information across projects. For example, the 16 Intensively Monitored Watersheds have conducted habitat restoration in sets of treatment segments or watersheds and compared them to controls where no habitat restoration was conducted. Given the wide variation in fish populations through time, and the vagaries of other confounding factors, there is often insufficient evidence from responses in any single IMW to draw strong conclusions from the time series of data available. However, recent methods allow incorporating information across sets of data to provide a weight of evidence to assess the strength of responses by fish to management actions.

Several varieties of “state-space” models have distinct advantages over traditional Analyses of Variance models for analyzing the results of BACI and other designs used in habitat restoration projects. Developed for analysis of time-series data, these hierarchical models allow analyzing complex relationships manifested at multiple levels of spatial and temporal organization. In addition, they can incorporate information from different sources, accommodate missing data, and estimate many unobserved variables (Scheuerell et al. 2015; Tolimieri et al. 2017).

For example, Scheuerell et al. (2015) evaluated the effects of hatchery supplementation on the time-series of adult Chinook salmon returns to 12 populations in the Snake River spring-summer ESU, versus 10 populations that were not supplemented (Figure 4.9). Data spanned 43 years, including 11-23 years of supplementation among the supplemented populations. The analysis, completed in a Bayesian framework, revealed that the average effect of supplementation across populations increased adult densities by only 3.3% (95% credible interval -7.7% to 15%), with a 73% probability that the effect was greater than zero.

This analysis was able to account for supplementation that occurred over different periods across populations, and in 6 of 12 populations supplementation was not conducted every year. The analysis simultaneously accounted for long-term trends in populations across the entire region and revealed a high level of year-to-year variation in adult abundance, which in most years (39 of 43) was more than twice that attributed to supplementation, on average. Hence, environmental variables operating at various scales played a stronger role than supplementation in influencing adult salmon density.

In another example of synthesizing information using diverse datasets, Tolimieri et al. (2017) used a multivariate autoregressive state-space (MARSS) model to integrate disparate information on an assemblage of ESA-listed marine rockfish garnered from citizen-science scuba surveys, a trawl survey, and recreational fishery surveys under varying bag limits. The results showed declining abundances (about 4% per year) that can be used to assess population viability and make management decisions about regulations to conserve this set of long-lived species.

Applying such state-space models to data from sets of habitat restoration projects like those conducted in the IMWs could allow further synthesis to reveal overarching effects of habitat restoration, while also accounting for trends at regional to local scales, and the high level of temporal and spatial variation that is characteristics of data on fish populations. Fitting such models will require practitioners to seek advice from statisticians with appropriate expertise, but this expertise is available in the region and should not be an impediment to developing such analyses.

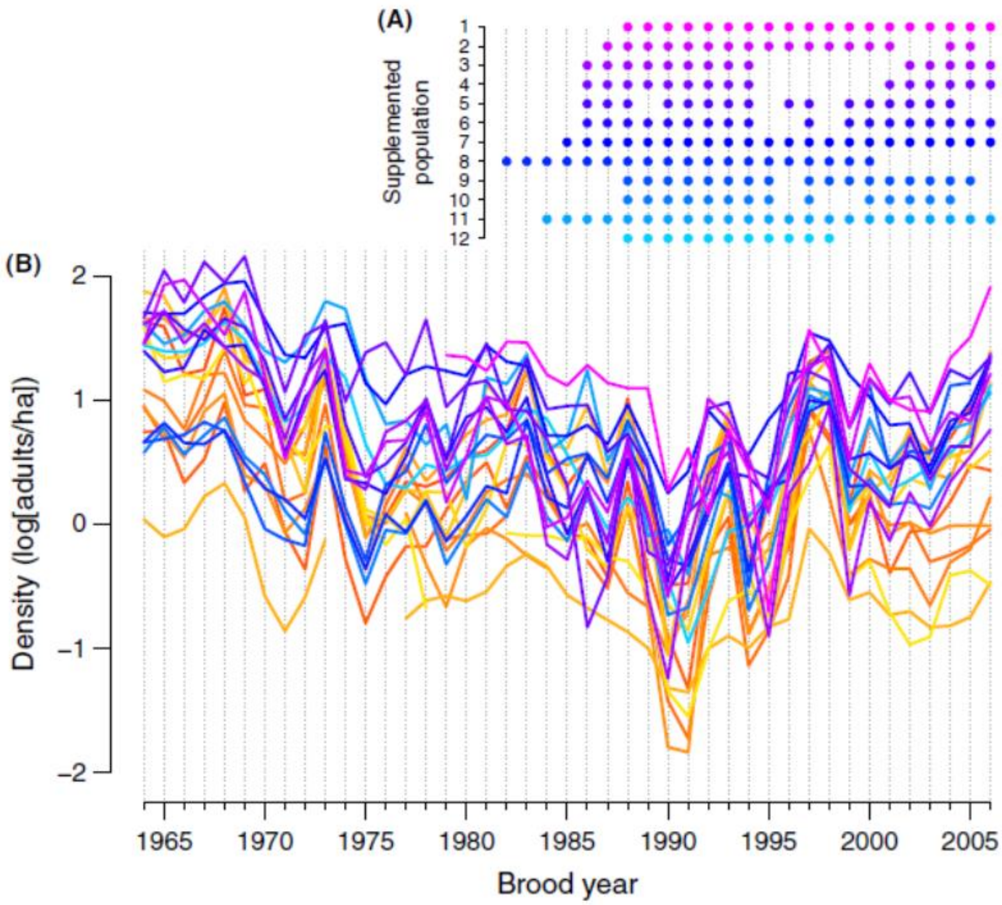

Figure 4.9. Time series of adult spring-summer Chinook salmon densities in 12 supplemented populations in the Snake River ESU are shown in blue to purple colors (brood years in which populations were supplemented are shown in the table in [A]), versus 10 populations not supplemented shown in yellow to red colors. A long-term decline across the ESU through 1990, followed by an increase through 2006 is evident and was detected by the analysis, despite the high level of year-to-year variation (from Scheuerell et al. 2015).

4.9. Conclusions and Moving Forward

Research, monitoring, and evaluation (RM&E) have been fundamental components of the Program since it began in 1982. The Council, BPA, and Program implementers have made multiple concerted efforts to address deficiencies in monitoring and evaluation in the Program, which resulted in improvements. The latest advance is the recently developed Columbia Basin Tributary RM&E Strategy (BPA/BOR 2022) that provides high-level guidance as to what to monitor.

Development and implementation of RM&E faces several major challenges.

Costs and time associated with monitoring and evaluation can limit the available resources and work of actually restoring habitat. Monitoring efforts have often not been prioritized, designed, or funded at a level necessary to demonstrate whether restoration was effective or not. Monitoring program sponsors have a wide array of protocols for habitat monitoring and analyses. Projects differ greatly in their technical expertise and analytical capacity. Coordination and sharing data and information among project participants are major challenges for monitoring and evaluation of habitat restoration projects. Nonetheless, targeted and effective RM&E projects are crucial for documenting effects, adaptively managing outcomes of habitat restoration, and ultimately maximizing benefits and reducing costs.

The ISAB's 2024 Review of the Fish and Wildlife Program (ISAB 2024-2) found that the Program currently lacks but would benefit from fundamental integration of monitoring and evaluation; and, although the Tributary Habitat RM&E Strategy provides useful guidance for RM&E at a site or reach scale, approaches for coordinated monitoring and evaluation for geographical areas or subbasins are needed.

ISEMP and CHaMP provided rigorous systematic measures of major habitat components in representative locations in the Basin and developed models for extrapolating these results to watershed scales. Although those projects were terminated in 2019, they were a major step forward in developing consistent, systematic habitat monitoring, and models to project those results across broad scales. AEM developed research to determine the effectiveness of specific restoration methods at the reach scale, and the results of AEM are included in this review. The Program needs to consider the history of basinwide efforts, such as CHaMP, ISEMP, and AEM, and critically explore objectives for which they succeeded and how and why they fell short of their intended outcomes.

The Council and BPA have long recognized the ongoing problems with RM&E and have taken many steps to make habitat monitoring and evaluation more consistent in the Columbia River Basin. The Council has made substantial improvements to monitoring and evaluation through coordinated programs, such as the Coordinated Assessments Partnership, Columbia River Basin Coordinated Assessment Data Exchange, and MonitoringResources.org of the Pacific Northwest Aquatic Monitoring Program.

Tributary Habitat RM&E Strategy

The recent Tributary Habitat RM&E Strategy is arguably the most significant attempt to develop a strategy to organize, evaluate, and report RM&E of tributary restoration funded by the Program. The Strategy represents a step forward because it describes a consistent and logical approach to tributary habitat

RM&E to assess the physical and biological benefits of restoration actions. It also supports the goal of targeted restoration work to better address habitat, species and population-specific ecological concerns in tributaries.

Key comments about the Strategy and areas for improvement identified by the ISRP include:

- The Tributary Habitat RM&E Strategy proposes that many action types do not require effectiveness monitoring and justifies this assertion by description of available literature for major types of restoration.
- An evaluation of restoration literature by those who developed the Strategy concluded that evidence is sufficient to conclude that most types of projects "worked" and that further verification of effectiveness with more monitoring is not warranted. The Strategy concluded that the greatest uncertainty of project effectiveness was associated with floodplain reconnection/enhancement and channel realignment.
- The ISRP concurs that floodplain reconnection/ enhancement warranted further evaluation, but that riparian restoration and coldwater refuges also require further monitoring to reduce uncertainty and determine effectiveness (see Section 3.5).
- The Strategy recommends that monitoring programs be designed so that information collected at the project or reach scale can be extrapolated to larger spatial scales. However, there is limited guidance provided for how to accomplish this, and it is uncertain whether some types of information can be scaled up. As the RM&E Strategy is implemented, more specific guidance on this topic will be needed.
- The Strategy does not include specific guidance for either data analysis or data management. As the Strategy is implemented, there is a need to advise or guide what analytical protocols are appropriate at the project and reach scales and what designs and analyses could be used to assess groups of projects at larger scales.
- The Strategy is specific to tributary habitat restoration. No guidance is provided on restoration in estuaries or lakes.
- The Strategy does not describe how it would be "rolled out" and implemented. Training will be needed as it is implemented.

- It is unclear how progress and success will be tracked once the Strategy is used. Strategy performance indicators should be developed and assessed to address these issues.

Study Designs

The most commonly prescribed design for measuring effects of environmental impacts such as habitat restoration is a before-after, control-impact (BACI) design. Within the BACI framework, staircase designs that stagger habitat restoration treatments in time can account for unplanned environmental perturbations. These designs are statistically efficient with low bias. In addition, recent advancements in analyzing mark-recapture data (i.e., the Barker model) allow efficient use of recapture information gathered from many sources through time and across whole watersheds.

Meeting the requirements of scientific experiments for randomization, replication, and controls becomes increasingly difficult as experimental units become spatially larger, and responses to treatments are more protracted and variable. Responses of fish to habitat restoration are inherently variable across years and locations (i.e., different streams), and may take years to manifest, as has been found for the IMWs.

It is essential to carefully specify the questions to be answered by monitoring and to select an appropriate and efficient study design. Considerations include the tradeoff between confidence in the results (often highest for measurements of individual fish at small spatial scales) versus relevance for answering the questions of concern (often highest for measurements of whole populations or communities at large spatial scales). A key component of study planning is to test the selected design using real or simulated data to ensure it will be sufficient to answer the questions posed.

Responses of fish to habitat restoration in tributaries of the Columbia River Basin occur at the large spatial scales over which entire fish populations carry out their life cycles.

When experiments are conducted at the smaller scale of reaches, fish movement may prevent treatment and control sites located near each other from being independent, but this can be ameliorated by spacing them appropriately if movement distributions are measured. Fish movement is a misunderstood process that can drive rapid responses of fish abundance and production to habitat treatments. Growth and movement are linked to habitat quality and density in complex ways, and failure to consider these linkages can result in mistaken inferences. In general, concerns that habitat restoration simply concentrates fish with no net increase in abundance or production are not warranted, assuming that any habitats vacated would be quickly filled by fish that otherwise would have died or emigrated.

An additional frontier in the analysis of habitat restoration is the opportunity to synthesize information across projects. Evidence from responses in any single IMW often is insufficient to draw strong conclusions from available time series data. However, recently developed statistical methods could be used to synthesize information across projects to provide a weight of evidence to assess the strength of responses of fish to management actions.

Recommendations

- Use efficient designs – When new monitoring efforts are planned, there is a great opportunity for specifying clear and specific questions, planning the biological, spatial, and temporal scale of monitoring, and using experimental designs such as the staircase design that have low bias and are efficient even given the high variation expected.
- Use state-of-the-art statistical analyses – Recently developed statistical analyses allow use of fish recapture information gathered by different methods through time and across whole watersheds (e.g., the Barker model), and synthesizing information from disparate sources across many studies (i.e., hierarchical state-space models). Such analyses can allow extracting new information from multiple studies and could be applied to analyses such as across IMWs.
- Effectiveness monitoring of various types of habitat restoration has provided evidence that they can “work” to increase fish abundance, survival, or productivity. However, the next step is to understand how much restoration is needed to produce biologically meaningful effects (i.e., a dose-response) and under what conditions such effects can occur (i.e., geomorphic, hydrologic, and ecological contexts). As examples:
    - How much large wood must be added, and how, to elicit a 25% increase in smolt production within 20 years in tributaries east of the Cascades versus those to the west?
    - How much riparian restoration in a process-based restoration project along a tributary is needed to increase wood loads within 100 years to a threshold that supports a given density of juvenile Chinook salmon per kilometer?
- Although implementation and compliance monitoring are expected for every project, as the Tributary RM&E Strategy indicates, rigorous effectiveness monitoring requires substantial time, resources, and expertise. Effectiveness monitoring is best undertaken when resources are

available for decades-long monitoring that will be required to answer questions at appropriate scales of space, time, and biological organization.

- To measure whether, for example, riparian restoration or floodplain reconnection is effective at increasing fish abundance, survival, and production across a range of different basins and habitat conditions will require a coordinated design that is stratified, hierarchical, and conducted over many decades.[10]
  - Planning such an effort is beyond the scope of this report, and will require expertise of managers, fish ecologists, and statisticians. Such an interdisciplinary team would be needed to oversee such an effort and be directed by a strong leader who could organize participants and information and communicate results effectively.
  - Data and lessons learned from past efforts such as AEM, CHaMP-ISEMP, and IMWs must be synthesized to provide baseline information about spatial and temporal variability of key components to be monitored.
  - Funding arranged in "monitoring banks" could offer resources to projects selected to fit within the hierarchical framework and are capable of rigorous long-term monitoring
- A goal of such a rigorous, hierarchical, long-term monitoring design is to generate statistically sound information to show how effectiveness varies with amounts of restoration and across different habitat conditions in different subbasins. Such information should be in a form that can be integrated (i.e., "rolled up") to the Columbia River Basin scale, and show relevant status and trends for key habitats and fish populations.
- To date, IMWs have provided important information at appropriate spatial scales that match management planning. A key need is to synthesize this information across sets of IMWs to determine what has been learned, what questions have been answered (or are not

[10] Examples of hierarchical multi-scaled frameworks for understanding and monitoring physical habitat and fish populations across the range of spatial and temporal scales in rivers are described in Fausch et al. (2002), Gurnell et al. (2015), O'Brien et al. (2017), and Wheaton et al. (2018).

answerable), and what monitoring must be continued versus stopped.

   - The ISRP expects that IMWs could be integrated into the hierarchical monitoring framework suggested above, and that other existing projects might fill current gaps in the framework regarding the effectiveness of restoration under different habitat conditions.

- The Program should create a hierarchical monitoring and evaluation framework, identify the major components of its RM&E program, establish the clearly defined RM&E relationships among projects within major subbasins and geographic areas, and ensure the transfer of information among those components, as recommended by the ISAB in its recent review of the Fish and Wildlife Program (ISAB 2024-2).

5. Intensively Monitored Watersheds

Long-term ecosystem experiments are a direct method for understanding the responses of environments and fish populations to management actions (Carpenter et al. 1995; Bennett et al. 2016). Regarding habitat restoration in the Columbia River Basin and other portions of the Pacific Northwest, the key questions are 1) did restoration improve habitat at the watershed scale and increase or stabilize fish populations, and 2) what mechanisms caused these improvements?

In the 2006 Retrospective (ISRP 2007-1), the ISRP stated their support of population-level monitoring as essential to understand effectiveness of restoration: "*we believe that a network of intensively monitored watersheds (IMWs) is needed in which restoration efforts can be coordinated in a way that will facilitate experimental learning by applying enough similar treatments to produce statistically robust results, coupled with thorough inventories of adult, juvenile, and smolt abundance*". The definition of an IMW provided by PNAMP is: "*an experiment in one or more catchments with a well-developed, long-term monitoring program to determine watershed-scale fish and habitat responses to restoration actions*" (PNAMP website).

Toward that end, in the new millennium a series of IMWs have been developed in western North America, from California through Washington, broadly overlapping the distributions of major Pacific salmon and steelhead populations along with other important salmonids (e.g., bull trout, cutthroat trout). Those watersheds declared to date as IMWs generally included suites of studies designed to evaluate limiting factors and conduct habitat restoration, followed by measuring the response of fish populations (Bilby et al. 2022). Most began monitoring in 2000 to 2009, and a few IMWs have completed all intended research and analyses. Some studies were specifically designed *de novo*, whereas others were developed in watersheds where large restoration projects and monitoring were ongoing.

To have qualified as an IMW, whether from the beginning of the project (such as those described in Anderson et al. 2023) or adopted later, a project or suite of cooperative projects within a watershed must generally have taken a watershed-scale approach. Individual IMWs are independent of each other, non-randomly spread across the landscape, and cannot be considered replicates of some larger overarching project. Nevertheless, it is appropriate to assess collective results from IMWs to shed light on what habitat and fish responses can be expected from various kinds of restoration efforts.

Progress in conducting restoration and monitoring responses has been summarized in a series of reports and publications. Major results have been summarized for 17 IMWs by Bennett et al. (2016), for 16 by Haskell et al. (2019), for 17 by Hillman et al. (2019), for 13 by Bilby et al. (2022), and for 5 by Anderson et al.

(2023). A total of 17 IMWs were recognized by Bisson et al. (MS, unpublished) in their effort to describe the value and expectations from IMWs. PNAMP supports a website that, of this writing, includes an overview of 13 IMWs. Within these IMW groupings, 9 IMWs are in the Columbia River Basin (Table 1).

Hillman et al. (2019) recommended that results from the network of IMWs could be analyzed in a meta-analysis, which has yet to be done, to answer broad questions about treatments and responses for salmon, steelhead, and other important fish across the Pacific Northwest. Some cross-IMW analyses have been reported. For example, Anderson et al. (2023) provide an analysis of fish and habitat response to large wood across the five IMWs funded by the State of Washington's Salmon Recovery Funding Board (SRFB). Summaries of fish responses across various groupings of IMWs have been provided by Haskell et al. (2019; see their Executive Table 1) and Bilby et al. (2022; see their Table 2). These across IMW evaluations will be of high value in ensuing years for documenting long-term responses and strength of legacy.

While not considered meeting the definition of an IMW by the various authors and entities mentioned above, several watersheds have supported restoration actions and intensive response studies that should be recognized. Roni et al. (2023) describes the large-scale restoration and study efforts within the Grande Ronde Model Watershed. Bosch et al. (2024) describes the long-term, comprehensive restoration and monitoring activities in the Yakima subbasin (BPA project 199506325). Bisson et al. (2008) provide a review of many multi-year study efforts in watersheds across the Pacific Northwest that have helped our understanding of fish response to various management actions. Results from these kinds of studies are important to include among those derived from IMWs.

Here, we summarize key lessons learned from IMWs over the last 25 years concerning effective methods for selecting restoration projects, analysis of limiting factors, effective methods of restoring habitat, and effective methods of monitoring and evaluating responses in habitat and fish populations. For this effort, we rely almost entirely on the syntheses that have been published to date. Owing to the large scales of space and time over which these results have been gathered, compared to reach-scale evaluations, the results and lessons learned tend to be different than those determined at smaller spatial and temporal scales, but are nevertheless complementary.

Table 5.1. Compilation of intensively monitored watersheds (IMW) in the Pacific Northwest based on other compilations.

Name of IMW (study articles)	Monitoring years	Location (State or Province)	In the CRB?	Major subbasin	Restoration methods	Focal fish species
Asotin Creek (a,b,c,d,e,f)	2008-present	WA	Yes	Lower Snake	Large wood, riparian work, beaver dam analogs	Steelhead, Chinook, bull trout, Pacific lamprey
Bridge Creek (a,b,c,d,f)	2007-2017	OR	Yes	John Day	Beaver dam analogs	Steelhead
Elwha River (a,b,c,d,f)	2000-present	WA	No	(direct to salt)	Barrier removal	Steelhead, Chinook, bull trout, cutthroat trout, Pacific lamprey
Entiat River (a,b,c,f)	2003-present	WA	Yes	Upper Columbia	Engineered log jams, boulders, side channel connectivity	Chinook, steelhead
Fish Creek (c)	1983-1990	OR	Yes	Clackamas	Large wood, boulders, floodplain reconnection, riparian improvement	Coho, steelhead
Hood Canal Complex (a,b,c,d,e,f)	2003-present	WA	No	(direct to salt)	Large wood, barrier removal, floodplain reconnection	Coho, steelhead
Keogh River (a,b,c)	1976-present	BC	No	(direct to salt)	Road decommissioning, boulder, large wood, nutrient additions, hatchery augmentation, flow augmentation	Coho, steelhead
Lemhi River (a,b,c,f)	2007-present	ID	Yes	Salmon River	Barrier removal, flow augmentation, large wood, floodplain reconnection	Chinook, steelhead, bull trout
Lower Columbia Creeks (a,b,c,d,e,f)	2001-present	WA	Yes	Lower Columbia	Nutrient and wood addition, floodplain reconnection	Chinook, coho, steelhead
Methow River (a,b,f)	2009-2018	WA	Yes	Upper Columbia	Engineered log jams, floodplain reconnection	Chinook, steelhead, bull trout

Name of IMW (study articles)	Monitoring years	Location (State or Province)	In the CRB?	Major subbasin	Restoration methods	Focal fish species
Middle Fork John Day (a,b,c,f)	2004-present	OR	Yes	Mid-Columbia	Engineered log jams, large wood, floodplain reconnection, riparian improvement, barrier removal, flow augmentation	Chinook, steelhead
Potlatch River (a,b,c,f)	2005-present	ID	Yes	Clearwater	Barrier removal, flow augmentation, large wood, riparian improvement	Steelhead
Pudding (a,b,c,f)	2006-present	CA	No	No. CA Coast	Large wood	Coho, steelhead
Skagit Estuary (a,b,c,d,e,f)	1992-present	WA	No	(direct to salt)	Restoration of tidal wetland inundation, reconnection of tidal channels	Chinook
Strait of Juan de Fuca (a,b,c,d,e,f)	1992-present	WA	No	(direct to salt)	Large wood, flood plain reconnection, barrier removal, road abandonment, riparian improvement	Coho, steelhead, cutthroat trout
Tenmile (a,b,c,f)	1991-present	OR	No	(direct to salt)	Large wood, road abandonment, barrier removal, riparian improvement	Coho, steelhead, cutthroat trout
Wind River (a,b,c,d)	2000-present	WA	Yes	Mid-Columbia	Barrier removal, large wood, engineered log jams, riparian restoration, side channel connectivity	Steelhead
Alsea River (a,b,c,g)	1988-1996	OR	No	(direct to salt)	Effects of forest practices; large wood; floodplain connection	Coho, steelhead, cutthroat trout
Carnation Creek (b,g)	1970-1987	BC	No	(direct to salt)	Effects of forest practices	Coho, chum, and steelhead

Footnotes: Reviews of various groupings of these IMWs can be found in: a) Bennett et al. 2016; b) Haskell et al. 2019; c) Hillman et al. 2019; d) Bilby et al. 2022; e) Anderson et al. 2023; and f) PNAMP website.

g) Some IMW reviews considered Alsea River and Carnation Creek as IMWs, but these studies were not considered to fit the moniker. See Bisson et al. (2008) for a compilation of these and other multi-year studies.

5.1. Effective methods of selecting restoration projects

The structured learning desired from an IMW demands a strategic project selection process (see Chapter 2, above). A "project," as defined here, is made up of complementary and interconnected actions that investigators hope are not confounded. Bennett et al. (2016) recognized that the best projects for an IMW are those that:

- Have adequate planning
- Include coordination among multiple stakeholders
- Select treatment and control watershed(s) without confounding attributes (e.g., large differences in preceding conditions or prior treatments)
- Have long-term funding commitment to complete the evaluations
- Have identified ecological concerns (e.g., limiting factors) with explicit testable hypotheses
- Have statistically valid experimental designs
- Have restoration designs at the watershed scale with definitive response targets
- Have strong monitoring plans.

In contrast, the type of projects that do not benefit an IMW are those that are small in scope over time and space and those that are more opportunistic than they are planned, especially when they do not directly address primary limiting factors and when they are confounded with ongoing experiments. Haskell et al. (2019) noted that it has been critical to the success of IMWs that managers and practitioners use their "lessons learned" in an iterative way, which involves selection of appropriate projects to enhance the clarity or magnitude while not confounding the habitat and fish response. Hillman et al. (2019) noted that, in some projects, detecting a response from the prescribed treatments may be too dependent on adequate spawning escapement and seeding levels, on absence of large natural disturbances (e.g., floods, fire, debris flows), and on lack of major changes in ocean conditions. They proposed a potential solution to rely more on biological significance (e.g., targets and milestones) rather than statistical significance.

To identify appropriate projects, Hillman et al. (2019) and Bilby et al. (2022) emphasized the value of starting with life-cycle models for the targeted fish species, followed by analysis of limiting factors to help guide project planning and selection. In some cases, proponents may want to add additional actions to boost habitat and fish response after major projects have been completed (e.g., a dam removal). However, it is imperative that the additive effect of new projects be clearly identified, so they are not confounded with the effects of responses to previous projects still unfolding.

While there is no single right way to conduct project prioritization and selection, the process should be internally vetted among stakeholders and subjected to external scientific review. To pass a rigorous review, the process needs to be transparent. If a novel process is developed, it should be thoroughly documented and pilot tested. Objective and quantitative methods are preferred for all evaluations, and the methods need to be thoroughly described if professional opinion is used. Weighting factors applied to quantitative values need to be described and sensitivity analyses should be conducted for these and any techniques used to convert qualitative ratings to quantitative values. If models or established analytical systems (e.g., EDT, Atlas) are used to incorporate professional opinion and convert qualitative data, the user should be able to describe and defend the reasonings within. If developed correctly, the use of formal prioritization criteria and a definitive project selection methodology should ideally lead to doing the right work in the right places in support of the goals of the IMW.

5.2. Analysis of limiting factors

As discussed elsewhere in this report, a limiting factor analysis seeks to identify one or more factors or processes that determine a population's vital rates and carrying capacity. Limiting factor analyses can differ in their formality and methodology, and the chosen approach depends on the stage of the project. The Identification and ranking of priority limiting factors may require extensive discussion, consideration of multiple types and sources of data, and inclusion of multiple interested parties. For example, during initial planning of an adaptive management process for the Asotin IMW, the "problem" (i.e., the set of ecological concerns or limiting factors) was identified through discussion with the Snake River Salmon Recovery Board and their partners, through consideration of prior watershed assessments, and through literature reviews (Bouwes et al. 2016a). To guide habitat restoration activities in the Upper Grande Ronde River subbasin, the BPA formalized the Atlas Restoration Prioritization Framework (Atlas), which outlines a consultation process for identifying limiting factors (BPA 2017). Reviews of IWMs often list the priority limiting factors that restoration seeks to address (e.g., Bilby et al. 2022), but they do not always report the underlying processes for prioritization.

Once priority limiting factors are identified for targeted restoration in an IMW, further refinements may be identified through additional study or as part of the adaptive management process. For example, in the Asotin IMW, key limiting factors were corroborated with field studies, monitored through assessment activities, and then analyzed and synthesized with other information to refine the problem (Bouwes et al. 2016a).

Life cycle models can be particularly informative for exploring how priority limiting factors influence life-stage-specific abundance, distribution, survival, and recruitment. For example, life cycle models were used to identify high water temperature as the primary factor limiting steelhead and Chinook salmon production in the Middle Fork John Day IMW, which could be addressed through planting of riparian vegetation (Hillman et al. 2019). Life cycle models also have been used to inform restoration activities in the Entiat, Lemhi, and Potlatch IMWs (Hillman et al. 2019).

A key feature of life cycle models is the integration of stage-specific, stock recruitment relationships, which underscores the importance of density dependence as a key limiting factor to consider when planning and evaluating habitat restoration. As emphasized by the ISAB (2015), knowledge about density-dependent growth, survival, and recruitment can help identify critical life stages, understand current capacity and productivity, and evaluate fish responses to habitat restoration. At one extreme, the abundance of spawners or juveniles that are too low to take advantage of increases in environmental carrying capacity (i.e., underseeding) will prevent detecting responses to habitat restoration. This implies that to detect the positive effects of habitat restoration, fish density must be high enough to elicit density dependence (Anderson et al. 2023).

Using data for coho salmon in the Hood Canal and Lower Columbia IMWs, Anderson et al. (2023) modeled and analyzed Ricker stock-recruitment relationships to better understand density dependence as a mitigating factor affecting fish responses to habitat restoration. They found support for density dependent recruitment from the spawner-to-parr and parr-to-smolt relationships in both IMWs. In general, density-limited recruitment was more apparent in the Lower Columbia IMW than in the Hood Canal IMW. Although the data were noisy, the stock-recruitment relationships were statistically similar before and after restoration. Informal sensitivity analyses showed that increasing intrinsic productivity or habitat capacity by 30% would evoke a greater increase in recruitment in the Lower Columbia IMW and at the parr-to-smolt stage. The differences between IMWs in their hypothetical responses to habitat improvements support the premise that low fish density can mask a response to habitat restoration. While potentially useful, a key assumption was that carrying capacity is determined by density dependence alone. Future consideration of stock-recruitment relationships will need to address the fact that carrying capacity is influenced by both density-dependent and density-independent mortality (see Appendix about Limiting Factors Analysis).

5.3. Effective methods of restoring habitat

The IMWs can best be thought of as an approach to evaluate a set of habitat restoration treatments designed to reduce those limiting factors perceived by managers to be the most important in hampering fish populations in a given watershed (see Chapter 3, above). Of the 13 IMWs for which Bilby et al. (2022) summarized results, only 2 applied single restoration treatments (Beaver Dam Analogs in Bridge Creek, large wood additions in Pudding Creek), and most applied 4 to 8 different treatments to address limiting factors. This lends realism to projects but makes it difficult to isolate effects of individual treatments.

Detailed analysis of some individual IMWs have been conducted to date (e.g., Anderson et al. 2023), but no detailed analysis has been conducted across the entire set of IMWs. Nevertheless, simply tallying of the direction of responses (positive, neutral, negative, although not necessarily statistically significant) can indicate the overall pattern of responses (Bilby et al. 2022). For example, of the 10 IMWs where barriers were removed, longitudinal connectivity increased in 9 (the 10th reported equivocal results), and some metric of juvenile or smolt abundance, density, survival, or growth showed a positive response in 8 of these 9 IMWs. Only 2 IMWs documented an increase in adult abundance, but this is expected because the post-treatment period after barriers were removed was too short to allow the salmonid population to fully respond to the new habitat. Moreover, adult returns are affected by many processes beyond the control of the project (see Chapter 6. Confounding Factors), so increasing numbers of adults may not be achievable if these other limiting factors cannot be addressed

Large wood structures or Beaver Dam Analogs (in Bridge Creek) were installed in 12 of the 13 IMWs reviewed by Bilby et al. (2022; all except the Skagit River Estuary). Increases in habitat complexity were reported in 8 of these, and metrics for juvenile or adult fish (abundance, density, survival, growth) showed positive responses in 10 of these 12 IMWs. It is important to reiterate that, in most cases, additions of large wood were only one of several habitat restoration treatments applied to address limiting factors.

A notable result of this tallying is that in very few cases were negative responses reported – in only two cases for 12 habitat metrics among the 13 IMWs (reduced sediment quality in both cases). For the 11 fish metrics tallied, negative responses were reported in only 2 cases (1 case each for juvenile growth and adult abundance). Nevertheless, in many cases responses were either equivocal (i.e., no change could be detected) or had not yet been evaluated. For example, no significant change could be detected in 41 cases for the 11 fish metrics across the 13 IMWs, or in 29% of cases.

Bilby et al. (2024; see also Bisson et al. MS) identified two key factors contributing to the disappointing responses by salmonid populations to habitat restoration throughout the Pacific Northwest, and these apply also to IMWs. The first is that resources to address habitat damage have been insufficient, so that too little habitat restoration has been done to cause an effect in most watersheds (including IMWs). In contrast, in two IMWs where increases in fish metrics were reported, 30-40 percent of accessible habitat was treated by adding large wood or structures designed to catch wood (Anderson et al. 2023). The second key factor is that restoration programs have been unable to identify the most important factors limiting fish populations and so are not "doing the right things in the right places."

An example from the Hood Canal IMW provides a case in point. Anderson et al. (2019) described efforts to address limiting factors in Little Anderson Creek and compared the results over a 14-year period to an adjacent reference stream. Removing a barrier near the stream mouth resulted in a tripling of coho smolts outmigrating from the stream. In contrast, adding large wood in three batches in about a 4-km (2.5-mile) segment over a 10-year period resulted in an increase in coho smolt abundance that was not statistically significant owing to natural variation, and no other detectable increases in parr or smolt abundance or survival.

These investigators concluded that a much greater magnitude of large wood would have been needed to elicit a response. Likewise, too few adults returned to saturate available habitat with juveniles; such a saturation of juveniles could result in density-dependent survival that, in turn, could be ameliorated by improved habitat. Instead, they concluded that high harvest rates of adults and a drastic decline in marine survival during the study limited population abundance. Given the low abundance, juvenile survival was likely driven by density-independent factors like floods, which are not influenced by habitat restoration (Anderson et al. 2023). Hence, they suggest focusing restoration where habitat-mediated density-dependence is a strong limiting factor.

5.4. Effective methods of monitoring and evaluating responses in physical habitat and fish populations

Although IMWs were not designed to test the effectiveness of methods for monitoring and evaluating responses in habitat and fish populations, several key lessons have emerged from the collective body of work:

- **Time and funding required for restoration and monitoring to detect effects** – A key lesson from the IMWs is the extensive time needed to conduct successful restoration, given funding and logistical challenges, and for subsequent flow events to cause geomorphic changes in habitat. Once these changes occur, it takes additional years for the life cycles of fish to respond and produce more juveniles, smolts, and adults. Finally, given the natural variability in environmental factors such as river flows (e.g., floods and droughts) and ocean conditions, it takes years to collect sufficient data to separate effects of habitat restoration from effects owing to natural variation. This makes it especially difficult to detect any increases in adult fish returns that may occur.

Removal of barriers and reconnection of floodplains and estuaries require the shortest time to produce effects (e.g., Clark et al. 2020), given that fish often have access to new habitats immediately. However, the quantity of suitable habitat upstream from barriers on streams may limit project success (Chelgren and Dunham 2015). Additions of large wood are likely to require two or three decades to fully evaluate, as reported for the Strait of Juan de Fuca IMW (Anderson et al. 2023), owing to the geomorphic changes that must first take place to create additional habitat for fish.

A key ingredient for successful evaluation is the number of years of pre-treatment data. O'Neal et al. (2016) reported that adding 1 year of pre-treatment measurements increased the statistical power to detect differences more than if up to 100 years of post-treatment data were included. Five years of pre-treatment data appear optimal, which is the average number of years pre-treatment for the 12 of 13 IMWs focused on riverine habitats (treatments in the Skagit River estuary began before the IMW was commissioned).

The commitment of time and funding to ensure success of an IMW is no small matter. Several currently designated IMWs were not designated as such from their beginnings but grew from simpler objectives. Funding for some IMWs is not assured simply because they are designated as IMWs, but the designation as an IMW has become a positive factor in their efforts to obtain continued funding. Whether the number and scope of activities for ongoing IMWs increase or decrease in the future is uncertain.

- **The need to increase technical rigor in design and analysis –** Detecting change in fish populations across watershed scales amid the background of annual variability is challenging. Optimal sampling designs, such as the staircase design (Loughlin et al. 2021; see Section 4.8.1 on optimal experimental/sampling designs) provide higher power and greater precision than standard BACI or Extensive Post-treatment designs, but they have not been employed to date for IMWs. Such improved sampling designs would provide greater technical rigor and allow improved detection of responses to habitat restoration treatments (Bilby et al. 2022; Bisson et al. MS).

Several sophisticated statistical models have been used to good advantage in IMWs to improve estimates of abundance, survival, and production at watershed scales. The Barker model provides improved estimates of survival over the traditional Cormack-Jolly-Seber model (Conner et al. 2015) because it can include PIT tag detections during discrete sampling events (e.g., electrofishing) as well as continuous sampling (e.g., PIT tag arrays distributed throughout watersheds). When combined with a BACI design and a Bayesian analysis approach, this model allowed sophisticated analysis of the effects of Beaver Dam Analogs, which increased steelhead survival by 52% and production by 175% compared to a control stream (Bouwes et al. 2016b).

In the Lemhi River IMW, researchers compared three methods for determining steelhead and Chinook salmon parr abundance throughout the watershed: reach scale sampling based on a spatially balanced GRTS design, spatially continuous sampling, and rotary screw traps at strategic locations (ISEMP-CHaMP 2018). Spatially continuous sampling increased precision of abundance estimates, and rotary screw traps provided larger sample sizes and better estimates of downstream survival, so a combination of these two methods appeared optimal.

These methods for analyzing data generated by individual IMWs will improve estimates, but an unexplored frontier is to find suitable approaches to analyze data across IMWs (see Section 4.8.3. Synthesizing information across multiple projects).

5.5. Conclusions and Moving Forward

IMWs are an approach to evaluate a set of habitat restoration treatments designed to reduce limiting factors perceived to be the most important for fish populations in a given watershed. During the initial establishment or early stages of an IMW, identification and ranking of priority limiting factors require extensive discussion, consideration of multiple types and sources of data, and inclusion of multiple interested parties.

Life-cycle models for the targeted fish populations, followed by analysis of limiting factors to help guide project planning and selection, are critical components of integrated assessment of watershed-scale priorities and goals for habitat restoration. A key feature of life cycle models is the integration of stage-specific, stock-recruitment relationships, which underscores the importance of density dependence and capacity as key limitations to consider when planning and evaluating habitat restoration.

Salmonid populations may fail to respond to restoration if resources or project scope are too limited. Two key factors are that 1) resources to address habitat damage have been insufficient and 2) too little habitat restoration has been done to cause an effect. An additional factor is an inadequate statistical design for detecting the true response, which can be exacerbated by inadequate funding to implement an effective statistical design and sampling program.

A key lesson from the IMWs is the extensive time needed to conduct and evaluate restoration. Detecting change in fish populations across watershed scales amid the background of annual variability is challenging and takes multiple salmon generations at a minimum.

Recommendations

- The ISRP recommends that each IMW be required to synthesize their information on the responses of habitat and fish to the restoration actions implemented.
- The ISRP recommends that the Fish and Wildlife Program support an integrated analysis of habitat restoration results across the network of IMWs in the region to answer broad questions about treatments and responses for salmon, steelhead, and other important fish across the Pacific Northwest (see Section 4.7.3. What methods of analysis can be used to measure responses of fish populations across large spatial scales?).
- The ISRP recommends the Council review how well the existing IMWs represent the landscapes and fish and wildlife resources of the Columbia River Basin. In underrepresented portions of the Basin or for underrepresented approaches for fish and wildlife restoration, the Program should develop new integrated IMWs to address unresolved questions about habitat restoration effectiveness and strengthen the existing network of IMWs.

6. Confounding Factors

Confounding factors can affect the planning, implementation, and monitoring and evaluation of protection and restoration. These confounding factors can interact among themselves, operate at various scales of space and time, and can occur intermittently or persistently to influence habitat protection or restoration. Some are related to historical and ongoing habitat degradation and changes to the landscape (Figure 6.1), and some are emerging concerns. Much is known about many of these factors, including within the Columbia River system. Our goal here is not an extensive review of these factors and how they operate, but a brief consideration of their effects on habitat protection and restoration in the Program.

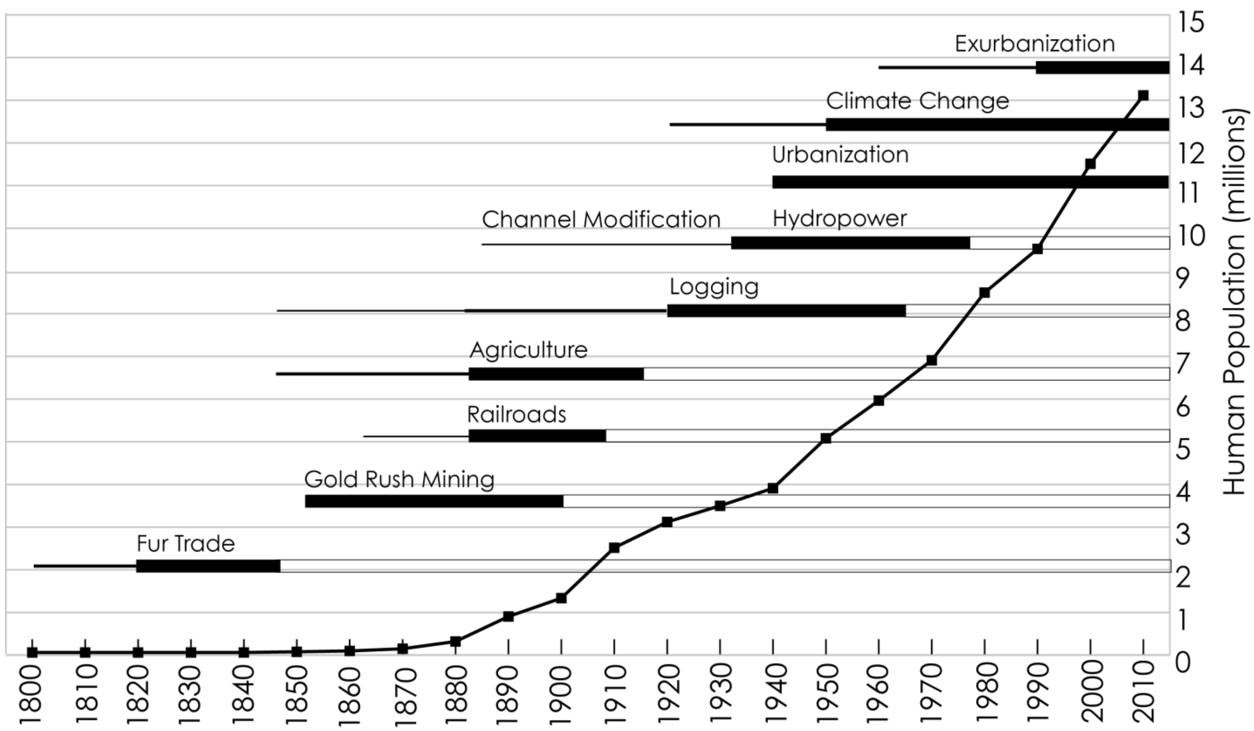

Figure 6.1. Primary anthropogenic factors driving landscape change in the U.S. portion of the Columbia River Basin, and concurrent changes in human population size. Wide dark bars indicate the period of peak effects and rapid habitat conversion caused by each factor. Wide light bars indicate continued effects following the initial period of rapid change (from ISAB 2011-4, Rieman et al. 2015; ISAB 2015-1).

6.1. Climate Change

Climate change may be the most important confounding factor for habitat protection restoration because it can affect nearly all types of restoration actions (Perry et al. 2015). The ISAB (2007-2) conducted an extensive review of climate change effects in the Columbia River Basin, including planning for changes and mitigating impacts. Warming air temperatures are altering the quantity, form, and timing of streamflows. Increased stream temperatures and altered flow regime are projected to significantly reduce habitat availability basinwide for salmonids (Wenger et al. 2011a, 2011b; Isaak et al. 2012; Isaac and Young 2023). Some currently inhabitable lower elevation stream reaches may become seasonally uninhabitable by focal salmonid species at base flows.

In the estuary, the primary implications of climate change are sea level rise, increased temperatures, and the amount and timing of inflow. Some research suggests that estuary habitats will not be able to keep up with sea level rise under current climate projections, as marshes and tidal wetlands are drowned (Temmerman et al. 2004; Saintilan et al. 2022; Davis et al. 2024). Attempts to protect habitat may fail when inundated under rising sea levels.

The ISAB (ISAB 2007-2) noted in 2007 that the impacts of climate change are rarely incorporated into natural resource planning in the Columbia River Basin, despite direction in subbasin planning documents to consider this issue. The proposal form for Fish and Wildlife projects reviewed by the ISRP asks that all projects explicitly address:

- How will climate change potentially impact your project in the future and what information sources were used to identify those impacts?
- What adaptation measures were taken to adjust your project for these impacts?
- How could you evaluate the success of your adaptation measures to inform future projects?

During the last decade of reviews, most project proposals mentioned climate change as a confounding factor. However, most provided few specifics on how they proposed to monitor effects of climate change or adaptively manage resources to ameliorate potential effects. The ISAB is currently working on a report examining strategies for prioritizing and implementing habitat restoration projects in the Basin, which is intended to help inform project proponents as they further develop their projects to address current and future climate risks and impacts. The report is scheduled for completion in the summer of 2025.

6.2. Landscape Change

Terrestrial and aquatic ecosystems shape the patterns of distribution, abundance, and productivity of salmon, steelhead, and other fishes and aquatic organisms of the Columbia River Basin. Habitat change (loss and degradation of stream habitat) occurs due to natural processes such as fire and major flow events, and anthropogenic processes such as agriculture and human population growth and development (ISAB 2007-3, Issak et al. 2010, Rieman et al. 2010). These changes occur at multiple scales of space and time. Bilby et al. (2024) noted that ongoing anthropogenic habitat changes were a major problem in Puget Sound salmon recovery because it was unclear whether restoration could outpace development and produce a net improvement in ecosystem conditions.

Natural disturbances are common and ecologically essential processes in terrestrial and aquatic ecosystems. For example, fires in terrestrial areas remove timber, including from riparian areas, destabilize slopes, and increase sediment loads in streams when rainfall occurs. Natural fire regimes have positive influences on Pacific Northwest ecosystems, but reductions in rainfall (increases in drought conditions) and effects of humans (e.g., altered forest composition and fire vulnerability, arson) increase the frequency, intensity, and extent of fires (Reilly et al. 2021). Fires can affect the landscape for decades to centuries as forests recover.

Clearly, the design and placement of various types of restoration actions in areas that have burned is a consideration, and fire can fundamentally alter plans to protect critical habitats. These include burning of recently replanted riparian areas, which then requires decisions about post-fire restoration of the entire burned area and associated riparian areas. Fire can reduce the amount of wood available for stream channel restoration and force projects to bring wood from longer distances, thereby increasing costs. Also, changes in sediment delivery and stream flow after fire can affect the success of restoration actions. Planners must decide whether to wait for natural processes to recover after the fire before adding projects or assume adding projects will accelerate recovery.

6.3. Ocean Conditions

Changing ocean conditions are perhaps the most challenging confounding factor for habitat restoration practitioners and the project managers who must prioritize among projects and evaluate them after implementation. On one hand, tributary habitat restoration projects themselves are entirely in the freshwater and estuarine habitats where adult salmonids migrate and breed, and where their offspring feed and grow prior to seaward migration and ocean entry. The great majority of lifetime mortality occurs in these habitats, and there is strong evidence for density dependence there. Consequently, because habitat quality and quantity are very important, habitat projects will likely increase the number and condition (size, timing, health, etc.) of juveniles migrating seaward. In the long run, producing more smolts in good condition will result in more salmon surviving to adulthood, taken in fisheries or returning to spawn.

On the other hand, the mortality of smolts in the ocean is commonly on the order of 95%, 99% or even more, and varies greatly among years and populations. Ten-fold variation in smolt-to-adult survival (e.g., 0.5% - 5%, etc.) is often observed and is primarily correlated with broad-scale oceanic conditions such as temperature, upwelling, zooplankton abundance. This dissociation from freshwater habitat can lead to frustration when adult returns are not commensurate with expectations after habitat restoration. However, in each year, the survivors typically differ from the mortalities in migration timing, body size, and health. Restoration projects can directly affect the number, condition, and diversity of salmonids produced in the affected freshwater area and improve their passage to sea. Their likelihood of surviving at sea is indirectly affected by these factors but only to a limited extent. Too often freshwater and estuarine restoration projects are judged on whether more adults returned to spawn than did prior to the project. This metric is understandable but only appropriate as a key indicator for determining the success of the intended restoration action to improve freshwater productivity with careful consideration of the variation in and influence of conditions beyond the project's scope that strongly affect adult returns.

There can be significant improvement in adult-to-adult productivity and adult abundance if the scale of the protection and restoration is large enough to influence habitat quantity and quality for multiple freshwater life stages such as pre-spawning adults, embryo incubation, fry distribution, and parr-to-smolt survival for a substantial proportion of the area used by a population or major spawning aggregate. Smolt-to-adult survival can increase with improved growth from fry-to-smolt stages. When habitat conditions are improved enough, it is possible to restore lost life history patterns that may be highly productive. Many of the spring Chinook populations in the Snake River have very low productivity because multiple life history pathways have been lost and density limits production in the small quantity and low quality of summer rearing habitat. Adult spawner abundance and adult-to-adult productivity should be considered as key indicators to assess response to habitat improvement when the scale of restoration is large enough.

Notwithstanding the importance of habitat protection and restoration, when ocean conditions are unfavorable for salmon and survival rates are depressed over wide areas of the coast, it can seem fruitless to restore habitats because the ocean has such a large effect on returns. However, improvement of habitat quality and quantity is especially crucial when ocean conditions are unfavorable to maintain populations, although the full benefits in terms of adult returns will not be evident until ocean conditions improve. Conversely, care should be taken not to rejoice and take credit when adult returns increase before a habitat restoration project has fully taken effect. As Lawson (1993) succinctly stated, “spawning escapement estimates are a poor measure of the success of freshwater habitat restoration projects.” This short, seminal paper should be widely distributed and discussed among researchers, practitioners, and managers.

In summary:

- Survival during early life stages is very low, as 95-99% of eggs and fry/parr often die. Habitat restoration and protection projects can increase the survival, abundance, productivity and attributes of populations, communities, and life histories that make them more likely to persist during variable ocean conditions.
- Small scale projects should be primarily evaluated using metrics of the physical environment and biotic responses at scales and life history stages directly affected by the project. Adult returns help track the population’s status and trends but are too heavily affected by processes beyond the project’s control to evaluate small projects.
- Larger-scale projects and especially those affecting multiple life-history stages are better suited for evaluation using adult returns, but due consideration should be given to systemwide and coastwide survival patterns.
- The Program’s influence extends as far as the estuary and plume (the area of freshwater discharge) of the Columbia River, and considerable mortality occurs in these regions. Attributes of the fish such as size, health, and migration timing are affected by freshwater habitats, and influence the probability of survival at sea.
- PIT-tags allow estimates of survival of individuals of known size and migration history in specific time periods in the smolt to adult life stages, including between smolt reference locations and downriver dams and the estuary (i.e., Bonneville Dam for upriver stocks), in the ocean (Bonneville to Bonneville), and adult in-river migration (Bonneville to smolt reference location). Reporting survival at sequential stages will help reveal where mortality occurs

and evaluate projects affecting specific life cycle phases.

6.4. Non-Native Species

Non-native aquatic species are prevalent throughout the Columbia River Basin and have come from both intentional and unintentional introductions (ISAB 2008-4, ISAB 2011-1, ISAB 2019-1). The ISAB have found in their reviews that the potential impacts and risks to native salmonids and other native fishes from non-native species were significant, with most subbasins in the Columbia River Basin already dominated by non-native fish species. The biomass of some introduced species, such as American shad, is staggeringly large and increasing (ISAB 2021-4, Quinn et al. 2024). Introduced species can compete with, or prey on, native salmonids and alter characteristics of habitat used by salmon (Sanderson et al. 2009). Different life history stages of introduced species can have different ecological roles, competing with salmonids at smaller sizes and preying on them as they grow larger. Examples of important non-native competitor species include brook trout (Dunham et al. 2002; Wenger et al. 2011a, 2011b), and major predatory species include walleye, smallmouth bass, lake trout, and northern pike (e.g., Carey et al. 2011, ISAB 2019-1). Reed canary grass is an example of a nonnative plant species that can modify habitat (ISAB 2008-4).

In 2008, the ISAB recommended to the Council and management entities that they elevate the priority of non-native species effects (ISAB 2008-4). Although the ecological effects of non-native species are the most significant issue, they also can represent a confounding factor when they directly affect restoration project success. For example, reed canary grass can alter estuarine habitat and species, so restoration projects have recently begun managing this invasive species. In blocked areas of the Basin, projects aimed at restoring bull trout and cutthroat trout must consider the tradeoffs of isolating segments from nonnative brook trout (Peterson et al. 2008, Fausch et al. 2009). Barrier removal can open upstream reaches to non-native competitors and predators. Restoration activities like reconnecting sloughs and floodplains can create favorable habitat for non-native predators like bass, catfish, and northern pike. Management of invasive predator species now often accompanies habitat restoration projects through the actions of other agencies or partners.

6.5. Predation

Predation by native and invasive species has been an important management issue for much of the Program's duration (ISAB 2019-1). Much of the focus has been on evaluating predation impacts (e.g., pinnipeds – Chasco et al. 2017, Wargo Rub et al. 2019; birds – Collis et al. 2001) and considering how impacts will affect progress in meeting Program goals. Management responses to predation in the Columbia River Basin have been varied and include focused research studies to evaluate levels of predation impacts (birds in the estuary), and control and removal programs such as the long-term (since 1991) northern pikeminnow control program in the mainstem reservoirs (Beamesderfer et al. 1996) and the recent pinniped removal program at Bonneville Dam.

Several features of the developed Columbia River Basin can exacerbate predation. Dams concentrate and injure migrating smolts and adults, making them more vulnerable to predation, and reservoirs delay smolt migration and enhance predation by species like non-native smallmouth bass (ISAB 2019-1). Islands created with dredged material provide nesting sites from which the birds can easily access outmigrating smolts.

A major issue for the Program is the reduction in benefits and effectiveness of restoration actions due to predation. Given the costs and complexities of recovery actions including not only habitat actions but hatchery and harvest, actions that increase the abundance or efficiency of predators are counterproductive. Benefits to focal species from restoration actions can be lost due to predation at multiple life stages throughout their time in the Columbia River Basin, so assessing the effects of specific predators is difficult.

6.6. Hatchery Fish and Supplementation

Although the focus of our report is habitat restoration, many subbasins also have hatchery programs that can represent potential confounding factors for habitat restoration. Some habitat restoration projects need to consider and address habitat limitations and factors that can influence the success of reintroduction and hatchery supplementation efforts. Additionally, there may be unintended effects of hatchery origin fish on natural origin fish. These interactions have been extensively studied for decades and include competition for food or space, predation by hatchery fish on natural origin fish, and transmittal of disease (McMillan et al. 2023).

Habitat restoration actions typically target natural origin/wild fish although hatchery fish can benefit from habitat actions. In addition, restoration of tributary habitat can also expand habitat capacity for supplemented populations to reduce density dependence that can result from increased spawner abundance resulting from supplementation. Restoring habitat in watersheds targeted for reintroductions and hatchery supplementation is an important strategy in the Fish and Wildlife Program and a criterion consideration in the Council's Step reviews for Program hatchery projects.

It is important to consider reintroductions and supplementation in the planning and prioritization of watershed restoration actions to integrate the objectives of the restoration with the objectives of hatchery management. Hatchery origin juveniles that are not ready to migrate downstream can use and benefit from restored floodplains and large wood additions. This benefit can be at the detriment of natural origin fish coming from a restoration action if they compete with natural origin fish for space and food.

Hatcheries require high-quality water from surface or groundwater sources, so the water supply and effluent return may be important considerations for habitat restoration and protection. One example that illustrates this connection between habitat restoration and protection, and hatchery production, is Lookingglass Fish Hatchery. This hatchery produces ESA listed spring/summer Chinook salmon of endemic origin from four populations including Catherine Creek, Upper Grande Ronde River, Lostine River and the Imnaha River to supplement these depressed natural populations. Land acquisitions above the hatchery and habitat restoration actions have been completed to protect the watershed and maintain a high-quality water source for the production of these important listed populations.

6.7. Dams

The Columbia River Basin contains many dams varying in size, age, purpose, operational features, and location. Much of the focus of dam impacts on fish have been on the large mainstem, federal dams, but there are many other dams throughout the Basin. Dams change how rivers function and affect the life cycles of many species. Impacts of dams, especially the larger dams, have been studied extensively throughout the Basin and countless documents summarize their impacts and actions to address those impacts (Homel and Bach 2024, Homel et al. 2025, ISAB 2011-4). Here, we are most interested in dam effects on habitat restoration.

Dams affect the way water moves down a river, by changing the amount and timing of flow, as well as its temperature and chemical characteristics. By transforming the upstream habitat of a river into a lake, dams change the amount and location of available habitat and alter salmonid interactions with predators and competitors.

Clearly, nearly all fish resulting from restoration actions in the Columbia River Basin will encounter some number of dams both as juveniles and adults. Dams act as barriers to both juveniles and adults during their migrations.

Juveniles and adults that encounter dams can die either directly (turbine impacts) or indirectly (e.g., via predators such as pinnipeds aggregating around dams). Sublethal impacts can also occur during passage such that fish are still stressed long after dam passage, for example, increasing their vulnerability to predators (Gosselin et al. 2017, 2021).

Many dams that fish will encounter are small and used for diversion of water for agriculture, but these can still cause direct and indirect effects on fish. Some dams, such as water diversion dams, can divert migrating fish into reservoirs or onto croplands where they can be lost.

Dam operations can affect the availability and location of habitat that can potentially be restored by altering the timing of flow and ramping. For example, dams can reduce the amount and change the location of floodplain areas that can be restored in some systems. In the estuary, the century-long reduction in flows has permanently cut off some floodplain areas from being restored because they are simply at too high an elevation. Floodplain areas in tributaries can be unavailable to fish permanently, and daily and seasonal dam operations can increase risks of stranding.

6.8. Water Quality

The role of flow and temperature in habitat restoration have been discussed elsewhere in this review. Toxic chemicals are another obstacle and can come from urban development, agriculture and industry (ISAB 2011-1, 2011-4). As noted in the ISAB's 2018 Review of the 2014 Fish and Wildlife Program (ISAB 2018-3), NOAA Fisheries identified toxic chemicals as a major obstacle to salmon recovery in the Columbia River (Lundin et al. 2019), in large part due to their pervasive effects on all life stages and multiple functions within life stages. Reservoirs in the Columbia River hydrosystem increase sediment storage and long-term accumulation of adsorbed toxic chemicals (EPA 2009). Future collaboration of the Program with water quality improvements to reduce toxic chemicals funded by the Columbia River Restoration Act and other entities would benefit habitat for salmon, steelhead, and other aquatic organisms (ISAB 2024-2). In addition, habitat restoration projects that disturb sediment in agricultural, industrial, and mining areas can stir up toxics, and the potential impacts need to be considered when restoring habitat in those areas. For example, this was a concern raised in the ISRP's review of the Yankee Fork, Salmon River, Idaho, restoration of an extensive dredge mining site (ISRP 2022-5).

6.9. Density Dependence

Density dependence is the relationship between a population's density and its growth rate. Typically, populations at low density grow (increase in numbers over time), but the rate of increase tends to decline as density increases. When the population reaches the carrying capacity of the habitat, it will simply replace itself (births = deaths) and no longer increase. If the population overshoots, such as when ocean conditions are ideal and a large number of adults return to spawn, the habitat carrying capacity for juveniles will be exceeded and fewer will survive, causing the population to decline toward carrying capacity. This relationship between the spawning population and the recruits that they produce is fundamental to fisheries science, and animal ecology in general. Compensatory density-dependence acts as negative feedback on population size and therefore has a stabilizing effect on population size. Depensatory density-dependence can also exist in which the population becomes so small that extinction becomes more likely.

Compensatory density dependence can occur directly when a population's density affects mortality rates or reproduction (both directly determine abundance), and indirectly through the growth rates of individuals that determine body size and by altered movement behavior (Rose et al. 2001). Body size determines many vital rates of individuals (e.g., maturity, fecundity, vulnerability to predation) that then determine abundance, and movement out of crowded areas often puts individuals in poorer habitat that results in lowered reproduction, increased mortality, or slowed growth rate.

The ISAB (2015-1) reviewed the topic of density dependence in the Columbia River Basin and concluded that many salmon populations throughout the interior basin are experiencing reduced recruitment at high levels of adult spawners, even though current abundances remain far below historical levels. Compensatory density dependence is now evident in most of the ESA-listed populations they examined and appears strong enough to constrain their recovery.

The evidence for strong compensatory density dependence at current abundance levels suggests that habitat capacity (quantity and quality) has been greatly diminished, even though abundances of most natural-origin salmon populations are well below historical levels. Degradation of habitat quality (e.g., temperature, channel structure, floodplain connectivity, sedimentation and silt, etc.) and reduction in total area by stream incision, channelization, and dewatering can decrease carrying capacity. The capacity of some watersheds to support salmon or steelhead appears to have been exceeded at spawning abundances that are low relative to historical levels.

Reasons for density dependence and reduced carrying capacity may be related to changes to environmental conditions related to climate change, chemicals, and intensified land use. Hatchery supplementation and juvenile releases may be contributing to high densities of juveniles compared to historical levels, and lead to competition and density dependent mortality.

Habitat restoration and population recovery actions can be planned and implemented more effectively by understanding mechanisms that cause density dependence in particular streams or watersheds, such as limited food supply, limited rearing or spawning habitat, or altered predator-prey interactions. If salmon and steelhead populations are limited by density dependence, then increasing the number of fish will not improve population growth and benefits can be less than expected. A key assumption of habitat restoration is that the system is at or near capacity, and that by making new habitats fish will be able to benefit from this "new" space. While this may be true, other limiting factors that lead to density dependence – such as inadequate food, predation, or interspecific competition – may negate the benefits of increased habitat area.

6.10. Logistical Complexities

Restoration projects typically take years from conception to completion. While project proponents can anticipate how long the physical implementation aspects (i.e., on the ground) of a project should take, it can be many years before implementation proceeds. Permitting can be delayed, funding may take longer to arrive than expected, engineering is delayed, contracting takes longer, and the right equipment and workforce to do the project is unavailable. Other permitting such as ESA or Clean Water Act permits can also take longer than expected and cause delays. Natural and human-caused disturbances, such as floods and fires, can cause changes that modify the timing, design, and costs of restoration actions.

6.11. Interacting Factors

While we have discussed confounding factors separately, many confounding factors may be operating simultaneously or sequentially. For example, the effects of water quality changes can affect outcomes of interactions with invasive species. A fire or large flood could affect the success of a riparian planting, perhaps eliminating it altogether, while a habitat restoration project may affect habitat of another species. These interacting factors present a significant management challenge because they may influence the net outcome of restoration. The ability to predict how interacting factors will influence the restoration outcome is limited. They can interact among themselves as well as with planning and implementing restoration. Confounding factors can also affect how projects are conducted at a site and alter the outcomes after restoration has been completed.

Many of these interacting factors have affected ecosystems in the past and will do so in the future. For example, climate change has been ongoing, and its consequences will depend on how fast global warming occurs. Thus, streams and rivers will change geomorphically, hydrologically, and ecologically due to the influence of past human actions and natural changes (e.g., flood, fire, landslides), which play out over decades. The challenge is to anticipate the future states of river systems and restore processes that will create resilient ecosystems and net benefits under those future conditions, not present conditions. Predicting these future conditions is complex and challenging, but restoration efforts will be ineffective if practitioners do not attempt to address these interactions.

As an example, dams constructed in the Willamette River Basin in the 1950s and 1960s now capture 60-90% of the sediment historically delivered to the mainstem river (O'Connor et al. 2014), modifying channel and floodplain dynamics and limiting responses to restoration actions. Restoration of the mainstem Willamette and its floodplains and lower tributaries needs to consider the future channel dynamics and riparian forest recovery that will occur as a result of the reduced sediment supply and reduced flood magnitudes and frequencies. Another example is the need to consider the consequences of sea-level change for restoration in estuaries and coastal river mouths.

6.12. Conclusions and Moving Forward

A variety of factors, which we refer to collectively as confounding factors, affect the planning, implementation, monitoring, and evaluation of restoration. These confounding factors can interact among themselves, operate at various scales of space and time, can occur intermittently or persistently, and can occur at any point throughout the restoration process. Some are related to historical and ongoing habitat degradation and changes to the landscape and some are emerging concerns.

While we have discussed confounding factors separately, multiple confounding factors may operate at the same time in the same place, or in sequence. For example, water quality changes can affect outcomes of interactions with invasive species. A fire or large flood could affect the success of a riparian planting, perhaps eliminating it altogether, while a habitat restoration project may impact habitat of another species.

Confounding factors present a significant management challenge because their interactions influence the outcome of restoration. Predictions about interacting factors and their influences are highly uncertain. These confounding factors can interact with planning and implementing restoration, how projects are conducted at a site, and can alter the outcomes after restoration actions have been completed.

Projects varied considerably in how they considered confounding factors and developed alternatives for how the project would respond or adapt to different outcomes of confounding factors.

Recommendations

- The ISRP recommends the Program help develop and employ tools that allow forecasting future conditions toward which practitioners can plan. For example, models can be employed to identify thermal refuges for anadromous species where restoration could be targeted. Models can also help identify key habitats to protect.

7. Exemplary Projects

7.1. Background

The ISRP has reviewed hundreds of habitat protection and restoration projects as part of the Council's review process. These reviews often identified exemplary projects based on multiple performance criteria. In this chapter, we identify specific attributes of exemplary projects that are applicable at a local scale and those that could apply at broader scales such as subbasins or watersheds. We build from the most recent ISRP category reviews including the 2016 – 2017 Wildlife Project Review (ISRP 2017-7), 2019 – 2020 Resident Fish and Sturgeon Project Review (ISRP 2020-8), and the 2021 – 2022 Anadromous Fish Habitat and Hatchery Project Review (ISRP 2022-1, which included 69 habitat projects). We highlight exemplary projects from these most recent reviews because they reflect advancements that have been made in project planning, implementation, and monitoring and evaluation. In addition to the category reviews, we used other relevant ISRP and ISAB reviews and reports.

Elements and Characteristics of Exemplary Projects

Projects recognized as exemplary or outstanding in recent ISRP reviews displayed the following elements and characteristics. Not all elements were necessarily accomplished in each exemplary project, but in most cases a high proportion were demonstrated.

Project elements and characteristics:

- Consistent with and strongly contributing to the Program goals and objectives
- Based on sound scientific principles and strategic guidance
- Guided by clear goals, SMART objectives, and quantitative desired outcomes
- Identified and addressed key habitat limiting factors and threats
- Used state of the art and innovative planning, implementation, and M&E approaches
- Accomplished objectives on schedule with effective action implementation
- Strong collaboration and effective partnerships
- Effective integration of restoration methods and an appropriate level of M&E
- Clear and effective adaptive management processes at project level and broader management scales
- Considered climate change and other emerging threats in developing actions

- Effective information sharing including timely reporting, publications, public outreach, and presentations to other agencies and the public

The ISAB Landscape Report, Using a Comprehensive Landscape Approach for More Effective Conservation and Restoration, concluded that "*Effective conservation and restoration of the Columbia River Basin requires a broader, more comprehensive, and more coordinated approach*" (ISAB 2011-4). The ISAB also recommended four themes that could serve as criteria for evaluating any comprehensive approach to conservation and restoration:

1. Engage the public and diverse social groups associated with the landscape and build socioeconomic understanding (*public engagement*)
2. Incorporate a strategic approach with a foundation in the concepts of comprehensive landscape ecology (*strategic ecological approach*).
3. Develop organizations that support collaboration, integration, and effective governance and leadership (*organization across boundaries*).
4. Promote adaptive capacity based on active learning through assessment, monitoring, innovation, experimentation, and modeling, combined with a clear process to share new information and revise objectives, strategies, and actions in response to that information (*adaptive management*).

The characteristics of exemplary projects are consistent with these ISAB criteria, and exemplary projects are often part of a larger, multi-project effort that address these criteria. The exemplary projects highlighted below are especially strong in public outreach, collaboration, and adaptive learning, which can be under-emphasized in restoration efforts.

7.2. Exemplary Project Examples

We identify and describe a few anadromous salmonid, resident fish, and wildlife projects that best exemplify these elements and characteristics. The projects we highlight below by no means represent all the exemplary projects. These represent a diversity of project types across a broad geographic area throughout the Columbia River Basin that were implemented by different entities. These projects received strong positive ISRP reviews and demonstrated many of the elements and characteristics of exemplary projects. These examples should help existing and future Fish and Wildlife Program projects improve their planning, implementation, and documentation.

7.2.1. Anadromous Salmonid Projects

The **Columbia Land Trust Estuarine Restoration Project** (FWP project #2010-

073-00) has been underway for over a decade. The critical location and unique communities of the Lower Columbia River and estuary are vital to viability and recovery of all anadromous fish populations in the Columbia River Basin and mitigation through the Program. The Land Trust works on private lands to permanently protect and restore historical floodplains and reestablish native vegetation. Primary objectives for the project include restoring natural processes and access to important habitats and improving shallow water habitats and intertidal wetlands and channels.

The project focuses on conserving and restoring key floodplain habitats that provide the most significant opportunity to provide ecological benefits and address factors limiting ecological integrity and recovery of listed salmonids. There are clear pathways and processes for effectiveness monitoring, evaluation of results, and adaptive management. The project is a critical component of an extensive multi-agency collaborative effort to restore the estuary. The proponents have completed 11 acquisition projects protecting 3,154 ha (7,794 acres) and restoring an additional 1,132 ha (2,798 acres) of estuary habitat. There are plans to acquire an additional 257 ha (636 acres) and restore 558 ha (1,380 acres) over the next several-year implementation cycle.

The **Wind River Watershed Project** (#1998-019-00) has many years of important accomplishments and exemplifies a fully cooperative landscape-scale project for protection and restoration of aquatic habitat. This project is a "*collaborative restoration and research effort directed toward wild steelhead in the Wind River*" based on a whole watershed approach. The project reflects a strong partnership between its four primary sponsoring agencies (U.S. Forest Service, Washington Department of Fish and Wildlife, U.S. Geological Survey's Columbia River Research Laboratory, and Underwood Conservation District), landowners, and other partners.

Restoration and protection actions are coordinated with a comprehensive and robust research monitoring and evaluation program including population-level monitoring of abundance, productivity, spatial structure, and diversity in an intensely monitored watershed program framework. Restoration work on private and federal land is guided by several strategic habitat restoration and action plans tied to watershed assessments, limiting factors, and condition frameworks.

Overall, an impressive range of projects have been completed throughout the watershed, including road decommissioning, invasive weed control, passage improvement, riparian vegetation management, and stream and floodplain restoration. Numerous projects have addressed both adult and juvenile passage limitations. A hallmark of this project is the significant progress achieved in restoring riparian and aquatic habitat on private lands. The proponents are commended for continuing efforts to understand how habitat restoration affects steelhead production and viability. The close coordination between restoration practitioners and researchers is more effective than many other habitat restoration projects reviewed.

The **John Day Watershed Restoration** project (#2007-397-00) was started about two decades ago by the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) and is an essential component of a comprehensive habitat protection and restoration program in the John Day River subbasin. This high-impact project has many partnerships, accomplishments, and a strong record of sharing results. The proponents have developed a diverse, scientifically robust, and collaborative approach to restoration and monitoring in the basin, and they have demonstrated strong commitment to managing information. The highly collaborative nature of the project, from sound restoration approaches through monitoring and data management, is a core strength.

The project focuses on restoring natural processes and promoting ecological integrity and sustainability. Diverse strategies are used to improve floodplain connectivity, instream complexity, upslope conditions, fish passage, and flow. The protection and restoration accomplishments over the past 20 years are impressive, including 64 km (40 miles) of stream restored, 1,127 km (700 miles) of stream made accessible through barrier removal, over 2,600 large wood structures installed, 7,689 ha (19,000 acres) of juniper thinning, and over 140,000 trees and shrubs planted in riparian areas.

The project has an effective outreach and public engagement program. Perhaps most notable is a short film, "Common Ground – John Day Basin Watershed," that highlights the project's approach and accomplishments with focus on the collaboration between the CTWSRO and ranchers along Fox Creek. The film is professional, inspiring, and has been viewed at multiple film festivals and classrooms in Oregon. The project contributes significantly to achieving ESA recovery goals for John Day River steelhead and to mitigation through the Fish and Wildlife Program.

The **Umatilla Anadromous Fish Habitat project** (#1987-100-01) is restoring habitat throughout the Umatilla River subbasin for ESA-listed and non-listed salmonids as well as other important focal species including mussels and lamprey. This project of the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) was initiated to protect, enhance, and restore functional floodplain, channel, and watershed processes to provide sustainable and healthy habitat for First Foods species.

The ISRP has been impressed with the proponent's process-based restoration approach to address root causes of poor river ecosystem function that affects habitat conditions and natural processes for all focal species. The project is well guided by the holistic CTUIR River Vision, Upland Vision, and First Foods strategies. The project was commended for its integration of Indigenous Knowledge and "western" science approaches in its development of strategic guidance, goals, and objectives as well as implementation strategies.

The project uses a diverse suite of protection and restoration approaches and has an impressive list of accomplishments including over 24 km (15 miles) of floodplain reconnection, restoring access to 301 km (187 miles) of blocked habitat, protecting 2,869 ha (7,089 acres) through acquisition and easements, 6 km (3.7 miles) of levee removal, 11 km (6.8 miles) of channel reconnections, 3,400 pieces of large wood added, 281 ha (690 acres) of vegetation plantings, and 1,659 ha (4,100 acres) of invasive weed treatments. In addition, 0.3 CMS (10.6 CFS) of instream water rights have been obtained during critical low flow periods. The project has developed an extensive education and outreach program that includes local K-12 and college student field days, use of a story map to display watershed assessments to the public, and numerous other tribal and non-tribal communication endeavors.

7.2.2. Resident Fish Projects

Highlighting exemplary projects that restore and protect habitat for resident fish is complicated because such projects often have multiple major implementation strategies beyond habitat restoration and protection actions. We briefly highlight several of the many complex multifaceted resident fish projects and then highlight another project primarily focused on habitat restoration.

The project to **Evaluate the Life History of Native Salmonids in the Malheur River Basin** (#1997-019-00) is focused on monitoring, managing, and restoring native populations of bull trout and redband trout. The project of the Burns Paiute Tribe accomplishes this through targeted studies, suppression of non-native brook trout, and habitat restoration actions to minimize negative effects from cattle grazing, restore riparian habitat, and maintain fish screens. The proposal included an excellent set of goals and objectives, was well-organized, clearly written, and a model for other projects. The project demonstrated extensive collaboration and strong adaptive management through a stepwise progression of new work built on the findings and knowledge discovered in previous work (see ISRP 2020-8 presentation to NPCC).

The ISRP commended the **Coeur d'Alene Reservations Fisheries Habitat project** (#1990-044-00) for success in managing a complex set of land and water resources. The project of the Coeur d'Alene Tribe focuses on protecting and restoring native westslope cutthroat trout through restoration of landscape processes, improvement of degraded instream habitat, and removing barriers. Anadromous fish have been extirpated from the Tribe's ceded area. Without access to the anadromous fishery, the Tribe was forced to rely solely on resident fish resources for subsistence. Cutthroat trout were an important food source for the Tribe in the past when an estimated 42,000 were harvested annually from the Coeur d'Alene Basin, but recent harvest has been reduced to about 10% of the historical estimate. The project contributes significantly to the Program's strategy to build outward from the strongest, healthiest native fish populations by addressing impaired riverine processes.

Restoration of landscape processes in mainstem habitats of watersheds entailed "partnering with beaver" to increase connectivity between channel and floodplain habitats that will promote water storage and the establishment of riparian/wetland native plant communities. In tributary habitats, restoration actions include 1) implementing Best Management Practices for roads to reduce sediment delivery, 2) riparian planting for shade and bank stabilization, 3) large wood additions, and 4) barrier removal.

The project has treated 7.4 km (4.6 miles) of stream with additions of large wood and beaver dam analogs, opened access to 24.4 km (15.2 miles) of stream by barrier removal, planted more than 160,000 riparian trees and shrubs, and purchased 694 ha (1,715 acres) of critical habitat. The project also works closely with the Coeur d' Alene Restoration partnership to improve the survival of native salmonids in Lake Coeur d' Alene.

7.2.3. Wildlife Projects

Restoration projects are implemented to improve wildlife habitat and provide enhancement benefits to wildlife populations. However, demonstrating benefits to wildlife populations for the Fish and Wildlife Program wildlife projects remains a challenge in the Columbia River Basin. As described in the Introduction of this report, wildlife-oriented projects tend to focus on protecting or acquiring land and enhancing habitat that then benefits species associated with the land, but support for monitoring specific species' responses is very limited. The ISRP identified a few key issues related to this challenge. In the ISRP 2017 Wildlife

Categorical Review of Fish and Wildlife Program wildlife-focused project proposals (ISRP 2017-7), the ISRP recommended that project proponents develop quantitative biological response objectives to assess the biological performance of populations that result from actions implemented to address population limiting factors. However, the Council recommended that wildlife projects should conduct implementation or compliance monitoring but were not expected to conduct species-response monitoring (NPCC letter to BPA, October 13, 2017).

Here we highlight two projects that are poised to make significant progress addressing these challenges. The first is the **Scotch Creek Wildlife Area project** (#1996-094-01). This is a wildlife mitigation project for Columbia sharp-tailed grouse in the Okanogan subbasin, led by the Washington Department of Fish and Wildlife. The primary biological objective is "*to increase the Columbia sharp-tailed grouse population through habitat manipulation, maintenance, and protection measures, and by local population recruitment and population augmentation if necessary*." In the 2017 review, the ISRP felt that significant progress was made in terms of monitoring and evaluating the benefits to the sharp-tailed grouse population. The project reported that "*recent population estimates of sharp-tailed grouse on the Scotch Creek unit show a halt to the decline observed since 1960 and have increased every year since 2000*." The Scotch Creek Wildlife Area exemplifies a project where restoration is aimed at the shrub-steppe habitat required by a specialist focal species, thus making it possible to link restoration activities to wildlife responses.

In contrast to the Scotch Creek example, many wildlife habitat restoration projects aim to improve the availability of high-quality habitat for a community of resident and migratory species, both aquatic and terrestrial. In such cases it is more difficult to link restoration actions to a specific wildlife population response. The **Kootenai River Operational Loss Assessment** (#2002-011-00), led by the Kootenai Tribe and Montana Fish, Wildlife and Parks, exemplifies this type of project. The objectives of this project are to "*protect, restore and/or enhance floodplain ecosystem, which has been altered and degraded by the operations of Libby Dam in the Kootenai Watershed (e.g. riparian, wetland, and related uplands and tributary areas) in order to promote healthy self-sustaining fish and wildlife populations, and functional restored or normative ecological functions within and among biotic communities with an emphasis on restoring sustainable hunting/gathering populations of flora and fauna for tribal sustenance.*" The ISRP in their 2017 review commended the proponents for evaluating wildlife responses using the

Avian Index of Biological Integrity (IBI), which summarizes data from avian point counts, and suggests that invertebrate diversity could also be monitored.

The **Upper Columbia United Tribe's Wildlife Monitoring and Evaluation Project** (#2008-007-00) is another example of effective monitoring of wildlife responses to restoration that addresses the ISRP recommendation to improve population response monitoring. The project uses repeat monitoring methods of vegetation and vertebrates at project restoration sites to assess performance and response. This method is used by the Albeni Falls Wildlife Mitigation project (#1992-061-02), led by the Kalispel Tribe.

Another issue highlighted by the ISRP in the 2017 Wildlife Review for many projects was the need for SMART (specific, measurable, achievable, relevant, and time-bound) objectives to guide implementation and evaluation. The **Shoshone-Bannock Wildlife Mitigation Project** (#1995-057-02) exemplifies a project well-positioned to adopt and implement SMART objectives. This project is part of the Southern Idaho Wildlife Mitigation Program (SIWM) to mitigate hydrosystem-related losses in Southern Idaho. During the ISRP review, the proponents provided examples of SMART objectives developed to guide the project into the future, clearly indicating their intent to incorporate quantitative biological objectives into their future management plans.

8. Concluding Remarks

This ISRP report is a culmination of an extensive retrospective evaluation of tributary and estuary habitat restoration and protection efforts since the inception of the Program. The purpose of the review was to evaluate progress in protection and restoration project planning, implementation, and RM&E efforts in the Program, identify current and future challenges, and provide recommendations for future improvement.

It is clear to the ISRP that there has been significant improvement in habitat protection and restoration efforts over the 40+ year lifespan of the Program. Of particular note is the increasing and effective use of models such as habitat and life cycle models, more rigorous analysis of limiting factors, and use of strategic planning which have helped significantly improve the planning and prioritization of projects. In addition, there has been an evolution toward greater complexity and integration of restoration actions, both within individual projects and in multiple coordinated projects across large spatial scales. Methods of restoring habitat have evolved over time as projects have embraced the greater complexity and scale of processes that drive fish population responses to habitat restoration. This has occurred in part due to results of monitoring efforts in the Columbia River Basin as well as outside the Basin. In addition, protection and restoration efforts have increasingly adopted process-based approaches to restore natural processes as opposed to focusing on simply restoring channel form and structure. Comprehensive RM&E projects implemented through the Fish and Wildlife Program, such as the ISEMP and AEM projects, have provided valuable information on the effectiveness of major restoration methods. Further study is warranted on floodplain reconnection and riparian restoration, both of which will require designing efficient long-term monitoring programs that can track changes over decades.

Although research, monitoring, and evaluation (RM&E) have been fundamental components of the Program since it began in 1982, monitoring and evaluation have been problematic and inconsistent in the Program and remain so. Both the ISRP and ISAB have repeatedly called for improving RM&E, and the Program has made multiple concerted efforts to address the deficiencies in RM&E, which have resulted in some improvements. One promising advance in RM&E is the recently completed RM&E Strategy. The Strategy deals most strongly with reach and project scales but is inadequate at dealing with larger spatial scales, including providing a mechanism for coordinated monitoring and evaluation of entire geographical areas or subbasins and sharing of data and information.

The Program needs to better measure results of restoration at the basin, watershed, and sub-watershed scales over greater time periods to track progress towards meeting mitigation goals. Two fundamental monitoring questions that need more emphasis in the Program are: 1) Did restoration improve habitat at the watershed scale and increase or stabilize viability of fish populations, and 2) What mechanisms caused these improvements? The ISRP also recommends the Program would benefit from a hierarchical basinwide monitoring approach, more support to develop experimental designs at large scales as well as to analyze data from these efforts. The ISRP recommends the Fish and Wildlife Program encourage synthesis by those conducting long-term experiments like IMWs and continue to fund those providing long-term data to answer key current questions, and unanticipated questions that will arise in the future.

One of the best opportunities for monitoring and evaluation at large scales is the IMW's and other similarly structured programs (such as Umbrella Projects). The use of IMW's in the Columbia River Basin has diminished over time, and we recommend that the Council consider expanding these efforts in the Program. The ISRP recognizes that it is impractical to implement IMWs everywhere and recommends a review of how well the existing IMWs represent the diversity of landscapes and fish and wildlife resources of the Columbia River Basin to identify where they should be expanded.

Appendix. Limiting Factors Analysis and Assumptions about Movement

A.1. How are salmonid populations regulated?

Concepts about population regulation have dominated ecology since the early synthesis by Solomon (1949). Population abundance and density vary widely but typically remain within some observed upper limit. A major contributor to population limitation is density dependent mortality, which determines the environmental carrying capacity. Density dependent mortality can arise through several processes, with intraspecific competition for limited resources, such as food or space, being particularly important. As vacant habitat is colonized by a cohort during a life stage, intraspecific competition is initially low, with minimal impacts on the growth and survival of individuals or their breeding opportunities. As density increases, intraspecific competition intensifies, thus increasing mortality at one or more stages of the animal's life. Competition may take different forms, such as scramble competition, interference competition, or a prior resident advantage forcing competitors into suboptimal habitat.

In salmonids, population regulation can occur extensively during freshwater life stages, including spawning, incubation, and juvenile rearing, and especially in streams but also lakes (reviewed by Quinn 2018). The amount of suitable habitat in streams and rivers may limit the number of females that can spawn, embryos that can be successfully incubated in the stream gravels, or the number of resulting juveniles that can be supported by the food and space in the stream before they migrate to the ocean. This conclusion is based on studies relating habitat quantity and quality with the production of juvenile salmonids. All other things being equal, larger streams produce more smolts than smaller streams (e.g., coho salmon: Bradford et al. 1997). However, after adjustment for stream size, some are more productive than others (Bradford et al. 2000, Barrowman et al. 2003), and this is primarily due to differences in habitat features (e.g., Sharma and Hilborn 2001, Burnett et al. 2007). Coho salmon have been a focal species in these kinds of studies because of their dependence on stream habitats for a year or two in most populations prior to seaward migration (Reeves et al. 1989), but species-specific differences in habitat use and consequent patterns of relative density are well-known for other salmonids such as steelhead and coastal cutthroat trout (e.g., Bisson et al. 1988; Roni 2002; Hicks and Hall 2003), and Chinook salmon (e.g., Hall et al. 2018; O'Neal et al. 2024). In summary, competition among adults for suitable spawning habitat may limit the number of fry that emerge from the gravel, and the quality and quantity of suitable habitat (i.e., food and space) may then limit the production of smolts from the number of fry that emerge.

For a particular life stage, productivity can be visualized by relating the number or biomass of individuals entering a life stage (i.e., the stock) to the number of individuals leaving the life stage (i.e., recruitment). Specifically, for the juvenile rearing stage, stock-recruitment relationships (SRRs) would typically relate the number of spawning females to the number of smolts. These visualizations (e.g., Figure 2.1) show a characteristic flattening of the curve at high female densities, attributable to density dependent mortality. However, a common misconception is that density dependent mortality is the dominant factor limiting maximum recruitment. In fact, density independent mortality modulates the maximum recruitment that could be achieved within the time constraints of a life stage (Appendix A.5). A fixed number of spawning females, from low to high densities, do not always produce the same number of smolts because physical factors operate. For example, extreme low flows in the summer can be an important density independent factor (e.g., coho salmon: Beecher et al. 2010; steelhead: Grantham et al. 2012; Chinook salmon: Warkentin et al. 2022).

A.2. What are limiting factors and ecological concerns?

A limiting factor can be a difficult term to define precisely. In general, an ecological factor can be viewed as limiting if it determines birth or death rates, and therefore equilibrium population size when births equal deaths. In a stricter sense, an ecological factor or process is limiting if it determines the carrying capacity of a population or life stage through density dependence; in modern textbooks (e.g., Krebs 2009), such factors are considered to be regulating factors. However, given that maximum recruitment depends on density independent and density dependent mortality (Appendix A.5), it may be more useful to consider a factor to be limiting if it strongly affects the carrying capacity (i.e., maximum recruitment). In a population targeted for restoration, it is important to identify the limiting life stages, processes, and factors.

For adult salmonids, the quantity and quality of breeding sites is the first potential limiting factor. At low densities, each female can obtain, spawn in, and defend a site with the combination of gravel size, water depth, and velocity that are appropriate for that fish of that size and species (reviewed by Kondolf and Wolmon 1993, Beechie et al. 2008). With increasing density, females arriving after spawning has begun must either spawn in other, inferior sites and thus experience lower survival of their embryos, or they must displace a female from her site, thus reducing the survival of that female's offspring. Regardless of the specific process, the effect of increasing density is lower per capita production from the population as a whole. In species that use streams only for spawning (typically sockeye, pink, and chum salmon), the spawning period is the primary density-dependent period, with flooding and other physical processes causing additional density-independent effects. However, for the species that feed as juveniles in the stream before migrating to sea (e.g., Chinook and coho salmon and steelhead), the most important periods of density-dependence usually occur during the feeding of juveniles because streams typically have a greater capacity to incubate embryos than their capacity to support juveniles.

For juvenile salmonids, intraspecific competition driving density dependent mortality is a key limiting process (Elliott 1994). There is also competition among different species for food and space, but among native species it is mitigated to some extent by their differences in preferred habitat (e.g., Bisson et al. 1988). In turn, the amount and quality of accessible habitat – in terms of providing food and shelter – are key limiting factors. If more high-quality space is available, then fish can space themselves out to minimize competitive interactions and the population can increase. Habitat configuration is also important, along with longitudinal and lateral connectivity among habitat types. Density independent mortality factors may also be important, not only through their influence on survival and maximum smolt production, but also through their influence on habitat suitability and therefore the competitive environment. Stream flow is a common density independent factor which affects the survival of juveniles feeding in the stream. Limiting processes and factors follow hierarchical structuring, whereby one process or factor (e.g., the hydrograph) affects local habitat features (e.g., the configuration of pools and riffles).

Limiting factors can be compared to the less restrictive category of ecological concern, which is considered to be synonymous with a threat. Hamm (2012) considers ecological concerns to encompass all factors that affect salmon abundance and productivity but does not require them to be limiting. Hamm (2012) presents a data dictionary for ecological concerns in an effort to standardize vocabulary. Top ecological concerns for salmonids include riparian condition, floodplain condition, instream habitat, channel stability, and channel modification. Consistent with the hierarchical nature of limiting factors, each broad category of ecological concern also has subcategories. For example, under floodplain conditions, loss of habitat connectivity and degraded side-channel habitat are two subcategories.

While eliminating limiting factors for salmon and steelhead production is generally a laudable and promising objective for habitat restoration, elimination of all limiting factors may be harmful to persistence of the anadromous life history trajectory in steelhead. As Thorpe (1994) notes, smolting and the associated oceanward movement are the result of failure of the habitat to meet the necessary and sufficient conditions for residence and reproduction in fresh water. Hatchery production offers a lesson, whereby too much food at the wrong times can lead to undesired residualism (Sharpe et al. 2007). In addition, life history modeling showed that when food resources were increased under optimal temperatures, steelhead juvenile progeny grew faster, resulting in reduced smolting and thus increased residualism (Benjamin et al. 2013). Temperature and food, and their subsequent effects on fish growth, survival, and smolting constitute a complex set of interactions (Connolly and Petersen 2003, Thompson and Beauchamp 2016) that need to be considered when acting to address limiting factors.

A.3. What is a limiting factor analysis?

A limiting factor analysis seeks to identify one or more factors or processes that determine (i.e., limit) a population's vital rates and carrying capacity. For example, a hypothetical stream might have abundant habitat suitable for breeding and embryo incubation but little suitable habitat for juveniles to rear, in which case the rearing habitat would be the limiting factor. Alternatively, a stream might have more than adequate habitat for rearing but too little suitable spawning and incubation habitat, in which case that would be the limiting factor.

As part of the process, a limiting factor analysis may identify a limiting life stage. In general, a limiting factor analysis begins with assessment, where practitioners identify ecological concerns for all life stages and reach or watershed, and then assess and rank potential limiting factors for their importance and feasibility to be ameliorated through restoration actions. To be most useful, a limiting factor analysis integrates the best available empirical fish and habitat data and local and regional professional expert knowledge to parameterize a stage-specific stock recruitment relationship, and involves population assessments along with habitat evaluations to inform the productivity and carrying capacity terms. If a life stage is below its carrying capacity but seeding from the prior stage is sufficient, then that life stage and one or more of its habitat features may be limiting. This general approach to a limiting factor analysis can be referred to as a “capacity deficit approach” (NMFS 2020a).

The methods used for a limiting factor analysis depend on the complexity of the problem. Identification and ranking of priority limiting factors may require extensive discussion and compromise among interested and knowledgeable parties. An excellent example of this approach is BPA’s Atlas Prioritization Framework. In addition, many tools (models, data sets) can be used to help guide a limiting factor analysis or other aspects of habitat restoration planning (Roni et al. 2018a).

Carrying capacity is typically estimated in two ways: an empirical approach and a comparative approach. In the empirical approach, a data set is generated of, for example, the numbers of adult spawners or females and the numbers of fry or smolts they produced over some years. The data are graphed as the numbers of fry or smolts against the number of adults or females, and the carrying capacity (estimated by eye or from a mathematical formula) is determined by the flattening of the curve. This approach has the advantage that it is relevant to the site of interest but has the drawback of requiring labor-intensive data collection over many years. The alternative is to take the data collected in many such studies and generate predictions for a reach of interest.

A habitat-centric approach is to model intrinsic potential (IP), which is the amount and/or quality of habitat for spawning, incubation, and/or juvenile rearing (Burnett et al. 2007). In this semi-quantitative approach, reach-specific geomorphic variables (e.g., stream gradient, bank-full width) are used to determine reaches that could support salmonids at varying densities. An example IP model was developed by the Interior Columbia Basin Technical Recovery Team, which used stream width, gradient, valley width, and confinement as their geomorphic variables, largely derived from remote sensing technology (Cooney and Holzer 2006). This approach is especially useful for assessing inaccessible (i.e., blocked) habitat but can also be used as a reference carrying capacity for an already occupied watershed if habitat configuration is known.

A complementary approach for conducting a habitat suitability analysis is to generate predictive equations of habitat use and fish densities based on specific habitat features using statistical models. Studies relating habitat features to salmonid populations typically adopt one of two approaches to acquire the necessary fish data. First, studies have related the density of juveniles with attributes of the habitat such as water depth and velocity where individual fish are seen by snorkelers (e.g., Healy and Lonzarich 2000), caught by electrofishing (e.g., Roni 2002) or a combination of methods (Hicks and Hall 2003). Alternatively, basinwide smolt production can be compared to physical habitat features such as overall gradient, pool density, etc. (Sharma and Hilborn 2001). Each of these approaches has merits and weaknesses. An important assumption of building any predictive model is that fish presence and density adequately reflect habitat quality. However, if there are too few fish to distribute among the available habitat patches, some suitable habitats may be unoccupied. Similarly, observed densities of fish and other animals may not reflect carrying capacities (Van Horne 1983). Under-utilization of suitable rearing habitat may occur if incubation habitat is limiting or if the system has inadequate escapement. While a few adults may be sufficient to produce enough fry to reach carrying capacity, this should not be assumed. On the other hand, fish densities may exceed carrying capacity if some habitat features act as an ecological trap or otherwise attract fish but provide no survival benefit. Stocking of hatchery reared fish may also inadvertently cause fish densities to exceed the carrying capacity (ISAB 2015-1). Thus, predictive models should not be trusted without careful consideration of these assumptions.

In many reaches or watersheds targeted for restoration, it will be important to know if current fish densities are near or above carrying capacity. If they are, restoration activities to improve habitat quality alone may not produce a measurable fish response. Instead, activities to improve habitat quantity may be more effective. A useful approach to gauge proximity to the carrying capacity, as recommended by the ISAB (2015), is to quantify the strength of density dependence, which can be done through evaluation of the stock-recruitment relationship. In their report, the ISAB evaluated stock-recruitment relationships and proposed that current carrying capacities may be lower than were historically present, and overstocking of hatchery fish may be a concern. Scrutiny of stock-recruitment relationships should not be done in place of habitat assessments but should help provide a better understanding of carrying capacities.

For a well-studied species, it may be possible to develop a limiting factors key for use by practitioners. For example, Reeves et al. (1989) describe a key for determining the physical factors affecting coho salmon smolt production in fourth to fifth order streams of coastal and interior (west of Cascades) in Washington and Oregon. The input for the key is data from two comprehensive, watershed-wide habitat surveys: one during late summer low flow and one during late winter low flow periods. In addition to using data on temperature, stream gradients, and habitat configuration, the key also can use population assessment data as input. In essence, the key enables practitioners to assess the degree to which stage-specific density is below habitat capacity as determined by literature-informed values, and whether there is under-seeding from the prior life stage. Density independent mortality is factored into equations, and density dependent mortality is factored into the key implicitly through assumptions about habitat-specific carrying capacity. The key can be used to assess if smolt production is near carrying capacity, and which prior life stage and/or habitat feature is limiting smolt production. In essence, the key allows a practitioner to identify any bottlenecks to coho smolt production.

A limiting factor analysis may also be coupled with life cycle models that integrate stock-recruitment relationships to explore population level impacts of the limiting factor and/or restoration action on productivity and capacity. For example, Honea et al. (2009) parameterized a spatially explicit, life-stage specific model to estimate the effect of habitat restoration actions on agents of mortality (e.g., fine sediments in spawning gravels) and spawner and fry capacity on overall productivity. Beverton-Holt SRRs were used for the spawner and fry stages (Appendix A.5). IP models were used to inform the carrying capacity terms of the SRRs, and density independent factors (temperature, % fine sediment) were used to inform the productivity terms.

A.4. In habitat restoration activities, what assumptions are made about fish movement?

Statistical approaches to estimate habitat- and reach-specific productivity and carrying capacity usually assume that fish know or can quickly learn the rankings of habitat suitability within a watershed (i.e., they are "ideal") and will be unconstrained in their selection of a habitat patch (i.e., they are "free"; Fretwell and Lucas 1969). Under these assumptions, spawning adults and juvenile fish will distribute among habitats such that higher-quality habitats are occupied by more fish. These assumptions that fish are "ideal" and "free" also apply when considering the impact of habitat restoration. In reality, fish are not omniscient and cannot know the existence of habitat unless they explore it. Fish may settle in a territory that exceeds a quality threshold, despite the existence of higher quality habitat in a location they have not explored. The movements used by fish during search and settlement will ultimately have implications for the implementation success of habitat restoration actions.

In some models, assumptions concerning fish movements are explicit.

For example, Honea et al. (2009) modeled stage-specific recruitment and made assumptions about settlement behavior at the spawner and fry stages in the Wenatchee River watershed. At the spawner stage, adults distributed themselves among all habitats in proportion to their intrinsic potential. Fry also distributed themselves among habitats in proportion to their intrinsic potential, but fry were constrained in their choice of habitat units based on proximity to their emergence site. The modelers also allowed for early movement of fry to an overwintering site, where density dependence was no longer a factor. This early movement of fry was assumed to be density dependent.

The movement of salmonids is more complex than most models assume. For example, it was long known that some juvenile coho salmon move downstream, and it was hypothesized that these fish were unable to obtain feeding territories because they emerged too late in the season or were competitively inferior (Chapman 1962). These results were challenged by Kahler et al. (2001), who measured the size and growth of individual fish and included the potential for upstream movement in the study design. They concluded, "*Habitat units that coho left were smaller and shallower but lower in density than units where coho remained. Thus, movement is a common phenomenon rather than an aberration, and may reflect habitat choice rather than territorial eviction. Moreover, movers grew faster than nonmovers, so the 'mobile fraction' of the population was not composed of competitively inferior fish but rather individuals that thrived. The phenomenon of small-scale habitat-, and growth-, and density-related movements should be considered when planning and interpreting studies of juvenile salmonid ecology in streams.*" The complexity of movement, including movements of fish in and out of treated reaches, makes it a challenge to understand some of the direct benefits of a restoration site. For example, Collins and Baxter (2020) found that habitat enhancement through the addition of salmon carcasses attracted and retained rainbow trout over the short term, but subsequent movement out of treatment reaches meant that the short-term numerical response was not maintained across years.

Habitat restoration projects should consider the interactions between density and movement. As described above, juvenile salmonids emerge from redds in spring, commonly exceed the carrying capacity of the stream, and experience local reductions in density from mortality and movement. Habitat features can affect the distribution of spawning by the parental generation, and the survival and propensity for movement by the offspring. Density, resulting from survival and distribution, affects growth, survival, and the timing of life history transitions. Consequently, local habitat restoration projects (e.g., wood placement) will likely have impacts that extend beyond the local area (see Gowan and Fausch 1996 for an example with resident trout). Thus, it may be necessary to evaluate juvenile production on a broader scale, and relate overall production to habitat features (e.g., Sharma and Hilborn 2001). A caveat is that the benefits of a specific restoration project may not be detectable at the basin scale, especially if the restoration area is very small in relation to the basin's area.

Studies of local fish density before and after habitat alteration or comparing restored and degraded habitats can be misleading if they do not explicitly consider movement dynamics. High densities can occur in good quality habitats, not only because mortality is reduced, but because a mobile fraction of the population encountered them as they moved throughout the watershed and then stayed. Much of the local abundance may be fish that "stay home," but it also includes fish that move long distances. It is the mobile fraction, coming from many locations throughout the watershed, that finds and colonizes new habitats. If density reduces growth and size affects survival prior to smolt migration (e.g., Quinn and Peterson 1996), then some habitats may ultimately be less productive than they seem. Perhaps this is why some local habitat features were not strongly correlated with survival (Ebersole et al. 2009).

A.5. The Beverton-Holt stock-recruitment model

The Beverton-Holt model assumes a form of compensatory mortality driven by intraspecific (i.e., intra-cohort) competition for limited space. Conceptually we can imagine an initial stock competing for space, which progressively gets depleted due to density independent and density dependent mortality. As fish are lost and density declines so does the density dependent mortality rate. Mathematically, the model assumes a mortality rate that is linearly dependent on the number of fish alive at a given time, resulting in the following model of fish loss:

$$dN/dt = -(m_1 + m_2 N)N \qquad (1)$$

where N is the population size at time t, m_1 is instantaneous density independent mortality, and m_2 is instantaneous density dependent mortality. Mortality is assumed to be additive.

Solving equation (1) for the number of recruits at time T (R) through integration gives the familiar Beverton-Holt model, which can be represented using different parameterizations (Hilborn and Walters 1992). For example,

$$R = \frac{aS}{b+S} \qquad (2)$$

where S is the stock size (e.g., number of spawners) at time 0, a is the maximum number of recruits when S is very large, b is the stock needed to produce a recruitment of a/2, and a/b is the initial slope (maximum R/S as S approaches 0), which we will call productivity. Importantly, "a" is often referred to as the carrying capacity, thus implying space limitation. However, a is a function of m_1 and m_2, as we will show below. In this formulation R and S represent numbers, although S could be estimated from female spawner biomass and fecundity or from spawning density and watershed area.

Alternatively,

$$R = \frac{a'S}{1+b'S} \qquad (3)$$

where a' is the maximum R/S, and a'/b' is maximum recruitment.

In another formulation,

$$R = \frac{a'S}{1+{}^{a'}/_{b''}S} \qquad (4)$$

where b'' is maximum recruitment, or after some arrangement:

$$R = \frac{S}{\frac{1}{a'}+\frac{1}{b''}S} \qquad (5)$$

Equations 2-5 model the same relationship but with different parameterizations. Equation (5) is particularly useful for decoupling intrinsic habitat productivity (a') and maximum recruitment (b'').

Equations 2-5 represent recruitment as a function of productivity and maximum recruitment, not in terms of m_1 and m_2. However, a recent formulation (Zimmerman et al. 2021) uses these parameters:

$$R = \frac{e^{-m_1T}S}{1+\frac{m_2}{m_1}(1-e^{-m_1T})S} \qquad (6)$$

where letting exp(-m_1T) = a' and (m_2/m_1)(1-exp(-m_1T)) = b' returns us to equation (3). From this parameterization we can see that a' depends on m_1, but maximum recruitment (a'/b') depends on both m_1 and m_2. This is because maximum recruitment is also limited by the amount of time spent in the life stage.

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