Hydropower-Related Salmon Research Plan

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Executive Summary

The following plan summarizes the approach and direction of hydropower-related salmon research by the Fish Ecology Division's Riverine Ecology Group. Activities are centered around the NOAA mission goal of protecting, restoring, and managing the use of coastal and ocean resources through ecosystem management approaches. Specifically, research focuses on identifying and mitigating the adverse effects associated with operation of the Federal Columbia River Power System on anadromous salmonid populations endemic to the Columbia River Basin, with particular emphasis on evolutionarily significant units listed under the Endangered Species Act. Riverine Ecology Group research activities reflect the recognition that 1) dams have greatly altered the Columbia River ecosystem within which the various salmon populations evolved, 2) dam passage continues to inflict direct mortality on juvenile and adult salmon, 3) dam passage likely imposes post-passage delayed or extra mortality on migrants, and 4) the Endangered Species Act, which emphasizes conservation of wild/natural populations, is now the major influence on all aspects of hydropower operations and research activities within the Columbia River Basin.

Introduction and Background

The Columbia River Basin was once inhabited by a prodigious and highly diverse population of Pacific salmon (*Oncorhynchus* spp.), with the Columbia and its estuary serving as a migrational corridor and rearing area that provided a link between freshwater and marine habitats. Today, the once spectacular runs of native salmon are only a small fraction of their historic size, with individual stocks of some species extirpated and many remaining stocks recently listed under the Endangered Species Act (ESA).

Damming the Columbia River and its tributaries drastically altered the riverine ecosystem and has been a major contributor to the decimation of the river's once extraordinary salmon runs. Scientists in the Riverine Ecology Group (Group) at the Northwest Fisheries Science Center (NWFSC) have been conducting research on the direct effects of Federal Columbia River Power System (FCRPS) development on salmon stocks for nearly four decades. This scientific endeavor has resulted in the implementation of numerous hydrosystem configurational and operational measures that have led to substantial reductions in the immediate mortality experienced by juvenile and adult salmon as they migrate through the succession of dams and reservoirs. These measures include:

- **Water management** - management of river flows and system storage to improve salmonid passage and survival
- **Juvenile salmonid transportation** - collection and barge transportation of salmonids to circumvent mortality at hydroelectric dams and in their reservoirs
- **Juvenile salmonid passage** - configurational and operational actions at hydroelectric dams and in reservoirs to improve survival

- **Juvenile salmonid reservoir survival** - operations and active management of salmon predators to improve survival
- **Adult salmonid passage** - configurational and operational actions at hydroelectric dams and in reservoirs to improve survival
- **Water quality** - monitoring and improvement in total dissolved gas levels and water temperatures
- **Fish facility operations and maintenance** - construction, operation, maintenance, and improvement of fish passage facilities at hydroelectric dams

While the challenge of reducing direct mortality even further continues, Group research is also focusing on the indirect effects of hydropower-system passage. The overriding question is how does passage through this unnatural system of dams and reservoirs impact performance and survival during subsequent life-history stages in marine and freshwater habitats? This question poses a much different scientific challenge than that posed by excessive direct mortality, and addressing it will require development and testing of new hypotheses and technologies capable of measuring changes in behavior, physiology, and survival over much greater dimensions of space and time.

Our challenge, then, with regard to determining and understanding the effects of contemporary hydrosystem operations on salmon populations is to develop the appropriate scientific hypotheses, study designs, and technologies necessary to conduct research to address two key questions of concern which are part of the NWFSC Salmon Research Plan and form the foundation of our Hydropower-Related Salmon Research Plan:

Regarding currently proposed (2000 NMFS FCRPS BiOp/Basinwide Salmon Recovery Strategy) or other hydropower system operational measures, how can we identify and quantify direct survival of salmonids migrating through the hydropower system?

The seven hydropower system configurational and operational measures listed above parallel those included in the 2000 NMFS FCRPS BiOp. Continued evaluation within each of these areas to further improve direct, inriver survival is necessary. As with past research in these areas, studies to identify where improvements can be made will likely require identification of specific individuals during both downstream and upstream migrational phases. Continued development, refinement, and application of PIT-tag technology, radiotelemetry, hydroacoustics, and other potential methods of remotely detecting, identifying, and tracking individuals and groups of fish throughout multiple life-history stages will be necessary.

How can we identify and quantify indirect or delayed effects of hydropower system operations on salmonid fitness and survival?

The hypothesis that indirect or delayed mortality results from passage through the hydropower system is the most critical uncertainty regarding the effects of hydrosystem operations on salmonid survival. Specifically, to what extent do variables of passage through the hydropower system environment (including passage history, transportation, flow, and migrational timing)

alter the fitness and survival of juvenile salmonids as they migrate to the estuary and ocean, and the survival and reproductive success of adult salmonids as they move upstream. To address this uncertainty, we will need to conduct studies linking 1) conditions during the juvenile salmonid rearing phase to subsequent survival and fitness during the migratory phase, 2) variable conditions during the juvenile migratory phase to differences in estuarine and ocean survival, and 3) upstream passage history of adults to differences in pre-spawning mortality and reproductive success. As with direct-effect studies, much of this research will rely on current and developing technologies that allow remote detection, identification, and tracking of individual fish. The success of ongoing research to design, test, and install PIT-tag detection systems for adult salmonid identification at Columbia and Snake River dams is critical, as are improvements to the juvenile salmonid PIT-tag detection systems and the development and application of remote surveillance technology for estuarine and marine environments.

Program Mission

Riverine Ecology Group research activities are centered around the NOAA mission goal of protecting, restoring, and managing the use of coastal and ocean resources through ecosystem management approaches. Specifically, research focuses on identifying and mitigating the adverse effects associated with operation of the FCRPS on anadromous salmonid populations endemic to the Columbia River Basin, with particular emphasis on evolutionarily significant units listed under the Endangered Species Act. The Group's research activities reflect the recognition that 1) dams have greatly altered the Columbia River ecosystem within which the various salmon populations evolved, 2) dam passage continues to inflict direct mortality on juvenile and adult salmon, 3) dam passage likely imposes post-passage delayed or extra mortality on migrants, and 4) the Endangered Species Act, which emphasizes conservation of wild/natural populations, is now the major influence on all aspects of hydropower operations and research activities within the Columbia River Basin.

The Group's research is intended to provide results that will assist managers in developing strategies and policies that address performance standards and the Reasonable and Prudent Alternative (RPA) actions detailed in the 2000 NMFS FCRPS Biological Opinion (BiOp) for Operation of the FCRPS and that will lead to recovery of ESA-listed stocks and benefit non-ESA-listed stocks.

Current Research Themes

Ongoing research of the Riverine Ecology Group focuses on the following four primary research themes, with examples of current projects and key research questions summarized under each:

1) Assessments of direct hydrosystem effects - these studies assess direct mortality that occurs as juvenile or adult salmon or other important anadromous non-salmonids (e.g., Pacific lamprey *Lampetra tridentata*) migrate through the FCRPS and provide information and recommendations to increase survival during these two life-history stages. Implementation of actions and recommendations derived from assessments in this category will produce incremental improvements in direct survival to meet hydropower performance standards as outlined in the 2000 NMFS FCRPS BiOp.

Project: Evaluation of adult salmon and steelhead migrations past dams, through reservoirs, and into tributaries in the Lower Columbia River

Adult salmon and steelhead migrating to their natal streams in the Columbia River must pass up to nine dams and associated reservoirs, four each in the lower Columbia and Snake Rivers and five in the mid-Columbia River. Losses and delays during passage at each hydroelectric project may impede recovery of native populations. This study indirectly or directly addresses 18 RPA actions in the 2000 NMFS FCRPS BiOp.

Question: *Do the current design and operation of the lower Columbia River dams negatively affect adult salmon and steelhead migration, fishway use, passage rate, and fitness?*

Project: Pacific lamprey bypass evaluation at Bonneville Dam

Pacific lamprey are an important cultural resource of Native Americans in the Pacific Northwest and historically supported a commercial fishery in the Columbia River. Lamprey populations have declined in abundance in the Columbia River drainage resulting in restrictions to the fishery and concern about their status and a petition to list under the ESA is under consideration. These declines may be due, in part, to the fact that hydropower dams can obstruct or delay lamprey pre-spawning migration in the lower Columbia River. Using radiotelemetry, we have found that adult Pacific lamprey exhibit poor passage efficiency at lower Columbia River dams and have particular difficulty in serpentine weirs near the tops of fishways. Further, they regularly entered makeup water channels (MWCs) which provide no ready outlet to the dam forebays.

Question: *How can we improve passage efficiency of adult Pacific lamprey at hydropower dams without compromising passage of ESA-listed anadromous salmonids?*

Project: Fish passage and survival at Lower Snake River and McNary Dams

The 2000 NMFS FCRPS BiOp calls for project operations at Snake and Columbia River Dams to rely on voluntary spill to expedite the migration rates of ESA-listed juvenile salmonids past hydroelectric dams and to increase total project survival by reducing the proportion of smolts passing through turbines. Increased spill volumes also raise the level of total dissolved gases (TDG) in the tailraces of these projects, often above state and federal water quality levels deemed safe for aquatic organisms. Construction of flow deflectors on spillbays has successfully reduced TDG levels allowing higher volumes of spill. However, recent studies of spillway passage survival at Ice Harbor Dam indicate that high spill volumes (resulting in high spill efficiency) at low total river flows (e.g., typical summer flows) result in lower than expected survival. PIT tags have been the preferred methodology in the Snake and Columbia Rivers to estimate in-river and passage-route survival. However, PIT-tagged fish must pass through bypass systems equipped with PIT-tag detectors at downstream dams. The advent of the voluntary spill program in the mid-1990s has reduced the number of fish passing through bypass systems, thus requiring larger sample sizes of PIT-tagged fish to provide adequate statistical precision of survival estimates. Additionally, information on the effects of the voluntary spill

program on passage behavior and timing at these projects is limited. Advancements in radiotelemetry have allowed us to collect information on passage behavior and timing as well as estimate survival through all routes of passage at these projects with less impact to the resource. Ultimately, this research will provide the management agencies with information needed to operate the hydropower system in a manner that will benefit both fish and people in the Pacific Northwest. This project addresses RPA actions 82 and 83 in the 2000 NMFS FCRPS BiOp.

Question: *What effects do project operations at lower Snake River and McNary Dams have on the passage behavior, timing, and survival of migrating juvenile salmonids?*

Project: Studies to Establish Biological Design Criteria for Fish Passage Facilities: High Velocity Flume Development

Hydropower development has severely impacted juvenile salmon migrants in the Snake and Columbia Rivers. Dams have radically altered the free-flowing river system into a series of impoundments that protract the duration of each outmigration. This migration delay may lead to an increase in smolt mortality in a wide variety of ways. Since the late 1960s, the NWFSC has been conducting research designed to alleviate the problems smolts encounter at these dams. Bypass facilities collect juvenile salmonids for subsequent transport and/or release back to the river. It is generally believed that chinook salmon smolts transported with steelhead smolts (which are generally larger than chinook salmon smolts) experience higher levels of stress than those transported with other chinook salmon; therefore, separation of smolts by size has been a goal at each of the juvenile fish collection facilities. The present bypass systems use an underwater separation technique that allows volitional separation. This type of separation requires exacting water controls that are difficult to achieve, which has led to variable separation results. Also, these systems allow fish to accumulate in relatively small holding areas which also may increase stress. During the past several years, studies have been conducted using a new high-velocity-flume concept for separating juvenile salmonids at McNary and Ice Harbor Dams. This system has been shown to effectively separate large (>180 mm fork length) from small juvenile salmonids and at the same time eliminate holding areas. The studies were conducted under very low densities (approximately 100 fish/hour passing through the separator) and additional research is required to verify results when large numbers of smolts are present. This project addresses RPA actions 94 and 95 in the 2000 NMFS FCRPS BiOp.

Question: *Can a high velocity flume effectively separate juvenile salmonids by size and also eliminate passage delays by removing the holding areas, when large numbers (in excess of 1,000 fish /hour) are being bypassed?*

Project: Electronic recovery of PIT tags from piscivorous bird colonies in the Columbia River Basin

Piscivorous birds nesting on islands in the Columbia River Basin may prey upon millions of juvenile salmonids annually. The majority of the impacts are inflicted on salmonids that survive to the Columbia River estuary only to fall victim to piscivorous birds nesting on natural and dredge spoil islands in the estuary. Visual observation of feeding by birds does not provide stock-specific information on which fish are being consumed. To address this issue, we identify PIT tags deposited on the islands by birds that have preyed upon PIT-tagged juvenile salmonids. We use tag recoveries to estimate relative vulnerabilities along with minimum estimates of total predation for various salmon stocks. This project addresses RPA action 104 of the 2000 NMFS FCRPS BiOp.

Question: *What are the relative vulnerabilities of various salmonid stocks to avian predation in the lower Columbia River and estuary, and what are the minimum predation levels on PIT-tagged juvenile salmonids?*

2) Assessments of indirect hydrosystem effects - these studies assess indirect or delayed mortality that occurs after juvenile and adult salmon have passed through the FCRPS. Studies of indirect effects of the hydropower system provide linkage between conditions or effects experienced by salmonids prior to entering or after passing through the FCRPS in either an upstream (adults) or a downstream (smolts) direction. Implementation of actions and recommendations derived from assessments in this category will also produce incremental improvements in indirect survival to meet hydropower performance standards for these life stages as outlined in the 2000 NMFS FCRPS BiOp.

Project Title: Monitoring the migrations of wild Snake River spring/summer chinook salmon smolts

Before this study began in 1992, little was known about the migrational behavior and survival of stocks of wild Snake River spring/summer chinook salmon during their parr-to-smolt life stage. Regional fisheries managers relied on branded hatchery fish, index counts at traps and dams, and flow patterns for information to guide their decisions on operation of the FCRPS. Since 1992, this project and other related studies have provided a broad mixture of PIT-tag data on the Columbia River's wild and hatchery chinook salmon and steelhead stocks. These data are used to adjust or modify FCRPS operations such as spill, turbine operations, fish bypass operations, and fish transportation in real time. This ongoing study also collects water quality and other environmental data in natal rearing areas that are linked to wild fish movements, behaviors, and life-stage survival. Our goal is to determine with precision which factors exert primary control over migrational behavior and survival. With long-term wild fish detection and environmental data, accurate, real-time predictions of parr-to-smolt migrational behavior and survival for each wild stock may be possible. This will ultimately lead to a linkage between conditions in the natural-rearing environment upstream from the FCRPS and behavior and survival during migration through the FCRPS. This project addresses components of RPA actions 149 through 152 and 188, 190, and 193 in the 2000 NMFS FCRPS BiOp.

Question: *What are the migrational characteristics and estimated parr-to-smolt survival rates for stocks of wild Snake River spring/summer chinook salmon to Lower Granite Dam, and what environmental factors exert primary control over these parameters during the parr-to-smolt life-history stage?*

Project: A study to compare the long-term survival of yearling hatchery chinook salmon smolts with different juvenile migration histories

Direct survival of juvenile salmonids migrating downstream through the FCRPS has improved over the last 25 years to levels believed comparable to those occurring in the mid- to late 1960s, a time when stocks were at healthy levels. Despite these improvements, wild stocks have not recovered. One hypothesis is that recovery has not been achieved due to delayed, adverse effects of hydrosystem passage or barge transportation. These potential effects are currently referred to as "differential delayed mortality" for fish captured from the river and transported to below Bonneville Dam by barge and as "extra mortality" for fish remaining in the river throughout downstream migration. These mortalities are not evident during downstream migration or manifested as mortality during barge transport, so are presumed to occur in the estuary or ocean. This research will provide information on delayed mortality and disease susceptibility of yearling chinook salmon smolts experiencing different migration routes during passage through the hydropower system and explore causal mechanisms for differences among the groups. This project addresses RPA actions 47, 185, 189, and 195 of the 2000 NMFS FCRPS BiOp.

Questions: *Can differential delayed or extra mortality be observed during a 6-8 month extended rearing period in an artificial seawater system? Can differences in the level of mortality be observed in response to Listonella anguillarum challenge during seawater holding for groups of hatchery yearling chinook salmon detected passing through one versus two-to-five mainstem dam juvenile fish bypass systems or after having been transported with and without steelhead smolts present? If so, can the conditions/mechanisms causing differential mortality be identified?*

Project Title: Evaluation of the relationship among time of ocean entry, physical and biological characteristics of the estuary and plume environment, and SARs

Changes in direct survival of juvenile salmon during migration through freshwater do not appear to explain observed changes in SARs for groups of fish within or between years. Characterizing the conditions that smolts encounter in the estuary and nearshore ocean along with SARs on a temporal basis should allow us to identify which estuarine or ocean biological/physical conditions are correlated with high or low levels of survival in the ocean. Managers can potentially use this information to determine optimal times for hatchery releases, or whether to transport smolts from collector dams or allow them to migrate naturally to synchronize their arrival to the estuary and nearshore ocean during optimal conditions. This project addresses RPA actions 187 and 189 in the 2000 NMFS FCRPS BiOp.

Question: *Which biological/physical factors in the estuary and nearshore ocean affect survival of juvenile salmonids entering the nearshore ocean environment?*

3) Assessments of both direct and indirect hydrosystem effects - data derived from these studies inform estimations of direct survival during passage through the FCRPS plus provide information necessary to evaluate post-passage delayed mortality.

Project: Survival estimates for the passage of juvenile salmonids through dams and reservoirs of the lower Snake and Columbia Rivers

Survival estimates for juvenile salmonids that migrate through reservoirs, hydroelectric projects, and free-flowing sections of the Snake and Columbia Rivers are essential to develop effective strategies for recovering depressed stocks. Knowledge of the magnitude, locations, and causes of direct smolt mortality under present passage conditions, and under conditions projected for the future, are necessary to develop strategies that will optimize smolt survival during migration and to evaluate success in meeting the passage survival performance standards in the 2000 NMFS FCRPS BiOp. Total hydropower system survival estimates are also required for measuring the latent effects of hydropower system passage such as differential delayed mortality of transported fish. Finally, adult returns from fish marked as juveniles provide insight into potential differential delayed mortality from differences in stocks, fish size, and intra and interspecific competition to name a few. This work addresses RPA actions 185, 187, 189, 190, and 193 in the 2000 NMFS FCRPS BiOp.

Questions: *What is the survival for each juvenile salmonid species or stock migrating through individual reaches and the entire hydropower system of the Snake and Columbia Rivers each year? How do the juvenile migration and survival histories for species and stocks relate to subsequent adult returns?*

Project: Survival and migration timing of juvenile salmonids in the Columbia River estuary

Survival and migration timing of juvenile salmonids between Bonneville Dam and the mouth of the Columbia River are poorly documented. Precise estimates of survival and timing to the estuary are important for understanding the contributions of various enhancement projects. We developed a specialized surface pair-trawl to detect PIT-tagged fish in the upper Columbia River estuary downstream from all hydroelectric facilities and just prior to ocean entry. This has allowed us to acquire data for juvenile salmonids with minimal impacts to fish and to compare migration behavior, timing, and survival of various treatment groups through a variety of environmental conditions. This project addresses RPA actions 196 and 197 in the 2000 NMFS FCRPS BiOp.

Question: *How does the survival and timing of juvenile salmonids migrating through the Columbia River estuary relate to stock productivity?*

Project: A study to compare SARs of inriver migrating versus transported anadromous salmonids

Although smolt transportation has been studied intermittently for 3 decades and is currently used as one of several tools to mitigate for hydropower-related mortality during the juvenile life stage, there remains a great deal of uncertainty regarding the overall effects of this procedure and, ultimately, of its effectiveness. Addressing these uncertainties and concerns is necessary to assure that juvenile salmon are provided with the maximum potential to survive and to meet the passage survival performance standards in the 2000 NMFS FCRPS BiOp. Recent, large adult returns of PIT-tagged fish with known juvenile passage histories have revolutionized this research, providing the means to address previously unanswerable questions such as effects on homing and differential delayed transport mortality or 'D.' This mortality is similar to the extra mortality hypothesized to occur as a result of smolts migrating volitionally through the FCRPS. Since it hypothetically affects transported smolts after they are released below Bonneville Dam, 'D'-related mortality is additive to extra mortality. This study addresses RPA actions 45, 46, 47, 53, and 185 of the 2000 NMFS FCRPS BiOp.

Question: *What are the effects of transporting juvenile anadromous salmonids around the FCRPS?*

4) Technological development - research and development of electronic marking/tracking technology (e.g., radiotelemetry, PIT-tag systems) for use in hydrosystem-related studies.

Project: New marking and monitoring techniques for fish

The development of PIT-tag interrogation technology that will enable the collection of passage, timing, and survival data on all life stages of salmonids is critical for successfully carrying out the actions, research, and monitoring activities specified by the 2000 NMFS FCRPS BiOp. PIT-tag detection is a critical tool for performing the monitoring and evaluation of mitigation actions within the Columbia River Basin that the NWPPC Fish and Wildlife Program identifies as needed to support its adaptive management framework. Currently, over 60 Bonneville Power Administration funded projects utilize PIT tags, as do many projects funded by the U.S. Army Corps of Engineers. This project addresses RPA actions 50, 87, 104, 192, and 193 in the 2000 NMFS FCRPS BiOp.

Addressing the above RPA actions will require more detailed and specific information on juvenile and adult salmon migration, timing, and survival over essentially the entire duration of their life cycle. For example, expanding the technology will enable studies that will yield more accurate adult-conversion-rate estimates, estimates of the effects of transportation, and SARs. PIT-tag system development efforts include designing and fabricating the electronic components (transceivers and antenna systems) as well as conducting biological evaluations with fish to determine the tag-reading efficiencies of the systems. These tests also help determine the accuracy of the statistical models the fisheries community will rely on in the future.
Project: Estimation of juvenile salmonid survival through the lower Columbia River and estuary using miniaturized acoustic tags

Mortality in the estuary and ocean comprises a significant portion of the overall mortality experienced by salmon throughout their life cycle. The contribution of the Columbia River estuary as a source of mortality and as foraging habitat for outmigrant salmonids is poorly understood. While stream-type outmigrants (spring/summer chinook, coho, and sockeye salmon and steelhead) appear to move through the lower river and estuary relatively quickly, there is evidence that ocean-type outmigrants (fall chinook salmon) move through more slowly, possibly utilizing estuarine habitats for extended periods before moving into the open sea. The ability to evaluate individual fish use and behavior in the estuary is presently limited. Acoustically-tagged fish could provide this information, but present tag size limits their application to fish generally larger than 150 mm long. This study addresses RPA actions 47 and 158 through 164 in the 2000 NMFS FCRPS BiOp.

Questions: *What is the comparative survival through the lower Columbia River and estuary for outmigrant juvenile salmonid cohorts defined by ESU, run-rear type, or migration (passage) history? How does interannual variation in survival through the estuary relate to physical processes in the system (flow, temperature, bed load transport), and how can mortality be mitigated by management of the hydropower system? What is the contribution of the lower river and estuary as rearing or refuge habitat as exhibited by migration timing? What component of hydropower-system-related delayed mortality can be identified in the lower river and estuary?*

Program Organization

The Riverine Ecology Group is composed of three closely-related research programs - Fish Passage, Riverine Survival, and Migrational Behavior (Figure 1) - with support from Fish Ecology Division's Fisheries Engineering Program. More than 50 Group scientists (including fishery biologists, ecologists, biomathematicians, and electronics personnel) and support staff are engaged on a full-time basis in the ongoing riverine-ecology-related research activities described in this document. Funding for these activities is derived primarily from the Bonneville Power Administration Fish and Wildlife Program and the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, with some support from NOAA Fisheries.

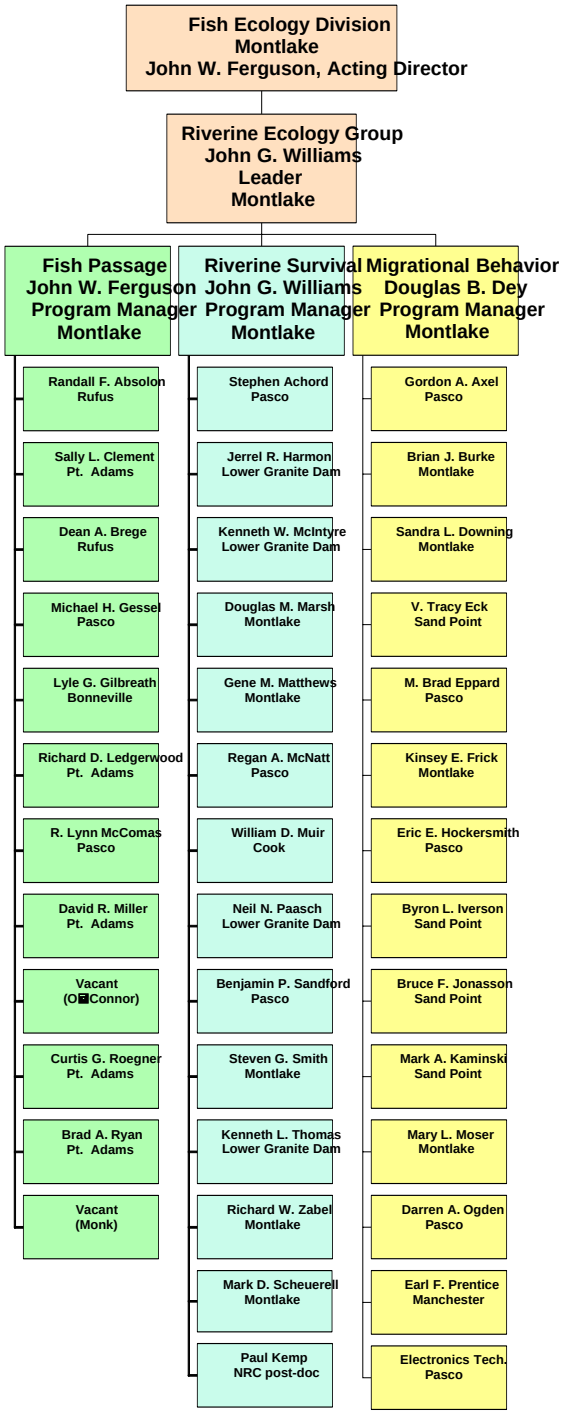

Figure 1. Organizational structure of the Riverine Ecology Group.

Prioritizing Research and Allocating Resources

Researchers at the NWFSC have been conducting studies for decades to identify the effects of dams on salmon. The highest priority research from the 1960s through the 1970s focused entirely on the direct or immediate effects of dam passage. Results of these pioneering efforts were instrumental in the identification and implementation of methods and procedures and the installation of passage facilities that substantially reduced direct mortality to juvenile and adult migrants. Moreover, most of this research has recently become relevant to salmon recovery issues under the ESA. While research to further reduce direct mortality continues, new research is beginning to take a more holistic, ecosystem-based approach in assessing the effects of the hydropower system on salmon. This new research paradigm emphasizes examining the effects of the hydropower system on a life-cycle scale. A key component of this work will be to continue to develop the tools and technologies that will be required to meet this new challenge.

Most of the Riverine Ecology Group's current research activities are funded through the Bonneville Power Administration Fish and Wildlife Program and the U.S. Army Corps of Engineer Anadromous Fish Evaluation Program, and priorities are established for individual projects through the extensive regional review process conducted under each of these programs. Within the Group, however, an interactive process has been established with the goal of defining and prioritizing potential future riverine ecology research in the areas of direct and indirect mortality and technological development that would be consistent with the NWFSC Salmon Research Plan.

From Riverine Ecology Group staff input, a long and diversified list of potential research ideas was generated and structured into two categories: 1) those with a biological basis, and 2) those related to technology and methodology needs (better equipment or analytical means) for improving research capabilities or products. Among the research ideas proposed and prioritized for each category were the following:

Research ideas with a biological basis. "We should conduct research to determine or examine..."

1. the mechanisms/causes of mortality on smolts in the early ocean phase.
2. the effects of hatchery fish on the survival of wild fish.
3. the impact of millions of shad on Columbia River salmonid survival.
4. the effects of reintroducing marine derived nutrients in streams.
5. what causes the large and rather sudden changes in smolt-to-adult returns (SARs) of transported fish.
6. how the long-term benthic invertebrate and plankton populations and water quality interact to influence salmon populations in the mainstem Columbia River and its estuary.
7. the effect on wild chinook salmon of separating, holding, and transporting them with steelhead and hatchery chinook.
8. the consumption rate of bird predators and its impact on fish stocks.
9. the ecological interactions between exotics (e.g., brook trout) and native stocks in freshwater spawning and rearing areas.
10. how parr-to-smolt growth rates relate to SARs.

11. the patterns and mechanisms of delayed effects of dams.
12. if passage of juvenile fish through bypass systems impacts their growth, behavior, physiology, or survival below Bonneville Dam.
13. the impacts of pinniped populations on survival of Columbia River salmon and lamprey.
14. how SARs of subyearling chinook salmon relate to migrational timing.
15. how juvenile salmonids respond to changes in flow fields.
16. parr-to-smolt survival dynamics above the hydropower system.
17. difference/impacts on fish passing through a full-flow bypass system vs. one with dewatering.
18. the temporal uses of freshwater spawning and rearing habitat, the estuary, and the early ocean and their relationship to survival.
19. why the ocean-age distribution of wild spring/summer chinook salmon has changed.
20. how to quickly and accurately estimate the abundance of wild salmon stocks in streams.
21. how river conditions affect survival of subyearling chinook salmon.
22. what happens to subyearling chinook salmon that overwinter in the hydropower system.
23. what is the contribution of large, 1-year-hold-over juveniles on SARs of fall chinook salmon populations.
24. the site-specific variability in parr-to-smolt survival and if it is affected by top down or bottom up processes or neither.
25. the survival of subyearling chinook salmon in the John Day Dam reservoir.

Ideas that will potentially help researchers through improved technology or methodology. "We need..."

1. a regional approach to assure juvenile salmon are PIT tagged in all river basins each year.
2. to develop maintenance friendly radio-tracking radar.
3. a low cost/high performance PIT-tag reader.
4. year-round monitoring of seawater conditions.
5. to develop a PIT-tag detector for use in spillways.
6. to develop a method to destroy PIT tags in the field (on bird islands specifically).
7. to develop separation-by-code for estuary PIT-tag sampling devices.
8. to investigate non-intrusive passive methods to detect non-marked fish.
9. to develop improved PIT-tag reader performance with DSP.
10. to develop better encapsulation material for PIT tags (radio or acoustic).
11. to develop new statistical models that extend Cormack-Jolly-Seber models to include time explicitly.
12. to understand loss of PIT tags (shedding) in wild parr.
13. to investigate means to improve PIT-tag retention in adult salmonids.
14. to develop PIT-tag detectors that are not as manpower intensive for use in estuaries.
15. to investigate if species can be identified by spectral analysis of scale patterns in mature fish in ladders.

The complete lists of potential research ideas, while lengthy, are not considered all-inclusive; additional questions will undoubtedly arise as results from ongoing studies continue to emerge. However, the list does include a broad array of topics for future scientific inquiry associated with

both direct and indirect hydropower-related effects and with the development of new tools and technologies that will be required to conduct many of these studies.

Past Riverine Ecology Group hydropower-related research has produced a tremendous volume of information related to the effects of dams on salmon together with a wealth of new knowledge on the biology and ecology of the species. Most of the information produced is directly relevant to management and recovery of ESA-listed salmon stocks of the Columbia River Basin. Current Group staff are committed to continuing this legacy of applying sound scientific principles and innovative methodology in the search for solutions to problems that provide immediate and long-term benefits to the resource and the nation.