4 Scientific Foundation for Recovery

This chapter provides the biological and ecological basis for recovery planning. The problem of diminished fish runs, the recovery planning process, the species of interest, and the factors limiting those species, have been described in the preceding chapters and in the Technical Appendices. Now, the next step is to lay out the biological basis for establishing the subsequent recovery objectives, regional strategies and measures, subbasin restoration actions, and an implementation plan. This chapter addresses extinction processes, the principles for biological recovery, the salmonid life cycle as an integrating model for recovery, the role of science, and the issue of managing uncertainty.

4.1 Understanding Extinction and Recovery

To recover salmon, it is particularly helpful to understand what extinction is and why fish go extinct. *Extinction* typically refers to the irreversible disappearance of a species, subspecies, or, in the case of the Endangered Species Act, a "distinct population segment." For Pacific Salmon, a distinct population segment has been defined as an evolutionarily significant unit (ESU) (Waples 1991). Salmon ESU's may contain multiple "demographically independent" populations that return to different areas of the ESU (McElhany et al. 2000). Extinction of an ESU occurs when all of the component populations are extinct. The ESA defines extinction risk at two levels: *endangered* which is to be in danger of extinction, and *threatened* which is likley to become endangered within the foreseeable future. All listed lower Columbia salmon and steelhead ESUs are classified as threatened.

Extinction results from the interaction of fish population processes and external factors to reduce population size to critical low levels that are no longer self-sustaining. Small populations are subject to a variety of problems that may preclude recovery, such as inability to find mates, skewed sex ratios, increased predation effects, genetic inbreeding, and risks of extinction from natural downturns in survival conditions or catastrophes. Functional extinction typically occurs at population sizes greater than zero when numbers fall to critical low levels from which they cannot recover.

A species or ESU that has a low risk of extinction is typically referred to as *viable*. Viability is also equivalent to having a high likelihood of long-term persistence. With relation to the definitions in the ESA, a viable ESU is one that is not threatened or endangered with extinction. In this plan, "recovery" refers to the restoration of salmon and steelhead status to some level at or above viability represented by the gray area between V*iable* and *Capacity* in Figure 1.

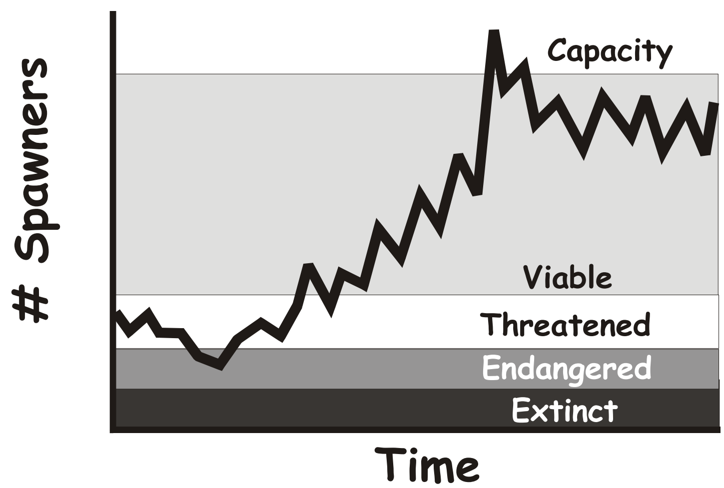

Figure 1. Continuum of abundance levels corresponding to potential fish recovery goals.

Capacity represents the maximum number of individuals that available habitat and resources can support, and is at the opposite end of the spectrum from extinction. Capacity is expressed through density-dependent population limits that reduce survival, growth, or reproduction via competition or other feedback mechanisms. Capacity may change as habitat quantity or quality increase. Current capacity of existing habitat conditions can be distinguished from potential capacity if conditions were improved. Average abundance may be less than the hypothetical habitat capacity as a result of mortality factors. Populations are typically viable at levels below the potential capacity of a system. Thus, viable species may often be recovered without restoring the ecosystem to its hypothetical capacity for salmon and steelhead as represented by pristine, historic conditions. However, a population may not be viable at the existing habitat capacity where numbers are constrained by low capacity of a small area with poor quality habitat.

Specific Recovery goals could be defined anywhere within the range between viable and the capacity of a fully restored habitat. Under the ESA, recovery of an ESU might be reached at the minimum viability threshold while the recovery vision in this plan of healthy, harvestable populations may require improvement to population levels greater than minimum viability.

4.2 Considering Biological and Social Values

Science can provide guidelines for the amount of risk that a species may be exposed to (i.e., extinction risk) but it is not the only factor in determining a vision for recovery. The development of recovery goals will require decisions by policy makers to balance both biological and social values. The vision may involve a description of an ESU's abundance and productivity, but it will also include choices about human-induced mortality and the cost to various sectors of society. Many combinations of actions could be chosen that would lead to recovery. Yet, the decision on which specific blend of actions to take will have substantial social, economic, and cultural costs and benefits.

The real pitfall occurs when the biological and social tradeoffs implicit in various standards are not clearly articulated and/or distinguished. These pitfalls can lead to unrecognized conflicts of interest, especially when social values are represented in purely biological terms. The line between biological and social considerations can sometimes be difficult to distinguish, especially because social values can often be expressed in biological terms. For instance, where the predominant social value derives from fishery benefits, a biological standard equivalent to maximum or optimum sustainable yield might be considered. Where the predominant social value derives from water use rather than fishery benefits, a biological standard equivalent to minimum population viability might be considered. Where ecological, intrinsic, or cultural fish values predominate, a biological standard equivalent to pre-development capacity might be considered. Considerations are also complicated by the broader role of salmon within a complex ecosystem. For instance, salmon provide food for wildlife and marine-derived nutrients that substantially affect plant and animal productivity, and even subsequent salmon production, in many watersheds.

4.3 Characteristics of Healthy Species

Fish go extinct when numbers fall to critically low levels from which they cannot recover. However, underlying population processes are the ultimate determinants of whether populations are viable. Key population parameters include abundance, productivity, diversity, and spatial structure. Each of these parameters is intimately interrelated. NOAA fisheries has incorporated these parameters into a Viable Salmonid Population (VSP) concept (McElhany et al. 2000) that provides useful guidelines for population viability. A Willamette/lower Columbia Technical Recovery Team proposed a series of viability criteria based on VSP guidelines (McElhany et al. 2003). These criteria are the basis for the viability recovery objectives described later in this plan.

4.3.1 Abundance

Abundance refers to the population sizes needed for recovery to levels that will ensure long-term persistence and viability. This population size depends on the buffer needed to avoid the risks of extinction in the face of normal environmental variation. Ideally, two determined fish of the opposite sex could forestall extinction but in practice, many more are needed to ensure population persistence and provide the raw material for recovery. Although there is little agreement on where functional extinction occurs and what population level is viable, NOAA

Fisheries generally assumes viability with at least 500 fish to ensure that critically low numbers do not result from normal environmental variation.

Small population sizes are subject to a variety of factors that affect viability (Lande and Barrowclough 1987, Nelson and Soulé 1987, Lynch 1996). Small numbers risk genetic bottlenecks that reduce diversity. The genetic diversity of salmon populations maximizes population persistence and productivity by allowing the salmon to capitalize on a wide range of habitats and environmental conditions. Small numbers also increase chances of inbreeding, possibly resulting in severe genetic side effects (e.g. expression of deleterious recessive genes). Small numbers increase demographic risks where scattered fish are unable to find mates, sex ratios are skewed by chance, or numbers are too few to escape predators (Hilborn and Walters 1992, Courchamp et al. 1999). Small numbers may also increase risks of extinction from natural downturns in survival conditions or catastrophes (e.g., poor ocean conditions, volcanoes, floods, chemical spills, dam failures, etc.) (Lawson 1993).

Reduced productivity at low densities is often referred to as depensation (also termed “Allee effects” or “inverse density dependence”) (Figure 2). McElhany et al. (2000) noted that depensation is a destabilizing influence at very low abundance and can result in a spiraling slide toward extinction. This downward spiral is sometimes referred to as an “extinction vortex.” The population size that can lead to this downward spiral is termed the “quasi-extinction” level. Because it is often unclear where this functional extinction level occurs, quasi-extinction is defined as a low abundance that does not guarantee extinction but from which recovery cannot be assured.

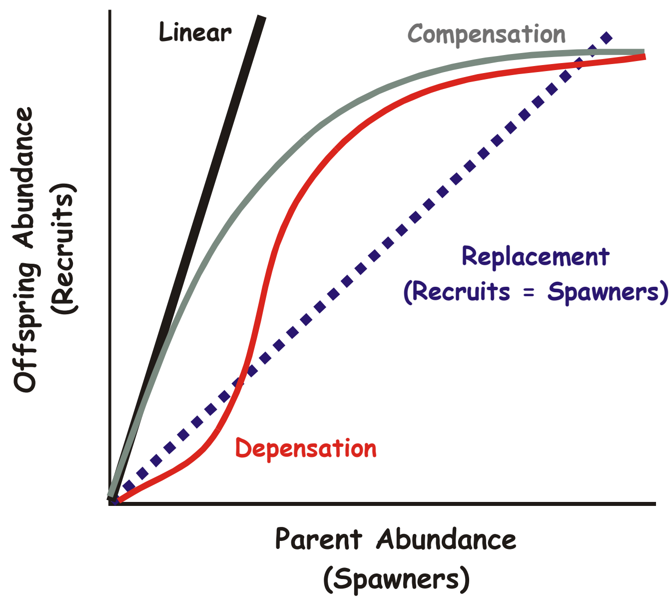

Figure 2. Reduced productivity (depensation) that results from small population processes and at high population sizes that results from competition for limited resources (compensation).

McElhany et al. (2000) identified key characteristics of viable and critical population abundance guidelines. Viable population size guidelines are reached when a population is large enough to: 1) survive normal environmental variation, 2) allow compensatory processes to provide resilience to perturbation, 3) maintain genetic diversity, 4) provide important ecological functions, and 5) not risk effects of uncertainty in status evaluations. Critical population size guidelines are reached if a population is low enough to be subject to risks from: 1) depensatory processes, 2) genetic effects of inbreeding depression or fixation of deleterious mutations, 3) demographic stochasticity, and 4) uncertainty in status evaluations.

Although biologists generally agree that extinction risks become increasingly acute as numbers decrease, there is little agreement on where functional extinction occurs and what population level is viable. Various viability and critical population size guidelines have been identified based on largely theoretical considerations for genetic and demographic risk. For instance, numbers needed to minimize genetic risks typically range from 30 to several thousand individuals based on theoretical models of genetic characteristics, effective spawner population sizes, and genetic diversity (Franklin 1980, Soule 1980, Allendorf and Ryman 1987, Lynch 1990, Waples 1990, Thompson 1991, Gabriel and Burger 1992, IUCN 1994, Lande 1995, NMFS 1995, Allendorf et al. 1997, McElhany et al. 2000). Thompson (1991) identified a 50/500 "rule of thumb" where 50 fish is a short term-effective population size which limits inbreeding and 500 is a long-term effective population size which maintains genetic variability. Recent viability analyses by NOAA Fisheries generally assume a 50-fish quasi-extinction threshold and produce minimum population viability levels of at least 500 fish to ensure that critically low numbers do not result from normal variation associated with environmental variation (McElhany et al. 2003). Uncertainties in actual minimum viable population sizes will require definition of recovery standards that incorporate appropriate safety factors.

4.3.2 Productivity

Productivity refers to a populations' ability to replace itself and reflects a populations' ability to rebound from a low level to the equilibrium population level. Productivity can also be defined in terms of intrinsic population growth rate independent of density dependent population regulating mechanisms. Highly productive populations produce larger numbers of juveniles or recruits per parent and can more readily rebound from low levels following perturbation. Less productive populations produce smaller numbers of offspring or recruits per parent and rebound more slowly or not at all. Highly productive populations generally sustain larger average numbers then unproductive populations. Productivity is directly related to density independent mortality or survival rates. Greater mortality rates (and lower survival rates) will proportionately reduce population productivity.

Extinction risks depend on the combination of abundance and productivity. While species go extinct when numbers fall to critical low levels, productivity is the engine that regulates risks associated with low numbers. Risks might be much less for a highly productive population even at low spawning escapements than for a larger population where productivity is low. Species can be predisposed to extinction by low population sizes that reduce population productivity and resilience well before extinction actually occurs. Cumulative effects of periodic poor spawning escapements may increase chances of future extinction even where numbers temporarily rebound (in good ocean years for instance) (Lawson 1993).

Productivity guidelines for viability are reached when a population's productivity is such that: 1) abundance can be maintained above the viable level, 2) viability is independent of hatchery subsidy, 3) viability is maintained even during extended sequences of poor environmental conditions, 4) declines in abundance are not sustained, 5) life history traits are not in flux, and 6) conclusions are independent of uncertainty in parameter estimates (McElhany et al. 2000).

4.3.3 Diversity

Diversity refers to individual and population variability in life history, behavior, and physiology. Diversity traits include some that are completely genetically based and others that vary as a result of a combination of genetic and environmental factors. Diversity is related to population viability because it allows a species to use a wider array of environments, protects species against short-term spatial and temporal changes in the environment, and provides the raw material for surviving long-term environmental changes (McElhany et al. 2000). Correlations between diversity and population productivity have been observed in many populations (NRC 1996). In general, greater diversity, productivity, abundance, distribution, and viability all go hand in hand.

Once lost, the unique features of each population may be gone forever. Preservation of unique groups of salmon populations is a central tenet in the development of recovery standards. Salmon populations are often organized into groups for various management purposes. Populations within a species that have similar life histories are often referred to as “races” (e.g. winter steelhead, spring chinook, early run “tule” fall chinook). Populations within races that are grouped together for harvest management purposes are referred to as “stocks”. When salmon, steelhead or trout species are listed as threatened or endangered under the ESA, populations within a region are grouped into ESUs, which are the organizational groups to which recovery standards are applied.

Each salmon species is comprised of many related but different populations, each of which is specifically adapted to the unique local conditions of their natal watersheds and the other habitats they experience during their migratory life. Local adaptations have been naturally selected over hundreds of generations to optimize success under the prevailing conditions. Local populations are typically more productive in their native watersheds than populations introduced from other areas. Salmon that stray or are transplanted among widely separated watersheds do not fare as well as the native stock. Thus, a population of wild coho salmon from the lower Columbia River cannot be replaced with wild coho salmon transplanted from Puget Sound. Differences among populations in adjacent watersheds may be small where habitat conditions are similar but differences typically increase with distance (Riddell 1993).

Adaptations may be expressed in a variety of forms such as run timing that returns adults to streams exactly when spawning conditions are optimal or that allows smolts to arrive at the estuary during the critical physiological window for transition from fresh to salt water. Local adaptation is made possible by the homing of salmon across thousands of miles of ocean and river to spawn in the same river or stream where they were born. Recent studies have shown that homing may be so exact that many salmon even spawn in the same river bend or riffle where they originated. Local adaptation and homing go hand in hand to give each salmon the best chance for reproductive success by returning to the exact conditions to which they are best suited. The degree of difference among populations can often, but not always, be identified by genetic analysis.

According to McElhany et al. (2000), diversity guidelines for viable salmonid populations are reached when: 1) variation in life history, morphological, and genetic traits is maintained, 2) natural dispersal processes are maintained, 3) ecological variation is maintained, and 4) effects of uncertainty are considered.

4.3.4 Spatial Structure

Spatial structure refers to the amount of habitat available, the organization and connectivity of habitat patches, and the relatedness and exchange rates of adjacent populations. Large habitat patches or a connected series of smaller patches are generally associated with a wider species distribution and increased population viability.

Spatial structure of a population is closely related to habitat quantity and quality. Salmonids typically use habitat patches of variable quality and salmon distribution may ebb and flow in response to normal environmental variation. In years of high ocean survival and high numbers, distribution may expand as fish fill the optimum habitats and spread out into other areas of suitable habitat. In years of low ocean survival and low numbers, distribution may contract into areas of high quality habitat. Marginal habitats may support fish under good ocean survival conditions but are not productive enough to sustain numbers under poor ocean survival conditions.

Spatial structure guidelines for viability are reached when: 1) the number of habitat patches is stable or increasing; 2) stray rates are stable; 3) marginally suitable habitat patches are preserved; 4) refuge source populations are preserved, and 5) uncertainty is taken into account (McElhany et al. 2000). The spatial distribution and productive capacity of freshwater, estuarine, and marine habitats should be maintained sufficiently to support viable populations. The diversity of habitats for recovered populations should resemble historic conditions given expected natural disturbance regimes (e.g. wildfire, flood, volcanic eruptions, etc.). Historic conditions represent a reasonable template for a viable population; the closer the habitat resembles the historic diversity, the greater the confidence in its ability to support viable populations. At a large scale, habitats should be protected and restored, with a trend toward an appropriate range of attributes for salmonid viability.

4.4 Natural Populations Spawning Naturally

Recovery ultimately depends on naturally-produced fish reproducing naturally. Natural habitats and wild populations are the only demonstrated alternative for guaranteeing long term sustainability. This biological fact is unchanged regardless of how current hatchery controversies play out or how NOAA classifies the significance of hatchery salmon stocks in salmon recovery. By both design and happenstance, fish produced in hatcheries sometimes spawn in the wild with naturally-produced fish. Numbers and effects of naturally-spawning hatchery fish vary widely among species and populations depending on hatchery proximity and practices. Some natural spawning populations include large fractions of hatchery fish. Other populations are largely free of hatchery influence. In the lower Columbia River, most tule fall chinook and coho have been heavily hatchery influenced, spring chinook populations rely on hatchery production, steelhead have been variously affected, and chum, bright fall chinook, and bull trout are largely free of hatchery effects.

Effects of natural spawning by hatchery fish have been extremely controversial (see Hatchery Section in Chapter 3). One issue has been the potential for reduced fitness and viability of some wild populations as a result of the introduction of domesticated or non-local hatchery fish that are ill-suited to local conditions. A second issue is the difficulty of accurately measuring numbers and productivity of wild populations where hatchery influence is significant. It can be especially difficult to distinguish situations where hatchery contributions to natural spawning reduce wild population productivity because of fitness effects or supplement wild population productivity because of high hatchery survival rates. The significance of each of these effects is in dispute but hatcheries clearly pose risks to population viability under certain situations.

Populations maintained through a continuing influx of hatchery fish are not sustainable if they might become extinct whenever the hatchery subsidy is removed. No hatchery has demonstrated the ability to preserve a full spectrum of wild population diversity and life history traits in the long term over multiple generations. This is not to say that hatcheries are incapable of long-term sustainability, but merely that significant uncertainty exists. Hatchery subsidies of wild populations also mask true status and can lead to a reduced imperative for protection and restoration of habitats critical to natural production. Gradual erosion of adaptive population diversity in the hatchery and coincident declines in natural population productivity are a formula for species extinction over the long term. Hatcheries depend on a continuing commitment of funding and other resources which places the long term viability of a hatchery-supported stock at the whims of political processes and competing funding priorities.

Hatcheries also provide significant fish population benefits in some circumstances and will be a critical tool for preservation, reintroduction, and supplementation over the short term. Many remnants of many lower Columbia River salmon currently exist only in hatcheries. Conservation values include preserving genetic stocks where habitat is gone, reintroducing fish in areas where habitat has been restored, and bolstering survival to offset survival bottlenecks.

This plan recognizes that current conditions and constraints on habitat restoration in some areas will require recovery using a combination of natural only and natural/hatchery populations. Hatcheries will continue to be operated for both conservation and fishery enhancement purposes and hatchery fish will continue to spawn naturally in some watersheds. Some populations will consist entirely of naturally-produced fish segregated from significant hatchery influences. Other populations will include natural and hatchery-produced fish from carefully integrated hatchery programs. Hatchery programs will need to be shaped to minimize risks while taking advantage of very real benefits. Integrated hatchery programs will be particularly important for preservation, reintroduction, and supplementation in the interim period until habitats that can sustain viable natural populations are restored. NOAA Fisheries hatchery policies will provide guidance on the role specific hatchery stocks may play in salmon recovery.

Hatcheries will continue to serve both production enhancement and fisheries enhancement purposes for the foreseeable future. Even after viable ESUs of salmon are recovered, hatcheries will be needed to provide fish for fisheries as mitigation for permanent loss of habitat and hydrosystem mortality. Fish populations in some areas will continue to include significant numbers of hatchery fish. It will not be necessary to exclude hatchery fish from every population in order to meet ESU recovery goals or to demonstrate individual population viability. Not every population needs to be restored to a high level of viability for ESU recovery. Viable populations capable of being naturally self-sustaining can also be restored in selected areas even when hatchery fish spawn in the wild. Natural fish population accounting practices will need to make the necessary adjustments to accurately represent the wild component independent of significant hatchery fish effects, thus providing an accurate assessment of the ability of the habitat conditions to support wild populations.

4.5 In-basin and Out-of-basin Influences

Effective recovery planning must consider in-basin and out-of-basin influences that affect salmon throughout their life cycle. Salmon numbers and population dynamics are affected by the interaction of a wide variety of human and natural factors operating over the salmon's far flung migration from freshwater streams, through the mainstem Columbia River and estuary, into the far reaches of the North Pacific ocean, and back again. Failure to consider all factors affecting the life cycle can overlook key limitations or changes in one area that potentially offset gains in other areas. For instance, it would be of little benefit to improve tributary habitat conditions and productivity if gains there were offset by increased mortality in the mainstem, estuary, and ocean. Conversely, improvements in multiple areas can provide compounding benefits over the course of the life cycle. For instance, benefits of tributary habitat improvements are enhanced where downstream improvements also improve survival such that the full effects of tributary improvements may be realized.

A comprehensive analysis of all factors limiting recovery helps ensure equitability in balancing the costs of salmon recovery among different stakeholders. Different combinations of stakeholders affect salmon in different areas. Without a systematic treatment for weighing impacts, discussions of site and action-specific recovery actions are easily confounded by counterproductive finger-pointing.

A fish life cycle focus provides a systematic means of effectively relating fish-specific recovery goals to factors limiting recovery and potential restoration actions (Figure 3). A life cycle focus identifies life stage-specific numbers, birth rates, and death rates that describe the biological processes regulating fish status. Stage-specific numbers and rates provide a consistent way to estimate fish effects from the impacts of a variety of stage-, time-, and area-specific factors that limit recovery. In addition, a life cycle approach provides the means of distinguishing wild and hatchery fish and explicitly evaluating the effects of their interactions. Finally, a life cycle focus incorporates the abundance and productivity elements of the NOAA Fisheries VSP approach.

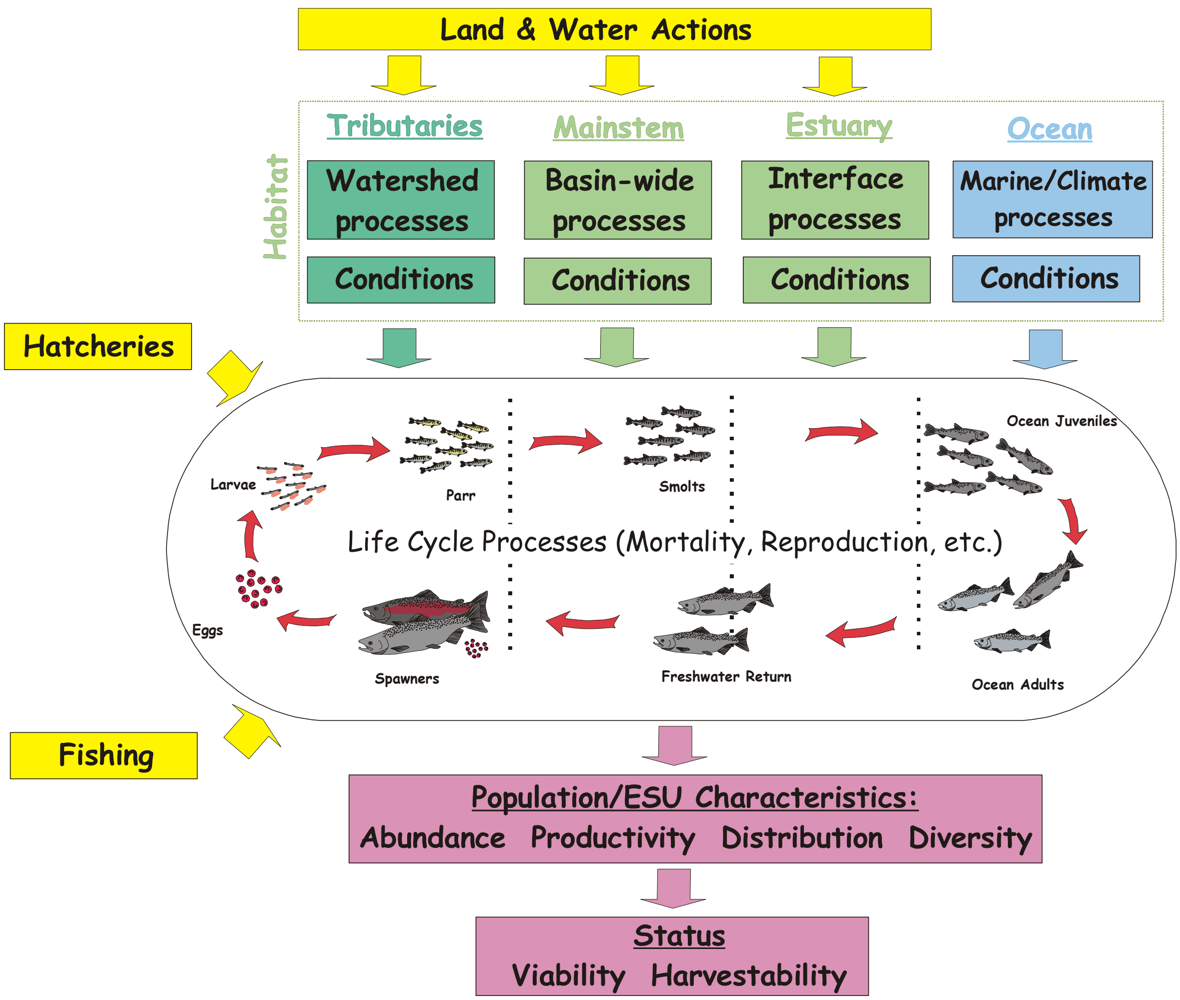

Figure 3. The basic salmonid life cycle, indicating how habitat, including dams, fishing, and hatcheries impinge on survival at various stages, and how this integrated process affects the viability and surplus production of the populations.

4.6 Ocean and Climate Variability

The comprehensive treatment of factors limiting fish recovery also warrants careful consideration of other influences that are beyond our control. These include environmental conditions such as ocean and climate cycles that can cause dramatic variation in natural mortality rates. The effects of human-caused mortality and restoration measures must be considered in the context of these significant and highly variable survival rates.

Large fluctuations in salmon numbers during the last few years have highlighted the importance of ocean conditions in regulating salmon survival, productivity, and abundance. Twenty years ago fish scientists generally regarded the ocean as a vast and consistently productive environment for salmonids. However, frequent El Niño circulation patterns over the last 20 years have demonstrated that environmental conditions are much more dynamic than previously thought. Ocean conditions are not randomly sorted – poor years tend to occur in groups as do good years. Transitions between good and poor regimes occur unpredictably and are obvious only in hindsight. Low salmon survival during El Niño years results in population declines and critically low numbers. Abnormally good salmon survival in cool, wet years following large El Niños results in temporary population increases and record returns like those seen in 2001–03.

Periodic poor ocean cycles are the stressor that bottoms out populations compromised by habitat degradation and overuse (Lawson 1993). Downturns challenge the persistence and health of impaired salmon populations and can precipitate irreversible consequences where fish have been heavily impacted by human-induced factors. Healthy populations are able to ride out the periodic declines without lingering effects. Large numbers, high inherent productivity, high diversity, wide distribution all help sustain viable populations in the face of normal environmental variability.

Recovery planning analyses must consider variable ocean conditions as an uncontrollable backdrop to the effects of human activities on salmon. Ocean conditions have always varied and always will. Just because salmon numbers decline during poor survival periods should not mean fish are threatened or endangered with extinction. Alternatively, high numbers returning in good ocean years does not mean that threatened or endangered fish are recovered. Recent large salmon runs suggest that we may have entered a period of better-than-average ocean survival conditions. Rather than relaxing the need for salmon recovery, this pattern provides an opportunity to implement substantive changes for population rebuilding needed to withstand the next down cycle. Habitat and demographic improvements require time to become effective and may come too late if the next period of decline is the one from which the population cannot recover.

4.7 Linking Actions to Limiting Factors and Threats

Species declines can be attributed to certain limiting factors and threats once they have been identified. Recovery actions can then be developed based on those limiting factors and threats. Once the factors that a species' decline have been adequately mitigated, it is likely that the species will recover.

Factors and threats include a wide spectrum of human-induced mortality factors that affect fish throughout their life cycles. These factors are sometimes referred to as the '4 Hs' (hatcheries, harvest, hydropower, and habitat), but also include ecological changes like predation and competition from introduced species. The '4-H' label oversimplifies the complex of direct and indirect relationships and the relative impacts of the different factors that affect fish. However, reference to this convenient characterization highlights the need to treat all factors limiting recovery in a similar and comprehensive fashion. Effective recovery planning must equitably address all human-induced mortality factors that limit fish status and have contributed to fish declines. This plan describes how harvest, hatchery, hydropower, habitat and ecological factors have influenced key fish species in the past, their current impacts, the anticipated trajectory of these influences, and actions to reduce corresponding threats.

The planning recovery planning process relates fish goals and status to specific actions, areas, and time periods. The plan weighs all the human-induced effects on mortality at the various life stages, identifies how mortality can be reduced overall, and determines how the distribution of mortality may be changed among life stages to meet delisting and other social goals. Analyses can identify the relative contributions of habitat, hatchery, and harvest impacts but should also relate necessary changes to specific activities that can produce the desired effect. Specific programs and activities need to be identified because that is the level at which changes will be implemented. Actions that are not specific will fail to provide a clear blueprint for recovery implementation and risk failure to ensure accountability. Additionally, specific management actions are required by the ESA for recovery plans.

Specificity of actions in time and space are important. Viability risks are extremely sensitive to implementation schedules, especially where small population numbers increase exposure to chance extinction events. Thus, fishing strategies that reduce impacts in low run years but increase catch in large run years might substantially reduce the risks of a fixed fishing rate strategy while optimizing use benefits. Similar suites of measures can also produce substantially different outcomes if implemented in different areas. For instance, concentrating aggressive habitat restoration actions in high quality habitats where fish production is already significant may provide relatively little benefit. These areas might be high priorities for protection but low priorities for restoration. Within marginal areas, systematic analyses can help distinguish smaller subareas for priority restoration where modest investments can restore significant fish production, from severely degraded sites where similar investments would be relatively ineffective.

4.8 The Role of Science: Guidance with limitations

Developing an effective recovery plan requires systematic analysis of questions related to goals, status, strategies, and proposed actions based on the best available scientific methods and data. Effective planning depends on our ability to answer five fundamental questions: 1) where are we now; 2) how did we get here; 3) where do we want to go; 4) how do we get to where we want to go; and 5) how do we know when we get there? While general planning questions can be simply stated, answers can be difficult and complicated. Fish are affected by a complex array of factors and our understanding of the relationships among these factors is highly indistinct. Efforts are complicated further by the need to consider multiple species, a large and diverse area, and a patchwork of overlapping jurisdictions and constituencies. Fundamental questions also need to be answered at several different levels in terms of fish populations and ESU status, fish life cycle parameters such as mortality rates, factors for decline, and programs by which actions may be affected.

Expectations for recovery must be tempered by our imperfect understanding of the complex interaction of fish, limiting factors, past and future human activities, both positive and negative, and the difficulties of collecting sufficient data. Analytical approaches that systematically relate fish status to underlying causal factors and actions can be extremely powerful tools for evaluating recovery goals and actions. Systematic analyses based on the scientific method facilitate the study, description, and prediction for complex systems and promote good decision-making (Grant 1986).

All scientific analyses and models are abstractions of reality subject to varying degrees of uncertainty. Systematic scientific analyses will help to reduce uncertainty, but cannot eliminate it. Clear paths for action will be provided by some analyses where relationships are well understood and data are substantial. Analyses in the gray areas may provide only partial answers and general compass directions. A gap will remain between what can be known and what cannot. Monitoring and evaluation will provide feedback for management adjustments, as well as identification of the most important data gaps and/or weaknesses, but the conundrum of decisions without full information will continue. Thus, science can continue to support recovery planning but will not supplant the need to make difficult policy decisions with less than complete information.

Science ultimately provides a prescription for recovery that includes a picture of what constitutes a viable population and ESU, an inventory of significant limiting factors and threats, a list of effective actions that address factors and threats, and some sense of the order of magnitude of improvements and actions needed to approach recovery. Science does not provide a cookbook recipe that details exactly how much of each action will be required to ensure recovery. It describes the cake and tells us the ingredients but does not always reveal the exact portions of each ingredient or how long ingredients need to bake. Science provides a direction for recovery, bounds the range of expectations, identifies critical first steps, and flags faulty logic and assumptions.

4.9 Dealing with Uncertainty

Incomplete human understanding of biological systems, and the effects of human activities and management practices on those systems, necessarily results in uncertainty about the outcomes of the Management Plan. These inherent uncertainties complicate the process of deriving, deducing, inferring, or interpolating estimates needed to characterize fish status and limiting factors, and to explicitly identify a level of effort and investment that will assure recovery. No amount of research or evaluation can be expected to entirely eliminate uncertainties. The key to effective analysis in an uncertain world is to frame an approach that recognizes that uncertainties will always remain in specific data, analyses, and assumptions. Uncertainties can be addressed by a variety of methods, all of which are incorporated into this plan:

- Explicitly identifying uncertainties and transparently communicating methods, strengths, and limitations of each analysis.
- Incorporating known uncertainties into the risk analyses. For instance, uncertain ocean survival can be incorporated as a random variable into a population viability modeling framework for integrated fish life cycle analysis to estimate extinction risks. Uncertainty in any population process or limiting factor can be captured similarly.
- Incorporating corroborative analyses to validate key conclusions independently.
- Using analyses to identify the risks associated with key uncertainties. Sensitivities of results to critical assumptions and uncertainties will be described for each analysis in the form of

testable hypotheses that may be addressed with future monitoring and evaluation through adaptive management.

- Identifying conclusions based on the weight of all evidence, rather than any specific analytical result, and with appropriate safety margins to buffer risks.
- Including substantive recovery strategies and measures that address every significant liiting factor and threat.
- Including safety factors into the plan to provide a buffer to offset the effects of uncertain or faulty assumptions. Safety factors may be included in biological objectives to target higher levels of recovery than minimum requirements in case efforts for some populations fall short.
- Incorporating a strong monitoring, research, and evaluation program that provides an information feedback loop for modifying prescribed actions. Future monitoring and analysis of lower Columbia salmon and steelhead populations is of utmost importance because, without sufficient data, it will be impossible to determine whether remedial actions are helping. Observed population trends, whether increasing or decreasing, may result from restoration activities, management changes, natural variation, or some combination of effects.