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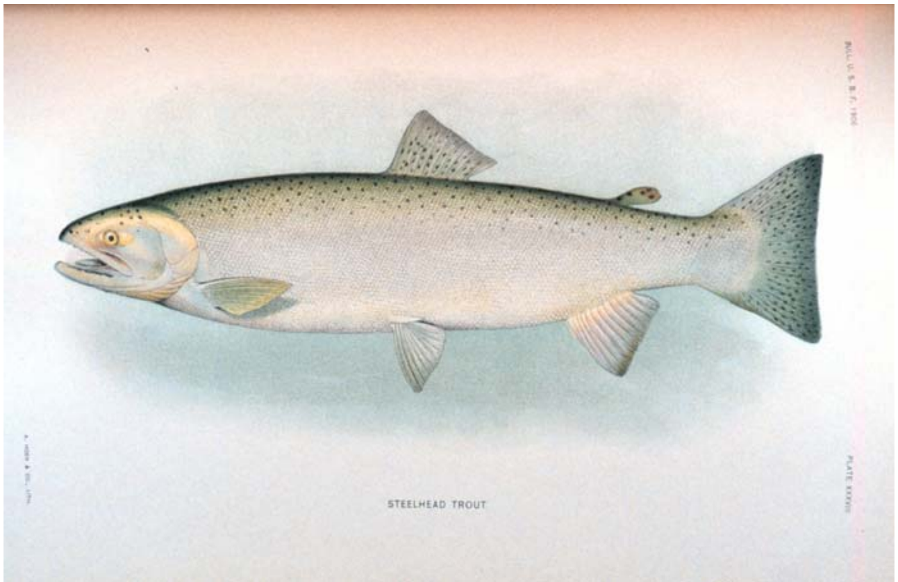

Oncorhynchus mykiss:
Assessment of Washington State's Anadromous Populations and Programs

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Preface

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The development, drafting, and review of this report has proceeded through a number of steps, many of which relied on entities outside of WDFW. The Hatchery Scientific Review Group, Steelhead and Cutthroat Policy Advisory Group, the Steelhead Summit Alliance, and some staff of western Washington tribes assisted in the identification of key questions and the development of a report outline. Previous drafts of this report have been reviewed by WDFW staff, the Steelhead and Cutthroat Policy Advisory Group (two occasions), and some staff of western Washington tribes. However, tribal staff assistance in the preparation and review of this report does not necessarily imply tribal agreement with report content.

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Executive Summary

From cold mountain streams to the Pacific Ocean, the waters that shape the landscape of the Pacific Northwest also define the lifecycle of native steelhead (*Oncorhynchus mykiss*). Fast and sleek, steelhead cover thousands of miles from the time they leave their natal streams for the open ocean, then return again – often more than once – to spawn. Known for their explosive power and their preference for fast-flowing rivers, these fish have long held a special place in the lore of Northwest anglers. Traditional Native American culture in the Pacific Northwest is also inextricably tied to steelhead and other anadromous salmonids. For many Northwest Indian peoples, these fish have always provided an essential source of food, a focal point of religious life and a central commodity for trade and commerce. A Northwest icon, steelhead were designated by the legislature as the Washington State fish in 1969.

Steelhead have also been the focus of significant controversy. Construction and operation of dams, habitat degradation, hatchery programs, and fishing have all sparked long and continuing debates, blue-ribbon panel reviews, and research papers. Two reviews of particular note -- “Upstream: Salmon and Society in the Pacific Northwest”, by the National Research Council, and the Royal report, commissioned by the Washington Department of Game in 1973, have had a substantial impact on fishery management in the Pacific Northwest.

Why, in the face of the already extensive literature, have we invested substantial time and energy in the development of yet another report? This report is not simply an assessment of Washington’s steelhead populations or a critique of current management practices. Rather, it is designed to lay the foundation for the development of improved management plans, scheduled to begin this year, that assure the productivity of Washington’s steelhead for future generations. To achieve this goal, we established four primary objectives for this report:

1) **Promote Progress in the Continued Evolution of Fisheries Management.** The underlying paradigm for fishery management is rapidly shifting from an approach that focused simply on the abundance of a single species to one that considers multi-attribute population assessments and community ecology. Abundance,

productivity, spatial structure, and diversity all contribute to the maintenance of viable salmonid populations (VSP) (McElhany et al. 2000).

2) **Reduce Information Lag**. A significant lag often exists between the completion of research or a monitoring project and its application in management. We seek to reduce information lag by providing access to cutting-edge analyses, including new methods for evaluating hatchery programs, assessing the historical distribution of steelhead, and estimating the risk of extinction.

3) **Collate Existing Data and Provide Statewide Perspective**. What is the status of Washington's steelhead populations and how do they vary throughout the state? Collation of existing information is a key step in the development of a management plan. Research in other parts of the state or the region can sometimes help answer a local question that has been difficult to resolve.

4) **Identify Critical Research, Monitoring, and Evaluation Needs**. The significant conservation concerns facing some steelhead populations and the rapid evolution in fishery management may require changes in monitoring and analysis. Preparation of this report provides an opportunity to evaluate our capabilities and identify key research, monitoring, and evaluation needs.

Our analyses, findings, and recommendations in these areas can be found in the seven chapters of this report and the extensive pages of supporting documentation. In this Executive Summary, we have attempted to highlight key points in the report and provide references to additional analyses. Topics in the Executive Summary are grouped into five categories: 1) Population Structure, Diversity, and Spatial Structure; 2) Habitat, Abundance, and Productivity; 3) Artificial Production; 4) Management; and 5) Additional Challenges and Opportunities. Within each of those categories, we provide the primary Findings and Recommendations of this report.

The development, drafting, and review of this report has proceeded through a number of steps, many of which relied on entities outside of WDFW. The Hatchery Scientific Review Group, Steelhead and Cutthroat Policy Advisory Group, the Steelhead Summit Alliance, and some staff of western Washington tribes assisted in the identification of key questions and the development of a report outline. Previous drafts of this report have been reviewed by WDFW staff, the Steelhead and Cutthroat Policy Advisory Group, and some staff of western Washington tribes. However, tribal staff assistance in the preparation and review of this report does not necessarily imply tribal agreement with report content.

Population Structure, Diversity, and Spatial Structure

The distribution of steelhead can be viewed from a variety of perspectives, ranging from the relatively fine scale of habitat patch utilization in a single stream to the distribution of populations throughout the range of the species. Characteristics of the environment at the lower levels of the hierarchy drive the adaptations of populations and provide the basic unit for the diversity of the species. The hierarchical organization of a salmonid species, Riddell (1993) concluded, implies that maintaining biological diversity necessarily requires conserving populations and the habitats on which they depend.

Findings and Recommendations:

- **Short-term abundance and long-term persistence of the steelhead resource requires viable, locally-adapted, diverse populations, but a substantial loss of population structure has occurred in some, but not all regions.** The percentage of historical populations remaining in 7 Washington regions ranges from 45%-100%. The two regions with 100% of the historical populations remaining - Olympia Peninsula and Southwest Washington - are both located on the Washington coast. The Upper Columbia River region has the smallest percentage of the historical populations remaining (45%). (Chapter 5, Finding 1)

- *O. mykiss* **displays a wide range of life history diversity that enables the species to persist in highly variable environments.** The diversity of life history characteristics expressed by *O. mykiss* include the presence of resident (rainbow or redband trout) and anadromous (steelhead) forms , varying periods of freshwater and ocean residency, summer and winter adult return timing to freshwater, and plasticity of life history between generations. The emphasis on life history diversity as a strategy for persistence contrasts with some other species of anadromous *Oncorhynchus*, such as pink salmon (*Oncorhynchus gorbuscha*), which exhibit relatively small variation in life history characteristics. (Chapter 2, Finding 1).

> *"The steelhead are a paradox and only their return is viewed with absolute certainty. They are composed of exceptions—every "fact" about their upstream migration will almost contain an opposite number somewhere else."*
>
> *Trey Combs, The Steelhead Trout*

- **A substantial loss of spatial structure and diversity of steelhead populations has occurred in some regions.** An estimated 9%-27% of historical winter steelhead habitat and 17%-30% of historical summer steelhead habitat in Washington is no longer accessible or utilized by steelhead. The largest reduction in utilization was in the Upper Columbia region, where an estimated 43%-52% of the historical habitat was no longer used by steelhead. The loss in spatial connectivity was categorized as "High" for 52% of the populations assessed statewide. For the 15 of 134 populations for which a diversity assessment could be completed, 73% had a "High" loss of diversity. (Chapter 6, Finding 1)

> *Recommendation.* Pursue opportunities to preserve and restore population structure, spatial structure, and within-population diversity through careful review of harvest, hatchery, and habitat management and implementation of improved strategies. (Chapter 2, Recommendation 1; Chapter 5, Recommendation 1; Chapter 6, Recommendation 1)

- **Increased emphasis on monitoring the diversity of *O. mykiss* populations is needed.** The assessment programs of WDFW, like many other resource management agencies, have traditionally focused on evaluating and monitoring abundance. However, fishery management is rapidly evolving with increased recognition of the importance of diversity in maintaining viable, productive populations. Unlike spawner abundance data, no consistent metrics, protocols, or structure for reporting and analysis of diversity currently exists. The lack of a monitoring program is of special concern for steelhead because of the wide range of life histories expressed by this species, the potential effects of artificial production, fishery harvest, and habitat modifications on diversity, and the reductions in diversity noted in some populations. (Chapter 6, Finding 2).

> *Recommendation.* Design and initiate a program to monitor the genotypic and phenotypic characteristics of steelhead populations and a management structure for analysis and reporting. Expanding the scope of the Salmonid Stock Inventory[1] (SaSI) to include data pertaining to diversity and spatial structure as well as spawner abundance data would promote concurrent reporting of all four of the viable salmonid population (VSP) characteristics. (Chapter 6, Recommendation 2).

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[1] SaSI provides a central repository for information on the abundance, status, and stock origin of naturally spawning salmonids in Washington.

Habitat, Abundance, and Productivity

Abundance and productivity are two of the four VSP characteristics that determine the health of natural populations and opportunities for sustainable fishing opportunities. Productive, accessible habitat is essential for the long-term viability and productivity of steelhead populations.

Findings and Recommendations:

- **Degradation of riverine, estuarine, and nearshore habitat has resulted in the loss of an average of 83% of the potential production of the 42 steelhead populations assessed in Washington.** Improvements in habitat protection measures and restoration of degraded or inaccessible habitat are essential to assure the long-term viability of natural populations of steelhead in Washington. (Chapter 7, Finding 2)

  Recommendation. Ensure that the technical expertise of WDFW is available to local planning groups and governments to assist in the identification of the habitat factors reducing the viability of steelhead populations. Provide web access to map-based information on the stream reaches of high value for protection and restoration actions. (Chapter 7, Recommendation 2)

  Recommendation. Enhance the ability of local planning groups to effectively pursue new funding opportunities and efficiently use existing fund sources by developing a web application that identifies a schedule of priority habitat protection areas and restoration projects. (Chapter 7, Recommendation 3)

  Recommendation. Through a recently initiated project to evaluate the feasibility of developing habitat conservation plans for the Hydraulic Project Approval (HPA) program, and for WDFW owned and managed wildlife areas: a) assess the potential impacts of WDFW land management activities on steelhead; b) assess the potential impacts of HPA-permitted activities on steelhead; c) evaluate potential conservation measures to fully mitigate for adverse impacts resulting from HPA permitted activities; d) identify HPA activities that will require new research or monitoring efforts to assess impacts and potential mitigation measures; and e) develop tools and strategies to facilitate the monitoring, tracking, and adaptive management of HPA activities. (Chapter 7, Recommendation 4)

Recommendation. Develop and implement a consistent method for using remote sensing data to monitor trends in the status of habitat. Many planning forums require or would benefit from information about the status and trends of habitat across Washington State. This coarse-scale information, in various forms, is widely available through remote sensing but little effort has been given to standardizing products to meet multiple stakeholder needs simultaneously or in providing a template upon which future updates can made. (Chapter 7, Recommendation 5)

Recommendation. Develop improved tools that relate environmental factors (e.g., climate, water temperature, stream flow) and the physiological status (e.g., length, growth rate) of juvenile *O. mykiss* to the diversity, spatial structure, abundance, and productivity of steelhead populations. (Chapter 2, Recommendation 2)

- **The status of steelhead populations varies substantially across Washington.** Over 90% of the populations in the Olympic Peninsula region and over 60% in the Southwest Washington region were rated as “Healthy”. However, less than 20% of the steelhead populations were rated as “Healthy” in the five remaining regions of Washington. Yet, recent data does suggest some reason for optimism. Possibly due to improved marine conditions, the average escapement for steelhead populations throughout Washington increased by 48% in the years 1999 through 2004 relative to the prior 5 years. (Chapter 7, Finding 3)

- **Population viability analysis identified thirteen populations of steelhead with the potential for substantive conservation concerns.** The population viability analysis (PVA) conducted for this paper can be used as a tool to filter data and identify populations with a potential conservation concern. However, additional information is needed to fully assess the risk of extirpation. PVA can be misleading, particularly where population structure is uncertain or, as in the case with this analysis, the potential contribution of rainbow trout to population performance was not considered. (Chapter 7, Finding 4)

Recommendation. Reassess the status of all populations in Washington on a 4 to 8 year cycle to assure that opportunities for early action are not missed. Use PVA to filter spawner abundance data and, for populations identified to have a potential conservation concern, broaden the analysis to evaluate the contribution of rainbow trout to population viability, the previous performance of the population, and factors affecting population status. (Chapter 7, Recommendation 5)

Recommendation. Annually monitor and review the status of populations at risk, identify limiting factors, and assess the effectiveness of management actions. If necessary, implement new programs to address limiting factors, and potentially initiate "rescue programs" like kelt reconditioning or hatchery supplementation to conserve natural populations until limiting factors are addressed. (Chapter 7, Recommendation 6)

- **The inability to monitor the escapement of populations introduces significant uncertainty and risk into the management of steelhead in Washington.** The status of 47% of the steelhead populations could not be rated because of the lack of a time series of escapement or other abundance data. (Chapter 7, Finding 1)

  Recommendation. Prioritize monitoring, solicit funding, develop alternative estimation methods and sample designs, and enlist the assistance of other organizations to increase the percentage of populations assessed on a regular basis. (Chapter 7, Recommendation 1)

Artificial Production

Hatchery-based production is a tool that can be used to increase fishing opportunities, conserve at-risk natural populations, or facilitate research, monitoring, and evaluation. Use of the tool is not without risks. Possible impacts can include reductions in the diversity and fitness of natural populations, deleterious ecological interactions with natural populations and other species, and migration impediments resulting from the construction of hatchery facilities. An important step in the evolution of hatchery management has been the explicit definition of two genetic strategies – integrated or isolated – for the management of hatchery broodstock. Integrated programs intend that fish of natural- and hatchery-origin become fully reproductively integrated as a single population. Isolated programs (sometimes called segregated) intend for the hatchery population to represent a distinct population that is reproductively isolated from naturally spawning populations.

Findings and Recommendations:

- **The recreational fishery for hatchery-origin steelhead provides substantial fishing opportunities and economic benefits.** In the nine seasons from 1995-1996 through 2003-2004, recreational anglers harvested an average of 99,300 hatchery-origin steelhead. The estimated expenditures by recreational fishers associated with the catch of hatchery-origin steelhead were approximately $99 million dollars per year, with an economic output (includes revenues generated indirectly) of $188 million dollars per year. (Chapter 3, Finding 1)

- **Hatchery programs using Chambers Creek Winter or Skamania River Summer steelhead coupled with an isolated strategy comprise over 68% of the broodstock collection programs in western Washington.** Over 68% (28 of 41) of the steelhead broodstock collection programs in Puget Sound, the Olympic Peninsula, Southwest Washington, and the Lower Columbia regions collect broodstock of either Chambers Winter or Skamania Summer origin. Juveniles from these programs are generally released in watersheds where these stocks are not indigenous. The programs are operated with an isolated (also called segregated) reproductive strategy with the intent that little or no gene flow will occur between the natural and hatchery population. In contrast, hatchery programs in eastern Washington primarily rely on an integrated strategy with broodstock of local origin (5 of 7 or 71% of broodstock collection sites). (Chapter 3, Finding 2)

- **Naturally spawning adults originating from hatchery programs using the Chambers Creek Winter or Skamania River Summer stock have low reproductive success.** Six empirical studies in Oregon and Washington demonstrated that returning adults from these programs have low reproductive success in natural spawning areas. In these studies, highly domesticated hatchery-origin spawners have have been found to have only 7% to 37% of the success of natural-origin spawners in the same river. (Chapter 3, Finding 3)

- **Chambers Creek Winter and Skamania river Summer steelhead programs pose a high potential genetic risk.** Although each returning adult of Chambers Winter and Skamania Summer origin may on average have low reproductive success, substantial production of juveniles can still result from the spawning of a large number of hatchery-origin adults. When considered together with the previous two findings, this suggests that the Chambers Winter and Skamania Summer steelhead hatchery programs could pose a substantial risk to both the among-population diversity and the fitness of natural steelhead populations. Direct empirical evidence for loss of diversity is limited because genetic samples were generally not collected from natural populations before hatchery programs were initiated and the power of tests that can be applied is limited by the small number of loci (7) evaluated. Despite these limitations, 2 of the 7 (29%) natural populations sampled had significant introgression by Chambers Winter type fish during the time period evaluated. (Chapter 3, Finding 4)

- **Integrated programs are likely to be more effective at maintaining population fitness for rates of gene flow >2%.** Theoretical analysis calibrated with field studies indicates that integrated programs using a local source of broodstock will be more effective than isolated programs in maintaining the fitness of natural populations when the rate of gene flow from adults of hatchery-origin to the naturally-spawning population exceeds 2% per year. (Chapter 3, Finding 5)

    Recommendation. Evaluate the potential range of gene flow from returning adults to natural populations in all watersheds where Chambers Winter or Skamania Summer type steelhead are released. Where risks are inconsistent with policy objectives for the natural population, implement one or more of the following actions: 1) release steelhead juveniles from isolated programs only at locations where returning adults can be captured; 2) adjust the size of the program, release location, fishery harvest rate, or other factor to achieve an acceptable rate of gene flow; or 3) replace the isolated program with an integrated program developed from local broodstock. (Chapter 3, Recommendation 1)

Recommendation. Design and initiate a program to monitor the genetic characteristics of steelhead populations. Prioritize the collection of samples from watersheds with both a hatchery program and a significant natural population to assess the potential loss of diversity associated with hatchery programs. (Chapter 3, Recommendation 2)

Recommendation. Support and expand research to link changes in genetic markers to the abundance and productivity of the population. Current genetic monitoring typically assesses changes in the frequency of neutral alleles, or alleles that are not believed to have a functional effect on fitness. If we could identify genetic markers that were related to fitness, we could provide an improved assessment of what changes in the frequency of these markers mean to population productivity and other characteristics. (Chapter 3, Recommendation 3)

Recommendation. Submit for publication in a peer-reviewed journal a paper describing the methods developed to compare the potential fitness loss associated with integrated and isolated artificial production programs. These methods may be of broad interest in the evaluation and management of artificial production programs. (Chapter 3, Recommendation 4)

- **Progeny from Chambers Creek Winter and Skamania River Summer adults that spawned naturally pose a potential risk of competition to the indigenous natural population.** Despite the limited reproductive success of some domesticated hatchery-origin spawners, the sheer number of hatchery-origin spawners in natural spawning areas can result in substantial numbers of juvenile progeny. Competition may occur with indigenous natural populations, but the potential magnitude of the effects is extremely difficult to quantify. (Chapter 3, Finding 6)

  Recommendation. Evaluate the potential effects of competition when considering the relative risks and benefits of isolated programs, particularly if conservation concerns exist. Where risks are inconsistent with policy objectives for the natural population, implement one or more of the actions described in Recommendation 3-1. (Chapter 3, Recommendation 5)

- **Integrated artificial production programs can increase the number of natural spawners and improve the productivity of the composite population, but the long-term effectiveness of these programs has not been conclusively demonstrated.** Successful implementation of an integrated program requires careful consideration of the number and characteristics of natural-origin broodstock, the incidence of hatchery-origin adults in natural spawning areas, and the juvenile release strategy (location and time of release; size and smolting status of juveniles at release). While integrated programs have proven effective in increasing the abundance and productivity of the composite population in the short-term, long-term impacts on diversity, spatial structure, and the potential loss of productivity associated with domestication have not been thoroughly evaluated. Long-term effectiveness also depends on maintenance and improvement of the productivity of natural habitat. Interactions between habitat, hatchery, and harvest are discussed further in Chapter 4. (Chapter 3, Finding 7)

> *Recommendation.* Evaluate the potential effects of integrated programs on the diversity, spatial structure, abundance, and productivity of the indigenous natural population. Carefully consider the size of the program and characteristics of the release strategy (location, time, size of fish) to assure that potential genetic and ecological risks are consistent with policy objectives. (Chapter 3, Recommendation 6)

- **Survival rates for steelhead released from Puget Sound programs are currently the lowest of any region within the state.** Survival rates for winter steelhead released from hatchery programs in Puget Sound dropped to an average of <0.4% for the 1995 through 1998 brood years. The survival rates are currently the lowest of any region within the state, including the Upper Columbia River and the Snake River, and appear to have resulted from a significant shift in the conditions encountered during early marine rearing in Puget Sound and the Georgia Basin. (Chapter 3, Finding 8)

> *Recommendation.* Develop a “population rescue” reference document that discusses the conditions under which a hatchery conservation program may be warranted and the key questions that should be addressed during the development of the program. (Chapter 3, Recommendation 7)
>
> *Recommendation.* Evaluate the fishery and economic benefits of isolated hatchery programs in Puget Sound relative to those of hatchery programs for other salmonid species and the potential benefits of conservation programs for natural steelhead populations. If necessary, adjust programs to provide enhanced economic and conservation benefits. (Chapter 3, Recommendation 8)

Management

The underlying paradigm for fisheries management is rapidly shifting from an approach that focused simply on the abundance of a single species to multi-attribute populations assessments and community ecology. In an appeal for a new era in fisheries management, Walters and Martell (2004) suggest that “the central objective of modern fisheries science should be to clearly expose trade-offs among conflicting objectives, and the central objective of fisheries management should be to develop effective ways to decide where to operate along the trade-offs, and how to operate successfully.”

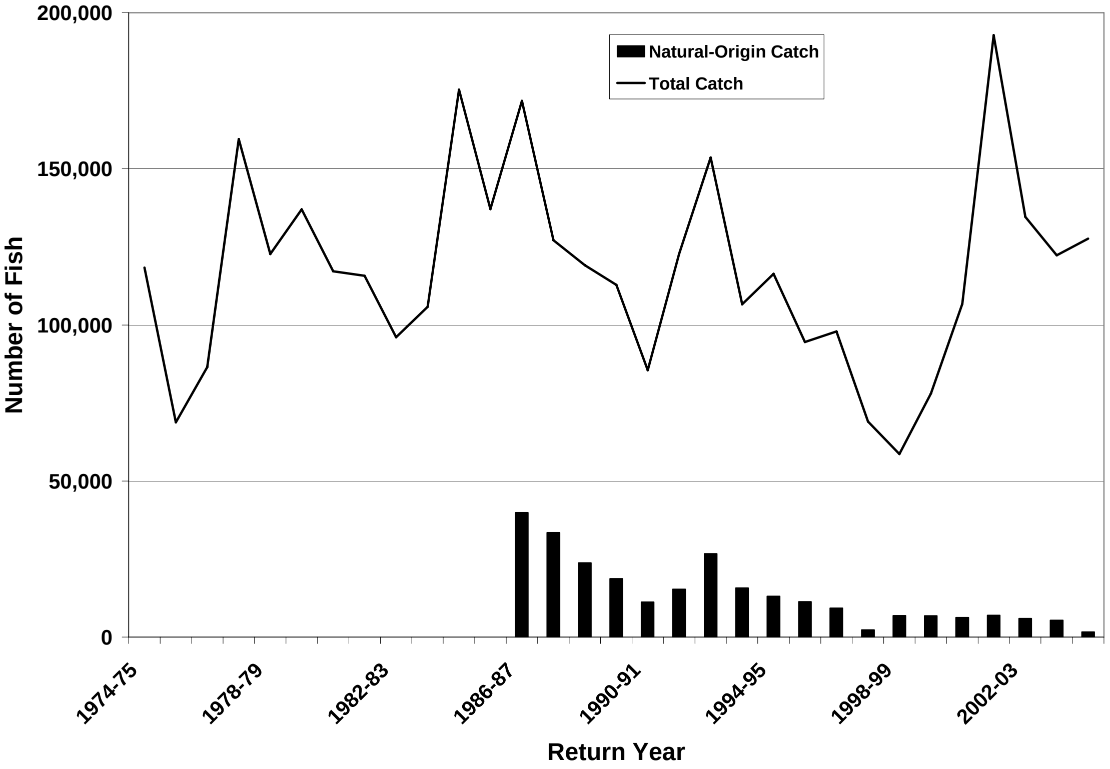
Findings and Recommendations:

- **Steelhead fisheries are an important part of the cultural heritage of Washington and provide substantial economic benefits.** Steelhead and anadromous salmonids are of nutritional, cultural, and economic importance to Native American tribes. Known for their explosive power and their preference for fast-flowing rivers, these fish have long held a special place in the lore of Northwest anglers. Recreational fishers spent an average of $105 million dollars per year fishing for steelhead during the last decade with an associated economic output of over $200 million dollars per year. (Chapter 4, Finding 1)

- **The diverse life histories of steelhead introduce management complexity.** Juvenile *O. mykiss* observed in freshwater may have originated from resident or anadromous parents, and anadromous parents may be of summer or winter return-timing. This diversity can make the collection and interpretation of juvenile genetic or abundance data difficult.

  The adult run of steelhead may be comprised of fish with multiple return-timing (summer and winter), a variable number of years of freshwater and marine residence, and adults that previously spawned. Understanding the effects of the environment and the number of spawners on the dynamics of the population requires age and run-timing specific estimates of fishing mortality and escapement. In some populations, further management complexity may be introduced by the contribution of resident *O. mykiss* to the production of steelhead. (Chapter 2, Finding 2)

- **Management of steelhead fisheries is based on a complex web of federal and state court orders, federal regulations associated with the Endangered Species Act, and state statutes.** Many steelhead fisheries in Washington are managed cooperatively with Native American tribes in a unique government-to-government relationship defined by treaties, court decisions, and legislation. The *U.S. v. Washington* and *U.S. v. Oregon* decisions determined that the Treaty Tribes and non-Indians are each entitled to a fair share of fish, defined as equal shares of harvestable salmon or steelhead. (Chapter 4, Finding 2)



- **The recreational catch of steelhead has fluctuated cyclically during the last 30 years, ranging from approximately 193,000 in the 2001-2002 season to a low of less than 59,000 in the 1998-1999 season.** Variations in the recreational catch can reflect many factors, including the abundance of steelhead, the catchability of steelhead as affected by conditions such as stream flow, and fishing regulations. Four peaks in the catch of steelhead are evident during the 30 years, separated by approximately by 7 to 9 year periods of declining catch. (Chapter 4, Finding 3)

- **The percentage of the recreational catch of steelhead originating from natural production has declined from 26% in the 1987-1988 season to approximately 1% in the 2004-2005 season.** The cautious management approach implemented by WDFW in the mid-1980s, including mark-selective fisheries, has effectively reduced the catch of natural-origin steelhead while providing opportunities to harvest steelhead of hatchery-origin. (Chapter 4, Finding 4)

- **Angler interest in catch-and-release fisheries has increased relative to 1987.** Phone surveys indicate that anglers are becoming more likely to release steelhead that can be legally retained. In the 1987 survey, anglers indicated that an average of 14%

of the steelhead landed were released; this increased to 40% in 1995 and 42% in 2003. (Chapter 4, Finding 5)

- **Achieving management goals for steelhead will be promoted by an integrated strategy for habitat protection and restoration, hatchery practices, and harvest management.** A strategy describes the general approach that will guide management actions in the pursuit of a desired future state. Strategies for habitat, harvest, and hatchery production, often referred to as the all-H sectors, have often been developed and evaluated in isolation. Misalignment of strategies can result in unexpected population and ecosystem responses and can make it difficult to achieve goals. (Chapter 4, Finding 6)

- **Management of steelhead requires evaluation of the trade-offs between conflicting objectives and an effective process for determining where to operate along these trade-offs.** Embedded in this paraphrasing of Walters and Martell (2004) are three important implications: 1) achieving all management objectives is rarely possible; 2) explicit evaluation of trade-offs promotes discussion and the development of improved strategies; 3) selection of strategies is not simply a technical analysis, but requires extensive communication and discussion with stakeholders. Trade-offs likely to be encountered in the management of steelhead include habitat quality versus spawner abundance, harvest level versus the fitness of the natural population, and population diversity versus versus harvest level. (Chapter 4, Finding 7)

> *"…the central objective of modern fisheries science should be to clearly expose trade-offs among conflicting objectives, and the central objective of fisheries management should be to develop effective ways to decide where to operate along the trade-offs, and how to operate successfully."*
>
> *Carl J. Walters & Steven J.D. Martell*
> *Fisheries Ecology and Management*

Recommendation. Develop and implement improved methods and forums to inform constituents about steelhead management trade-offs, generate and discuss new strategies, and solicit review and comment on alternative strategies. In addition to the existing Fish and Wildlife Commission process and the Steelhead and Cutthroat Policy Advisory Group, these methods could include informal workshops and focus groups. (Chapter 4, Recommendation 1)

Recommendation. Building on the concepts developed in this paper, develop and apply on a population specific basis analytical tools to evaluate trade-offs between competing management objectives. (Chapter 4, Recommendation 2)

Recommendation. In conjunction with the fishery comanagers, continue to annually assess the predicted abundance of steelhead populations, identify allowable fishing rates, and monitor the impacts of fisheries. (Chapter 4, Recommendation 3)

- **The complex reproductive and ecological interactions between anadromous and resident forms of O. mykiss may necessitate a holistic assessment of management actions.** Initial research suggests that extensive reproductive and ecological interactions can exist between resident and anadromous *O. mykiss* in some watersheds. These interactions can include breeding between resident and anadromous forms and the production of anadromous progeny from one or more resident parents. Where substantial interactions occur, predicting or understanding the response of the population to management actions will require a holistic assessment of resident and anadromous *O. mykiss*. (Chapter 2, Finding 3)

  Recommendation. Build on studies in the Cedar River, Yakima River, and other locations to develop a better understanding of the relationship of resident and anadromous *O. mykiss*. From these studies, develop improved tools to assess the potential effects of management actions and enhanced management strategies that effectively address resident and anadromous life history forms. (Chapter 2, Recommendation 3)

Additional Challenges and Opportunities

During the development of this report, we identified new genetic and geographic information system analyses that would substantially enhance the management of steelhead.

Findings and Recommendations:

- **The population structure of steelhead in the Puget Sound, Olympic Peninsula, and Southwest Washington regions is uncertain.** Inadequate genetic samples are currently available and new tools developed and applied by technical recovery teams have not been systematically applied in these regions. (Chapter 5, Finding 2)

  > *Recommendation.* Evaluate the population structure of steelhead in the Puget Sound, Olympic Peninsula, and Southwest Washington regions. Evaluate assumptions of the 1992 comanager analysis and, building on the tools developed by the Puget Sound, Willamette/Lower Columbia, and Interior Columbia technical recovery teams, define and implement a consistent procedure for evaluating population structure. (Chapter 5, Recommendation 2)

- **Steelhead life history diversity creates significant challenges for adequate sampling and accurate genetic analysis.** Genetic analysis is potentially a powerful tool for identifying population and metapopulation structure. However, genetic analyses of previous samples from juveniles of potentially mixed life history types were often inconclusive. Newer genetic markers, such as single nucleotide polymorphisms (SNPs) and microsatellites, may enhance the power of genetic analyses, but the development and implementation of improved sampling protocols will be required. (Chapter 5, Finding 3)

  > *Recommendation.* Focus future collection of genetic samples in areas with significant uncertainty in population structure. Collect genetic samples for microsatellite or SNP analysis with methods that assure run timing and life history type are known. Conduct analyses using high-resolution DNA markers appropriate to research objectives. (Chapter 5, Recommendation 3)

- **A geographic information system (GIS) provides a powerful, cost-effective tool to analyze and present spatial data.** Mapping the characteristics of habitat and distribution of redds now and in the future will be invaluable as we begin to assess the effectiveness of improved management strategies and recovery actions. (Chapter 6, Finding 3)

Recommendation. Enhance GIS capabilities by creating spatial data layers that identify barriers to fish passage, by incorporating additional variables into the model developed in this paper for predicting fish distribution, and by annually mapping the distribution of redds. (Chapter 6, Recommendation 3)

Chapter I

Introduction

> *"The Pacific Coast is the land of the mountain torrent. Only in the great valleys of the enormous rivers do we have quiet flowing water, and even here the quietness is not long nor is it without a fierce strength. Most of the streams we fish are rushing and rock-broken, alternations of deep pools and white water rapids, sometimes shadowed by canyons of solid rock, sometimes spreading among built-up gravel bars. They have their own quietness, but it is the quietness of accustomed sound, their own peace, but it is the peace of energy unbounded, leaping its free way through sunlight and shade to the never-distant seas. No fisherman could ask for better things than these to live with. They are trout and salmon waters beyond all other waters of the earth. They are clean and clear, they are full of infinite variety."*
>
> *Roderick Haig-Brown, Fisherman's Spring*

1.1 A Steelhead Landscape

From cold mountain streams to the Pacific Ocean, the waters that shape the landscape of the Pacific Northwest also define the lifecycle of native steelhead (*Oncorhynchus mykiss*). Fast and sleek, steelhead cover thousands of miles from the time they leave their natal streams for the open ocean, then return again – often more than once – to spawn. Known for their explosive power and their preference for fast-flowing rivers, these fish have long held a special place in the lore of Northwest anglers. Traditional Native American culture in the Pacific Northwest is also inextricably tied to steelhead and other anadromous salmonids. For many Northwest Indian peoples, these fish have always provided an essential source of food, a focal point of religious life and a central commodity for trade and commerce. A Northwest icon, steelhead were designated by the legislature as the Washington State fish in 1969.

Steelhead have also been the focus of significant controversy. Construction and operation of dams, habitat degradation, hatchery programs, and fishing have all sparked long and continuing debates, blue-ribbon panel reviews, and research papers. Two reviews of particular note -- “Upstream: Salmon and Society in the Pacific Northwest”, by the National Research Council (1996), and the Royal report, commissioned by the Washington Department of Game in 1973, have had a substantial impact on fishery management in the Pacific Northwest.

Why, in the face of the already extensive literature, have we invested substantial time and energy in the development of yet another report? This report is not simply an assessment of Washington’s steelhead populations or a critique of current management practices. Rather, it is designed to lay the foundation for the development of improved management plans, scheduled to begin this year, that assure the productivity of Washington’s steelhead for future generations. To achieve this goal, we established four primary objectives for this report:

1) **Promote Progress in the Continued Evolution of Fisheries Management.** The underlying paradigm for fishery management is rapidly shifting from an approach that simply focused on the abundance of a single species to one that considers multi-attribute population assessments and community ecology (McElhany et al. 2000; HSRG 2004; Walters and Martell 2004; Mangel and Levin 2005). Abundance, productivity, spatial structure, and diversity all contribute to the maintenance of viable salmonid populations (VSP). We review these concepts and describe their potential application to the management of steelhead.

2) **Reduce Information Lag**. A significant lag often exists between the completion of research or a monitoring project and its application in management. New genetic analyses, computers, and computer applications like Geographic Information Systems (GIS) are revolutionizing fishery management. We seek to reduce information lag by providing access to cutting-edge analyses, including new methods for evaluating hatchery programs, assessing the historical distribution of steelhead, and estimating the risk of extinction.

3) **Collate Existing Data and Provide Statewide Perspective**. What is the status of Washington’s steelhead populations and how do they vary throughout the state? Collation of existing information is a key step in the development of a management plan. Research in other parts of the state or the region can sometimes help answer a local question that has been difficult to resolve.

4) **Identify Critical Research, Monitoring, and Evaluation Needs**. The significant conservation concerns facing some steelhead populations and the rapid evolution in fishery management may require changes in monitoring and analysis. Are we collecting the data we need? Is it accessible? Preparation of this report provides an opportunity to evaluate our capabilities and identify key research, monitoring, and evaluation needs.

Steelhead are currently listed under the Endangered Species Act in four regions of Washington (Lower Columbia, Middle Columbia, Upper Columbia, Snake River) and listing has recently been proposed for populations in Puget Sound. Populations in many Washington coastal rivers remain strong. Our effectiveness in protecting and restoring steelhead populations and the habitat on which they rely will help shape the steelhead landscape for future generations.

1.2 Report Structure

We have organized this report into seven chapters, beginning with a brief overview of the biology of steelhead (Chapter 2), an assessment of artificial production (Chapter 3), and a review of management (Chapter 4). The final three chapters assess the status of steelhead, including Population Structure (Chapter 5), Diversity and Spatial Structure (Chapter 6), and Abundance and Productivity (Chapter 7). The chapters are framed around a series of questions designed to stimulate discussion and focus subsequent analyses. Each chapter ends with Findings and Recommendations driven by the analyses.

Although we have attempted to include as much relevant information in this report as possible, we recognize that some important work may have been missed and additional results from ongoing research and monitoring can be expected. To address these issues, the report has been compartmentalized to facilitate future updates. There has also been an attempt to provide Internet links in each section to help the reader pursue additional information and access posted data as they become available.

Effective resource management requires the ability to quickly access and analyze current and historical data. In the preparation of this report, we found that historical steelhead data were often difficult to obtain or contradictory. Indeed, a substantial amount of the time required to complete this report was invested in data collection and a preliminary reconciliation of conflicting information. The redoubling of efforts to improve the accuracy and accessibility of historical data was one substantive benefit resulting from the preparation of this report, and one that will become increasingly important to complete. Many biologists familiar with historical steelhead data are now reaching an age at which retirement from WDFW may occur.

The quality of the data available to assess steelhead populations and programs in Washington varies substantially through time, with data of higher quality generally becoming available in the late 1970s. Four particularly important enhancements were: 1) the initiation in 1962 of a 12-month catch record card (CRC) to record recreational catches; 2) the development and implementation for the 1974-1975 season of a bias correction factor for the CRC estimate of recreational catch; 3) the extension in the late 1970s of intensive spawners surveys to a broader range of watersheds; and 4) marking of hatchery-origin steelhead provided the ability to estimate the catch of natural and hatchery-origin steelhead in the mid-1980s. Because of the substantial changes in the types and quality of data collected, comparisons of current and historical data on steelhead populations can be difficult. For this reason, most of the analyses in this report rely on data collected since the late 1970s.

1.3 Report Authorship and Tribal Review

This report was written by the Washington Department of Fish and Wildlife (WDFW). Many of Washington’s steelhead stocks and fisheries are managed jointly with Native American tribes in a unique government-to-government relationship defined by treaties, court decisions, and legislation. Some tribal staff assisted in the development of the outline for this report, provided data, or reviewed earlier drafts of the report. However, tribal staff assistance in the preparation and review of this report does not necessarily imply tribal agreement with report content.

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Chapter 2
Biology

Key Questions:

a) *What are the defining biological characteristics of O. mykiss?*
b) *What are the habitat, harvest, and hatchery management implications of these biological characteristics?*
c) *What management complexities result from these biological characteristics?*

2.1 Introduction

Steelhead are considered by many fisheries biologists to be the most difficult Pacific salmonid species to protect and manage because of the diversity in life history patterns that exist both within and between populations. This diversity includes multiple times for the return of adults to natal streams, varying periods of freshwater and ocean residency, and plasticity of life history between generations. The life history of steelhead also differs from many *Oncorhynchus* species in several fundamental ways. These include the frequent presence of resident forms of *O. mykiss* and iteroparity, or the ability to complete more than one cycle of spawning. This diversity introduces management complexity – but also enables the species to persist in highly variable environments.

> *"The steelhead are a paradox and only their return is viewed with absolute certainty. They are composed of exceptions—every "fact" about their upstream migration will almost contain an opposite number somewhere else."*
>
> *Trey Combs, The Steelhead Trout*

Given the diversity of steelhead, our intent in this chapter is not to provide a comprehensive, population by population review of the biological characteristics of steelhead. Rather, we illustrate the diversity of steelhead throughout Washington, assess the habitat, harvest, and hatchery management implications of this diversity, and discuss the resulting the management complexities. More detailed presentations of the biological characteristics of steelhead can be found in Burgner et al. (1992), Busby et al (1996), Reiser et al. (1979), and Withler (1966).

2.2 Diversity Groups

Two genetically distinct groups of *O. mykiss* inhabit Washington (Allendorf 1975; Phelps et al. 1997), a coastal form native to the area west of the Cascade crest, and an inland form native to the area east of the Cascades. Both the coastal and inland forms exhibit anadromous and resident life histories. Behnke (1992) considers these two groups different subspecies, *O. mykiss irideus* and *O. mykiss gairdneri*, respectively. Inland *O. mykiss* are commonly referred to as redband trout, and in Washington the term can be used to describe any native resident or anadromous *O. mykiss* population east of the Cascades crest. This term needs to be used cautiously, however. Redband trout occur in British Columbia and in several western states. Wherever they occur, they are distinctive from the coastal form, but they do not consist of a single taxonomic entity (Behnke 1992; Currens 1997). Although they may seem morphologically and ecologically similar, a redband trout from Washington is genetically quite different from one from California.

Genetic, morphological, and life history variations and similarities exist among steelhead populations of Washington at finer geographic scales. Leider et al. (1994) identified seven Genetic Conservation Management Units (later called Genetic Diversity Units or GDUs) for steelhead in Washington. These were refined in subsequent analyses (Leider et al. 1995; Phelps et al. 1997) and eventually led to the identification of Evolutionarily Significant Units (ESUs) by NOAA Fisheries (Busby et al. 1996). While a GDU is strictly a biological method for organizing the diversity of steelhead, an ESU has regulatory implications under the Endangered Species Act. An ESU is a population or group of populations within a species that: 1) is substantially reproductively isolated from other populations (or groups of populations) of the same species and; 2) represents and important evolutionary legacy of the species as a whole (Waples 1991). NOAA Fisheries has identified 7 ESUs residing wholly or partially in Washington: 1) Puget Sound; 2) Olympic Peninsula; 3) Southwest Washington; 4) Lower Columbia River; 5) Middle Columbia River; 6) Upper Columbia River; and 7) Snake River Basin. ESUs and populations of steelhead in Washington are discussed further in Chapter 5, Population Structure.

Photo 2-1. Redband trout from the Naches River, March 2004. Photo source: Jim Cummins, WDFW.

2.3 Anadromous and Resident Life History Types

O. mykiss is a highly polymorphic species and Washington watersheds can be inhabited by resident (rainbow or redband trout), anadromous (steelhead), or a mixture of both life history types. Although anadromy appears to have some genetic basis (Thrower et al. 2004), it is a relatively complicated phenotype in this species as evidenced by its variability and plasticity of expression. The presence of alternative life history types can occur under a variety of conditions and, as the RSRP (2004) noted, "represents different phenomena in different locations, from a polymorphism within some populations to a secondary contact between divergent subpopulations to reproductively isolated, long-separated lineages".

Non-anadromous *O. mykiss*, referred to as rainbow trout, and which spend their entire life-cycle in freshwater, occur throughout the range of steelhead in the Pacific Northwest, and in areas that are not accessible to steelhead due to geomorphology or human intervention. There is genetic support for the hypothesis that resident life-history forms of *O. mykiss* developed from the anadromous form because greater genetic similarity often occurs between the two forms within a basin instead of between the same life-history types in different basins (Phelps et al. 1994; Phelps et al. 1997; Docker and Heath 2003).

Resident rainbow trout populations often occur in smaller streams where large anadromous adults cannot migrate, but these trout will also use mainstem areas of larger rivers during their life cycle. There are few locations in the state where the abundance of sympatric resident and anadromous steelhead is estimated. Resident trout may have been more abundant in lower mainstem areas of large rivers in the past, but have vanished due to habitat alteration and fishing pressure (Kostow 2003). Resident trout also inhabit lake systems, which are not always strictly land-locked, as small fish may be able to move downstream into steelhead-accessible areas.

Hatchery-produced rainbow trout that are planted in lakes throughout Washington are nearly all non-native origin, having been derived from trout lineages of California (Crawford 1979). It is assumed that they behave as resident, non-migratory trout, although studies in Snow Creek suggest that at least some will enter marine waters where downstream passage is possible (Michael 1989). If spawning occurred among hatchery-origin trout it is also assumed that, as a result of their ancestry and domestication history, they would rarely, if ever, produce anadromous offspring.

2.3.1 Evolution of Anadromy

Gross (1987) theorized that diadromy would evolve if the fitness (W) costs of migration were less than the benefits associated with rearing in an alternative environment. Applying this theory to *O. mykiss*, we would expect that anadromy would evolve if the costs of smolt and adult migration were less than the survival and reproductive benefits resulting from rearing in marine waters:

$$W(H_1)_A + W(H_2)_A + W(M_T)_A > W(H_1)_R$$

where $W(H_1)_A$ is the growth and survival of anadromous fish in freshwater; $W(H_2)_A$ is the growth and survival of anadromous fish in marine waters; $W(H_1)_A$ is the growth and survival of anadromous fish during the smolt and adult migration ; and $W(H_1)_\mathrm{R}$ is the fitness of resident fish (by definition set equal to 1).

In an extensive review of anadromy in salmonds, Hendry et al. (2004) predicted that "The tendency for anadromy should decrease as its benefits decrease, with the same true for non-anadromy. The relative benefits of anadromy, and therefore its prevalence, should decrease with increasing freshwater productivity (growth) or increasing migratory difficulty (distance or elevation)." This prediction, if correct, has important ramifications for evaluating the potential effects of harvest, habitat, hatchery management actions assessing the status of populations of *O. mykiss*.

Fishery management actions that disproportionately affect the mortality of the resident or anadromous fish may shift the relative abundance of these life history types. Hendry et al. (2004) reviewed studies of Russian lakes where fishery mortality has resulted in a reduction in the abundance of anadromous adult sockeye salmon. Concurrently, these studies found "a decrease in juvenile densities, an increase in juvenile growth, and a dramatic increase in the proportion of residuals among males (13% to 82% in Uyeginsk; 26% to 92% in Sal'nee)" (Hendry et al. 2004).

Habitat characteristics can differentially affect the reproductive potential and relative abundance of the resident and anadromous life history types. Bohlin et al. (2001) evaluated the density of resident and anadromous juvenile brown trout in populations in streams along the coast of Sweden. The altitude of the stream in which the population occurred was assumed to be a surrogate measure of the costs associated with migration to marine waters. At low elevations, both resident and anadromous populations existed, but the density of anadromous juveniles was greater than the abundance of resident juveniles. As the altitude increased the density of anadromous, but not resident, brown trout decreased. Anadromous and resident brown trout were of similar abundance at an altitude of approximately 150 meters, and few anadromous populations existed above that elevation. Bohlin et al. interpreted these observations as support for the hypothesis that increased costs of migration to marine waters were associated with higher altitude, and that higher costs of migration were associated with a reduced likelihood of anadromy.

2.3.2 Reproductive Interactions

In drainages where anadromous fish have access, reproductive interactions may occur between steelhead and resident rainbow trout. Researchers are beginning to document interbreeding and population relationships or structuring between resident and anadromous *O. mykiss* within a watershed. Zimmerman and Reeves (2000) used otolith microchemistry and spawning ground surveys to determine whether steelhead had resident fish maternal origins and whether resident trout had anadromous fish maternal origins. They found that resident and anadromous *O. mykiss* in Deschutes River, Oregon had a high probability of being reproductively isolated populations, whereas in a coastal Canadian drainage (Babine River) complete reproductive isolation was not likely the case. Pearsons et al. (in press) evaluated the potential for gene flow between Yakima Basin resident and anadromous *O. mykiss* using ecological and genetic data. They observed many instances of interbreeding between rainbow trout and steelhead and in one drainage, the North Fork Teanaway River, found that wild rainbow trout and steelhead were genetically indistinguishable. In a study of genetic relatedness among offspring from steelhead redds in the Hamma Hamma River, Kuligowski et al. (2005) found a male-biased sex ratio (16 males to at least 5 females) among parents that they attributed to matings by either a male resident trout or precocial steelhead parr with female steelhead.

In a Hood River, Oregon steelhead reproductive success study using DNA pedigree analysis methods, researchers estimated that about 40% of returning steelhead had non-anadromous male parents (Ardren 2003; Blouin 2003). It is not known which type of non-anadromous (resident trout, planted hatchery trout, or residualized steelhead) male parent were the contributors, but work to determine this is underway. A pedigree-based study in Snow Creek (Olympic Peninsula, Washington) showed that in some years of low steelhead return mature (precocious) non-anadromous males may collectively be more successful at producing anadromous offspring than anadromous males (Seamons et al. 2004). In another Snow Creek study, Ardren and Kapuscinski (2003) found that the ratio of effective population size to the actual number of steelhead spawners was significantly higher in years with low steelhead spawner density. Seamons et al. (2004) stated that an explanation for this observed pattern may be a proportional increase in reproductive success of resident males when few anadromous males occur. These results suggest that resident males may increase the probability of persistence for a small steelhead population.

Photo 2-2. Spawning pairs of *O. mykiss* may include adults of anadromous, resident, or mixed origin. Resident males may be an important contributor to the viability of small populations. Photo source: unknown.

Given the results of these and other studies, there is much interest in determining the rate and extent that resident trout populations might produce steelhead. In an on-going breeding study using Grande Ronde Basin (OR) steelhead and trout, all possible crosses between resident trout and between trout and steelhead all produced out-migrating smolts, and the steelhead by steelhead crosses produced the largest proportion of detected outmigrants (Ruzycki et al. 2003). Adults from these crosses are beginning to return, and after all age groups return, the ability of Grande Ronde resident trout to produce steelhead will be determined. In a breeding study focused on heritabilities of growth, precocious maturation and smolting using crosses among steelhead and lake-resident rainbow trout derived from steelhead 70 year earlier, Thrower et al. (2004) found that the lake population retained the ability to produce smolts, and that resident crosses produced lower proportions of smolts than steelhead crosses. The results of Thrower and Joyce (2004) indicated that marine survival of smolts of the lake-derived fish was poor relative to the smolts derived from anadromous parents.

Breeding also can occur between resident trout and residualized precocious male steelhead (Pearsons et al. in press), which are offspring of steelhead parents that have become mature while residing in freshwater. The importance of precocious male reproductive contributions, i.e. the proportion of offspring they produce within a steelhead population, is only beginning to be studied. As indicated by the steelhead studies described above, however, this may be an important life history variation for steelhead. Males can reproduce without the survival risks of going to sea.

A few studies have documented reproduction between non-native hatchery rainbow trout and hatchery steelhead and between these hatchery trout and native resident *O. mykiss* (Campton and Johnston 1985; Pearsons et al. in press). However, the genetic impact of non-native hatchery trout stocking on resident native *O. mykiss* populations or steelhead populations often has been found to be less than expected given an extensive history of stocking. Kostow (2003) describes findings of this nature for a variety of Columbia Basin drainages.

Current information demonstrates that native, resident populations of *O. mykiss* are often a component of the genetic population structure of steelhead. This is likely to be particularly true among Columbia Basin inland steelhead because environments there often support large resident rainbow trout populations that are sympatric with steelhead. In coastal drainages, trout are often more abundant above artificial barriers such as dams than in drainages below them, which are usually dominated by steelhead. The resident life-history strategy may be favored under certain environmental conditions, and when migratory or ocean conditions are unfavorable for steelhead, resident fish may serve to maintain the genetic heritage of a drainage's *O. mykiss* population. Native, resident trout populations increase the genetic diversity of the species, which likely provides for a greater ability to adapt to a wider range of environmental conditions.

The potential for reproductive interaction of the resident and anadromous life history forms indicate that effective management may require, at least in some watersheds, consideration of steelhead parr, smolts, and rainbow trout as integral components of the *O. mykiss* population.

2.3.3 Ecological Factors Affecting Anadromy

Construction of dams and other anthropogenic activities may have ecological effects that alter the prevalence of anadromy. Morita et al. (2000) found that juveniles of white-spotted char located below dams were more likely to migrate to marine waters than white-spotted char located above the dams. However, juvenile char collected from both upstream and downstream of a dam were then transplanted to a barren location upstream of a dam in another stream. Low rates of smolting were observed regardless of whether the juveniles originated from the upstream (resident) or the downstream population (resident and anadromous). Morita et al. (2000) suggested that the reduction in anadromy observed upstream of dams was a phenotypic response to the reduced density and faster growth rate observed for char populations located upstream of dams. The phenotypic plasticity expressed, the authors concluded, "can have an important role in preventing local extinction."

The projected benefits of habitat restoration projects to steelhead populations may vary depending upon model assumptions regarding interactions with rainbow trout. Preliminary analysis of rainbow trout and steelhead in the Yakima River (Mobrand-Jones & Stokes 2005) illustrate the potential importance of considering rainbow trout and steelhead interactions. Steelhead emigrating from or returning to the Yakima River must pass four dams on the Columbia River and up to seven diversion dams in the subbasin. Resident and anadromous population of *O. mykiss* exist in the subbasin, but rainbow trout are currently more abundant than steehead in the upper Yakima River. Mortality related to dam passage has been hypothesized to be a significant factor affecting the relative abundance of rainbow trout and steelhead. Based upon the work of Gross (1987), a model was developed to help guide the evaluation of potential restoration actions. In some cases, the predicted increases in steelhead abundance resulting from restoration actions were dependent on the inclusion or exclusion in the analysis of the existing populations of rainbow trout. For example, the abundance of steelhead in the West Fork Teanaway River was predicted to increase from 0 adults to 63 adults with the elimination of dam-related mortality in Yakima River and without consideration of rainbow trout (Watson pers. comm.). When rainbow trout were included in the analysis, the abundance of steelhead was predicted to increase from 0 adults to 12 adults (Mobrand-Jones & Stokes 2005).

2.3.4 Proximal Factors Affecting Anadromy

The size or growth rate of juvenile salmonids appears to be a significant factor regulating the initiation of smolt metamorphosis (Bohlin et al. 1993, 1996; Okland et al. 1993). Evidence for this relationship for steelhead includes a relatively consistent size (160 mm fork length) but variable age of migrants along the west coast of North America (Burgner 1992) and the development of osmoregulatory capability at a size of 140 to 160 mm (Conte and Wagner 1965).

Thorpe et al. (1998; see also Metcalfe 1998) developed a general theory for salmonid life histories that relates proximal factors, such as lipid reserves or length, to smolting and maturation. A key feature of the theory is that a series of developmental switches were hypothesized to regulate the initiation of the smolt metamorphosis and maturation. Metcalfe (1998) described the application of this theory to Atlantic salmon:

> "Therefore analyses of size at the time of spawning or entry to sea tell us nothing about the underlying triggering mechanisms, since size by this stage is partly a consequence, rather than a cause, of the life history strategy that has

> been adopted. Models based on threshold size at this time (e.g., Power and Power 1994) do not therefore present a real picture of the life history decisions reached by the fish. We must instead examine the state of the fish at the time of the decision: what makes a fish begin the process of smolt transformation in late summer or maturation in late autumn? Current evidence (summarized by Thorpe et al. 1998) suggests that these events are triggered if the fish is on course to surpass a threshold state (cf. Roff 1996) by the time of entry to the sea or time of spawning, respectively. Thus smolt transformation is triggered in late summer if the fish is set to exceed a threshold level of resources by the following autumn. In either case, the future state of the fish is presumably estimated from a combination of its current state and the rate at which that state is currently changing at the time of the life history decision. Therefore, in late summer the fish would be, in effect, estimating (from its current size and growth rate) what its size should be at the time of the smolt migration the following spring; if its projected size was above the genetically determined threshold then smolting would be triggered, while if it fell below the fish would remain a parr in freshwater for a further year…"

Photo 2-3. A series of developmental switches have been hypothesized to control the initiation of smolt metamorphosis and maturation. Photo source: Todd Pearsons, WDFW.

Improved understanding of the relationship between environmental factors (e.g., water temperature, stream flow), physiological status (e.g., length, growth rate), and life history patterns of steelhead would be a powerful tool for developing and evaluating management actions. Mangel et al. (2004) have proposed the development of models linking the physiological status and life history patterns of steelhead in the Central Valley and in coastal streams of California. In assessing the continued decline of steelhead in those areas more than 40 years after the major period of dam construction, Mangel et al. (2004) surmised that "…major shifts in the environment can result in a high proportion of fish that have entered an inappropriate pathway. Our overall hypothesis is that water flow levels and the temporal pattern of water delivery have a major impact on growth opportunity an life history expression in age-0 steelhead, which will echo through the rest of their life history and populations dynamics. Alteration of water flow patterns potentially disrupts the natural adaptive responses of juvenile steelhead, resulting in reduced survival as fish make crucial mistakes in selected life history trajectories."

2.3.5 Ecological Interactions

For purposes of this discussion, ecological interactions are defined as any direct or indirect interactions that would occur between resident and anadromous *O. mykiss* other than interbreeding. Competition (for food and habitat) and predation are two major types of ecological interactions expected between the two life-history forms. In drainages where native resident and anadromous *O. mykiss* have occurred together over long time periods, it is reasonable to assume that the net outcome of interactions perpetuates the existence of both forms. In other words, resource use by one form does not lead to the decline of the other.

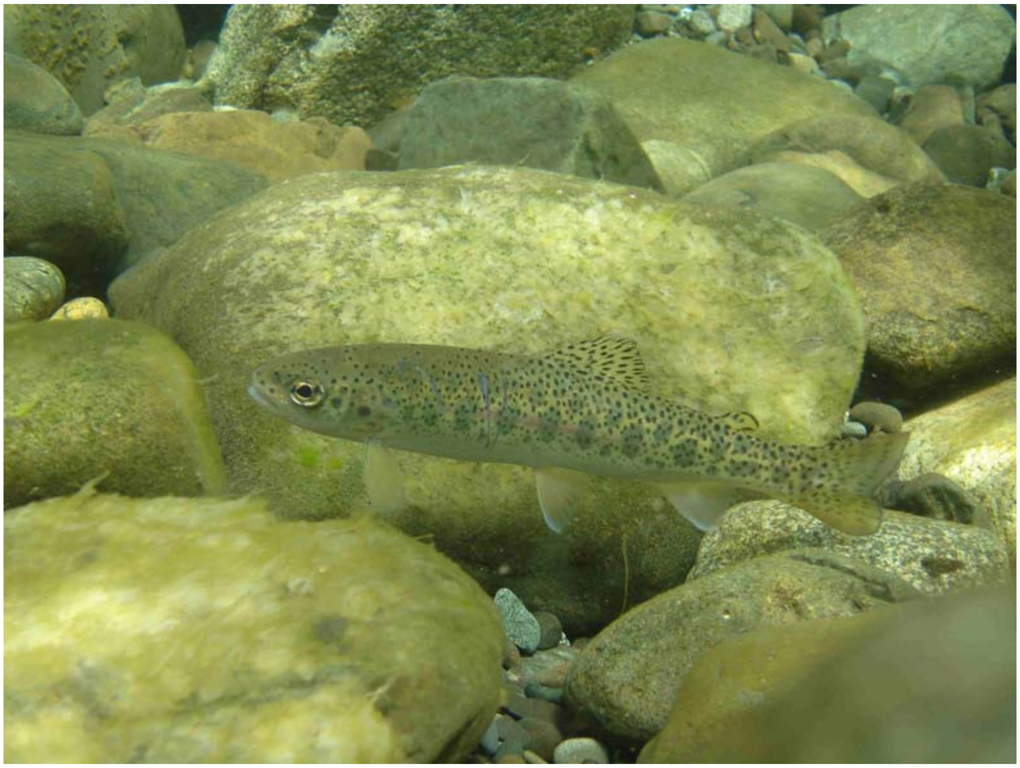


Photo 2-4. Scarring and ragged fins are sometimes evident after competitive attacks between juvenile *O. mykiss*. Little is known about the effects of competition between the juvenile anadromous and resident life history types. Photo source: Todd Pearsons, WDFW.

The greatest opportunity for competition between resident trout and steelhead occurs during the stream-rearing period for juvenile steelhead, which is quite variable in length. Juvenile resident trout and steelhead would compete for the same food resources and territories where and when they shared habitat. Although spatial distributions can overlap extensively, resident trout often inhabit smaller or higher elevation streams not utilized by adult steelhead (Pearsons et al. in press), and this partitioning reduces competition. However, interactions between both types of juveniles are not limited to overlapping habitats of adults. Rearing steelhead may migrate into trout territories, and young trout may move downstream into steelhead habitat. Juvenile abundances are regulated by food and space resources, predation, flooding, drought, and many other factors (Keeley 2001). Competition is a consistent factor and changes in abundance of resident or steelhead progeny would likely modify competitive pressures on the alternative form.

Resident trout might be expected to prey on smaller juveniles of their species. Steelhead and sympatric trout have similar spawn timing, and even if no interbreeding occurred, their juveniles would likely be present and available as prey to adult trout at generally the same time. Thus, unless there is some behavioral difference between trout and steelhead juveniles that increases either's predation risk, it is likely that piscivorous resident trout (or juvenile steelhead) could prey equally on both juvenile types. At this time we have found no empirical studies documenting resident rainbow trout differential predation effects on steelhead. The issue of whether rainbow trout could pose a significant predation risk to steelhead is likely most relevant where habitat damage, fisheries, or artificial stocking has led to steelhead declines and enhanced trout abundance.

The discussion above is focused solely on native, naturally occurring steelhead and resident rainbow trout populations. Releases of hatchery-origin steelhead and trout can impose impacts on native populations through disease, competition, and predation. These types of ecological interactions have been studied extensively in the Yakima River Basin (Pearsons et al. 1994; Pearsons et al. 1996; McMichael et al. 1997; 1999a; 1999b; McMichael and Pearsons 2001). Artificial production programs and their potential effects on natural populations are discussed further in Chapter 3, Artificial Production.

2.4 Life History Diversity of Anadromous *O. mykiss*

2.4.1 Multiple Adult Run Times

Two broad life history types of steelhead exist in Washington: winter-run and summer-run fish. The life history types are principally distinguished by the timing of adult return and the level of sexual maturity at the time of river entry (Burgner et al. 1992). Adult winter steelhead typically return to the river mouth from November through May or early June, with peak spawning occurring from mid-April through mid-May in most Western Washington streams. Summer steelhead return to the river mouth between April and October, enter freshwater sexually immature, and require several months to mature and spawn. In general, summer steelhead spawn earlier in the year than winter steelhead.

Indigenous steelhead of both life history types exist in most large watersheds in western Washington. For example, sympatric populations of summer and winter steelhead exist in the Nooksack, Skagit, Stillaguamish, and Snohomish rivers in Puget Sound, and in the Quillayute, Hoh, Queets, and Quinault rivers on the Washington coast (see Chapter 5 for a more detailed discussion of population structure). In general, summer steelhead are not found in small watersheds in western Washington. Withler (1996) suggested that summer steelhead occurred in small, coastal watersheds of British Columbia only if seasonal migration barriers promoted the reproductive isolation and subsequent evolution of the summer and winter life history types. In contrast to western Washington, all historical steelhead populations in the interior Columbia River basin are of the summer life history type. A similar pattern in the distribution of steelhead is evident in British Columbia, where winter steelhead are absent from the interior Fraser River basin but predominate in coastal drainages (Withler 1966; Parkinson 1984).

The presence of summer and winter steelhead in the coastal rivers of British Columbia and Washington apparently resulted from the repeated evolution of run timing in multiple watersheds rather than the evolution of two run timing types with subsequent dispersal to multiple watersheds. Numerous studies have found that summer and winter steelhead from a particular coastal watershed are genetically more similar to one another than to populations with similar run timing in adjacent watersheds (Allendorf 1975; Utter and Allendorf 1977; Chilcote et al. 1980; Reisenbichler and Phelps 1989). Summer type steelhead in the interior Fraser and Columbia basins, however, are believed to have originated from two or more founding populations that existed in glacial refugia in the interior of these basins during the last glaciation (Beacham et al. 1999). The origin of summer and winter life history types has important implications for planning conservation efforts or evaluating hatchery programs (see Chapter 3, Artificial Production).

Research conducted at the Kalama River since 1974 provides a long-term assessment of the run timing of sympatric populations of summer and winter steelhead. Returning adults are collected at a trap (river km 17) located downstream of nearly all summer steelhead spawning areas (Crawford et al. 1977) and approximately 90% of the winter steelhead spawning areas (Hulett pers. comm.). The life history type of each fish passed upstream is determined by physical appearance and sexual maturity (Leider et al. 1984). The trapping data indicate that adult steelhead migrate upstream in every month of the year (Fig. 2-1). The peak passage of summer steelhead occurs on average in July, but adults return as early as April and as late as March the following year. Winter steelhead are migrating upstream at the trap site from October through July, with most of the adults generally passing upstream in April.

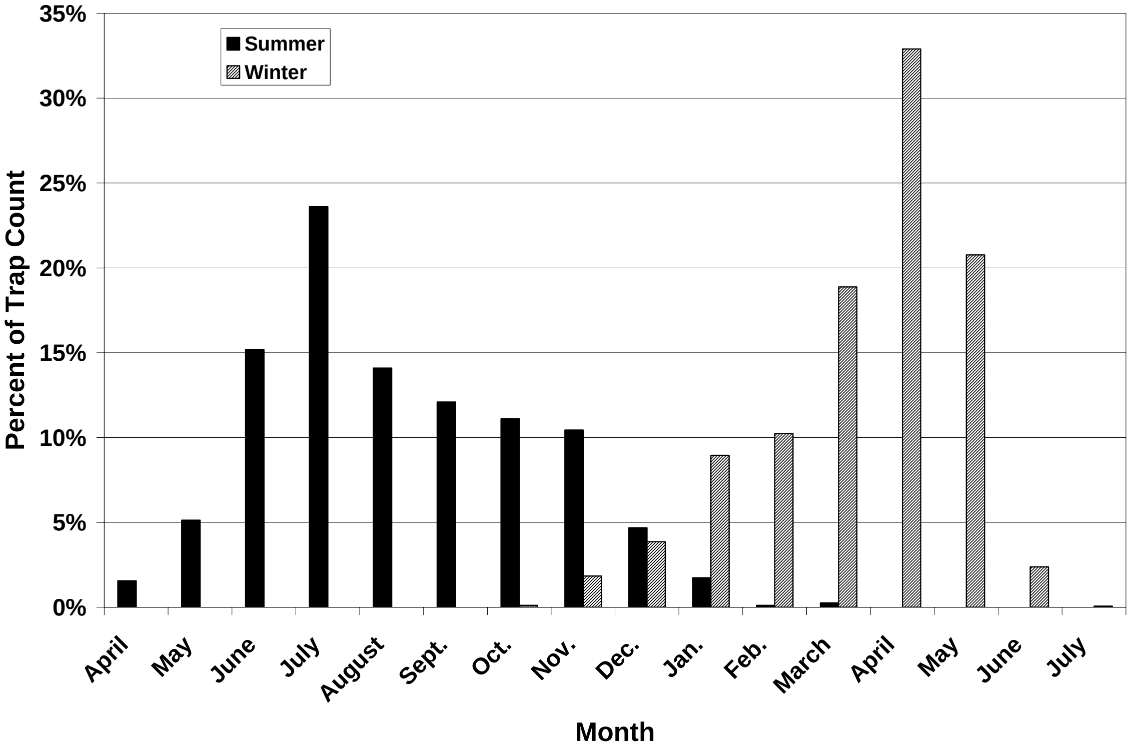


Figure 2-1. Average timing of natural-origin summer and winter steelhead past the Kalama River trap, 1976-1977 through 1995-1996 seasons.

The time period of spawning in the Kalama River is contracted relative to entry and migration past the trap. Leider et al. (1984) marked summer and winter steelhead prior to passing the fish upstream and subsequently monitored the date of spawning. In the three years of study, summer steelhead spawning occurred from December through April of the following year (Fig. 2-2). Peak spawning occurred in the month of February, 7 months months past the peak month of entry (July). Spawning of winter steelhead was observed from January through May, with most of the spawning occurring during the month of April (Fig. 2-3).

Estimates of spawn timing are available for only a limited number of other naturally-spawning populations of steelhead in Washington. This is primarily due to the difficulty of distinguishing natural and hatchery-origin spawners on the redds, but also reflects the challenging nature of counting redds in mid-winter. However, an understanding of the timing of spawning of natural-origin steelhead is important when evaluating potential genetic interactions with adult returns from hatchery programs. The best data set that we are aware of is for Snow Creek, a small stream that is a tributary to Discovery Bay and the Strait of Juan de Fuca. Prior to initiation of research at Snow

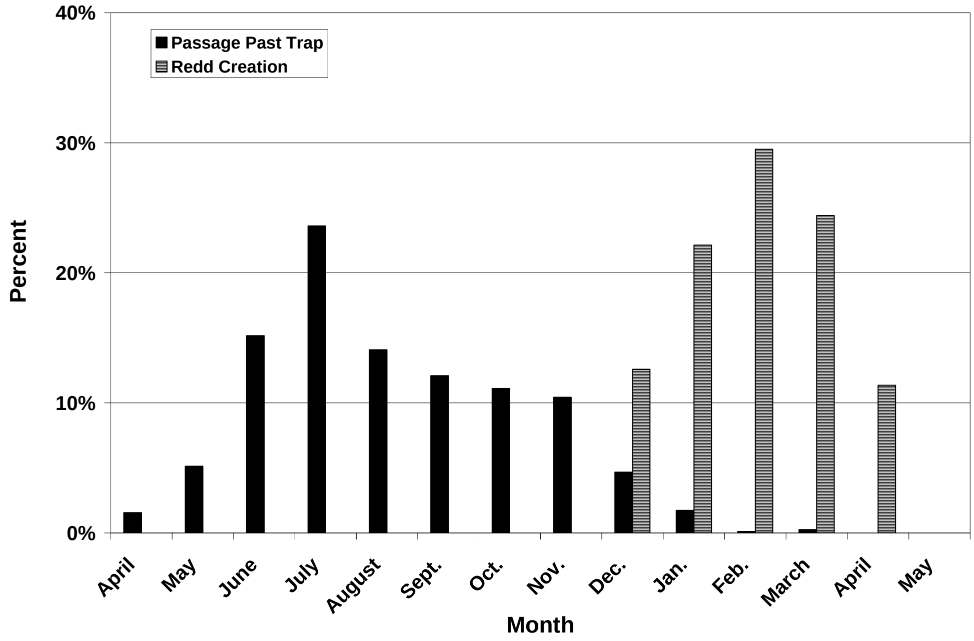


Figure 2-2. Average timing of natural-origin summer steelhead passage at the Kalama River trap (1976-1977 through 1995-1996 seasons) and redd creation (1979-1980 through 1981-1982 seasons).

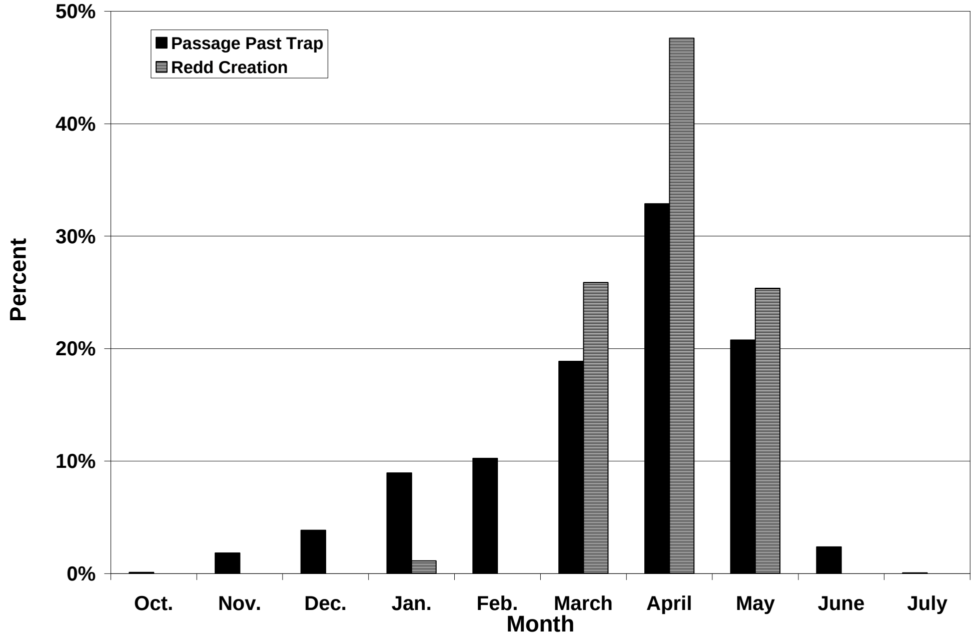


Figure 2-3. Average timing of natural-origin winter steelhead passage at the Kalama River trap (1976-1977 through 1995-1996 seasons) and redd creation (1979-1980 through 1981-1982 seasons).

Creek, no hatchery-origin smolts had been released into Snow Creek and, in the return years 1977-1978 and 1979-1980, any hatchery-origin strays from other watersheds were identified as they were passed upstream at a rack (Johnson et al. 1978; Johnson et al. 1980). Based on analysis of scale patterns, only one hatchery-origin steelhead is known to have been passed upstream during these two years. Redd surveys were conducted at approximately one week intervals with redds first observed on February 4 (1980) and the last new redds constructed were observed on May 24 (1978). Over the two years, the average date of redd construction was March 28 with a standard deviations of 18.1 days (Fig. 2-4).

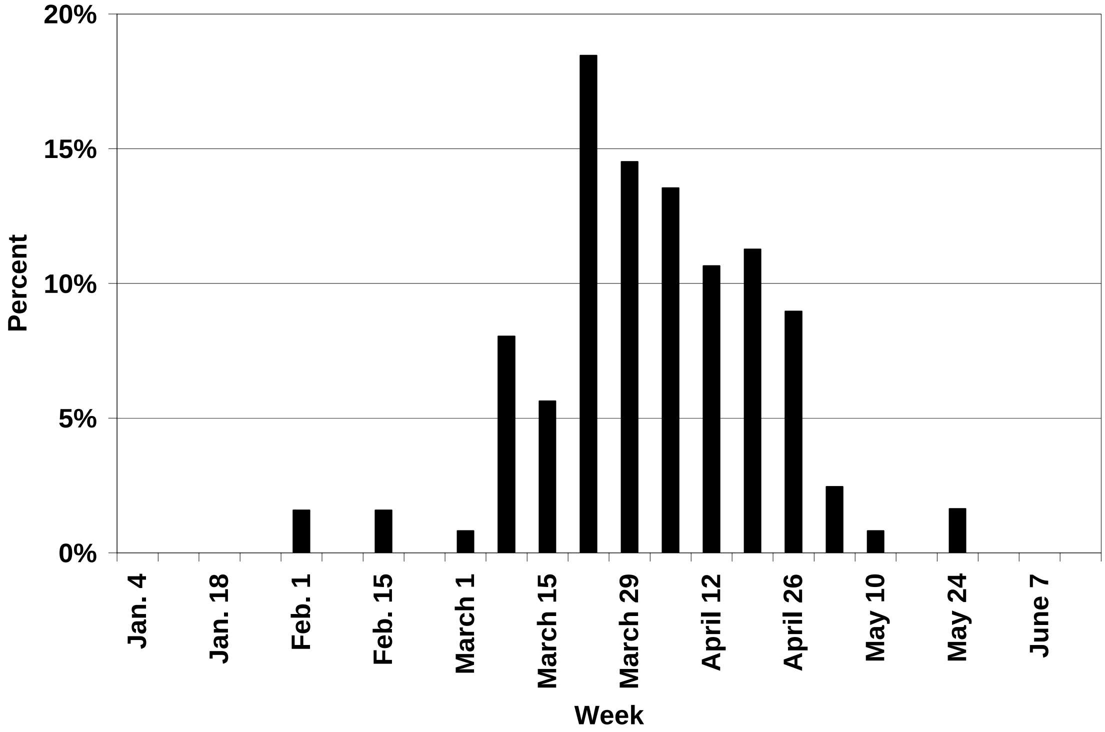


Figure 2-4. Average percent of total redds constructed by week for natural-origin winter steelhead in Snow Creek, 1977-1978 and 1979-1980 seasons.

More limited information on the spawn timing of winter steelhead is available for the Clearwater River, a tributary to the Queets River on the north Washington coast. Redd surveys were conducted in the mainstem of the Queets River and in tributaries on an irregular schedule in the years 1973 through 1980 (Cederholm 1984). Cederholm reported survey data for every year from 1973 through 1980, but 1978 was the only year with at least one survey in each of the months of January, February, and March. As in Snow Creek, no releases of hatchery-origin steelhead had occurred in the watershed in the years prior to the surveys. However, unlike Snow Creek, the incidence of hatchery-origin steelhead that may have strayed from other watersheds is not known. Cederholm found that redd construction appeared to occur earlier in the tributary streams than in the mainstem Clearwater River. The average date that a new redd was seen in the tributaries was March 27 versus April 21 in the mainstem of the Clearwater River (Table 2-1).

Table 2-1. Average date and standard deviation for observations of new redds for winter steelhead.

Location	Average date new redd observed	SD (days)	Years	Source
Snow Creek	March 28	18.1	1977-1978 1979-1980	Johnson et al. (1978); Johnson et al. (1980)
Clearwater River Tributaries	March 27	35.9	1977-1978	Cederholm (1984)
Clearwater River	April 21	20.4	1977-1978	Cederholm (1984)
Kalama River	April 12	23.1	1979-1980; 1980-1981; 1981-1982	Leider et al. (1984)

Significant complexity is introduced in fishery management and monitoring in watersheds with populations of both summer and winter steelhead. When developing fishing regulations, the abundance, spatial distribution, and run timing of summer and winter steelhead must be considered. Catch and escapement data must be collected, maintained, and analyzed separately for each run-timing component to accurately evaluate population productivity and status. Monitoring the smolt production from the adults of each run timing within a watershed may not be feasible because no visible differences exists between juvenile summer and winter steelhead. Although summer and winter run steelhead are generally quite similar genetically, new methods of DNA analysis may be able to distinguish smolts of each type. However, this would likely entail a substantial investment of staff time to sample the smolts and analyze the genetic samples.

2.4.2 Iteroparity

A species is called iteroparous if individuals can reproduce more than one time throughout their life. Steelhead and cutthroat (*Oncorhynchus clarkii*) are the only species of *Oncorhynchus* in Washington that typically display iteroparity. Male Chinook salmon (*Oncorhynchus tshawytscha*) that breed without migrating to marine waters may also spawn multiple times under unusual conditions (Unwin et al. 1999).

Adults that return to reproduce a second time are generally females (Withler 1966; Ward and Slaney 1988) that have been in marine waters for as little as 2-6 months but more typically one year. These repeat spawners can comprise a significant proportion of the run; up to 23% the total spawners have been repeat spawners in the Quillayute River (Table 2-2). More typically in Washington, 5-10% of the winter run is comprised of repeat spawners. The incidence of repeat spawners among summer steelhead in the interior Columbia Basin is lower, generally 0-5% of the run (Table 2-2).

Variations in the incidence of iteroparity among populations reflect both natural and anthropogenic factors. Natural factors include both the latitude and the distance of the migration inland (Withler 1966; Busby et al. 1996; Fleming 1998). A decreasing incidence of repeat spawners is evident for populations north of Oregon and for populations with substantial migration distances inland (e.g., tributaries to the upper Columbia River and Snake River). Anthropogenic factors can directly or indirectly effect the incidence of repeat spawners. Direct effects can include an increase in the mortality of kelts (e.g., Evans and Beaty (2001) describe dam passage mortality) or fishery related reductions in the number of spawning adults. Larson and Ward (1954), for example, suggest that the "larger percentage of re-spawners entering the catch in the Hoh River in 1948-49 was undoubtedly the result of the long periods of high water during the 1947-48 season, when flood conditions caused the sport catch and the Indian catch to drop to a low level." Anthropogenic factors may also indirectly affect the incidence of repeat spawners by changing the intensity of density-dependent processes, growth rates, or other processes that ultimately affect the age structure and maturation rates of the population (Fleming 1998).

The limited historical information available does not indicate that a change in the incidence of repeat spawners has occurred since at least the late 1940s. Larson and Ward (1954) compiled age data for winter steelhead from four rivers (Green, Hoh, Chehalis, and Cowlitz) and found that repeat spawners comprised an average of 6-10% of the run.

Iteroparity can significantly complicate analyses that attempt to define a relationship between the number of spawners and abundance in the subsequent generation. Traditional stock-recruit analyses, such as the Beverton-Holt or Ricker model, assume that all fish die after spawning. Although extensive mathematical theory and models have been developed for iteroparous species (see Quinn and Deriso 1999), these have rarely been applied to steelhead. If large variations in the frequency of repeat spawners occur, abundance forecasts that rely on the average frequency may have significant error.

2.4.3 Variable Length of Freshwater and Marine Residence

Steelhead can spend from 1-7 years in freshwater and 0-5 years in marine waters before returning to spawn (see Box 2-1 for a description of the methods used to determine the age of steelhead). However, the majority of winter steelhead in Washington smolt after two winters in freshwater and subsequently spend one winter in marine waters (age 2.1+)(Table 2-3). While that same life history pattern is seen for summer steelhead, the primary age class for summer steelhead in the Kalama, Yakima, and Wenatchee rivers spends two full winters in marine waters (age 2.2).

Estimating the age composition of the adult return can be difficult if a random sample of adults from throughout the run cannot be collected. Age and sex composition can vary during the return, and fishing can be size and age selective. In the Quillayute River, for example, winter steelhead that were in marine waters for two winters appear to return to the river prior to adults that spent just one winter in marine waters (Fig. 2-5). In the 12 return years of 1981-1982 through 1992-1993, the ratio of age 2.1+ to age 2.2+ adults in the sport catch averaged 0.7 in November and 2.6 in April. The percentage of repeat spawners in the sport fishery catch also increased during the season, averaging 1-2% in November and December but 8-9% in February and March (Fig. 2-6). Shapovalov and Taft (1954) also found that repeat spawners comprised a larger percentage of the latter part of the run in Waddell Creek, California.

Although providing a hedge against environmental variability, the multiplicity of freshwater and marine ages can make it difficult to estimate the productivity of a population. Since the production resulting from a single brood year can return over a period of many years, accurate estimates of productivity require that the age composition of the run be estimated in each year. Obtaining a random sample of adult steelhead can be difficult. Fishing gear is often size-selective and, because steelhead do not die immediately after spawning, finding spawned-out carcasses to sample for scales is rarely feasible. If large variations in age structure occur, abundance forecasts that rely on the average age at return may have significant error.

Table 2-2. Percentage of repeat spawners observed for natural-origin summer and winter steelhead at select locations Washington.

Watershed & Run	Geographic Location	Average % repeat spawners (range)	Source (years)
Summer Steelhead			
Kalama	Lower Columbia	7% (3-15%)	Hulett (pers. comm.) (1975-1976 through 1997-1998)
Touchet	Middle Columbia	4% (0-8%)	Bumgarner et al. (2004) (1993-1994 through 2004-2005)
Yakima	Middle Columbia	3%	Hockersmith et al. (1995) (1989-1990 through 1992-1993)
Wenatchee	Upper Columbia	0% (0-0%)	Murdoch (pers. comm.) (1997-1998 through 2004-2005)
Methow & Okanogan	Upper Columbia	1% (0-3%)	Murdoch (pers. comm.) (1997-1998 through 2004-2005)
Tucannon	Snake	1% (0-3%)	Bumgarner et al. (2004) (1999-2000 through 2004-2005)
Winter Steelhead			
Skagit	Puget Sound	6% (0-14%)	Bernard (pers. comm.) (1985-1986 through 2004-2005)
Snohomish	Puget Sound	9% (0-18%)	WDFW unpublished data (1980-1981 through 1991-1992)
Green	Puget Sound	6% (5-7%)	Meigs and Pautzke (1941) (1939-1940 through (1940-1941)
Green	Puget Sound	6% (0-19%)	Cropp (pers. comm.) (1977-1978 through 2004-2005)
Snow Creek	Puget Sound	9% (0-33%)	Johnson (pers. comm.) (1976-1977 through 2004-2005)
Hoh	Olympic Peninsula	10% (7-14%)	Larson and Ward (1954) (1948-1949 through 1949-1950)
Quillayute	Olympic Peninsula	11% (4-21%)	Cooper (pers. comm.) (1978-1979 through 2004-2005)
Chehalis	Washington Coast	9%	Larson and Ward (1954) (1947-1948)
Cowlitz	Lower Columbia	6% (4-8%)	Larson and Ward (1954) (1946-1947 through 1947-1948)
Kalama	Lower Columbia	9% (4-20%)	Hulett (pers. comm.) (1975-1976 through 1997-1998)

Table 2-3. Primary age classes of natural-origin summer and winter steelhead in Washington. % is average percentage of adult return comprised of that life history pattern.

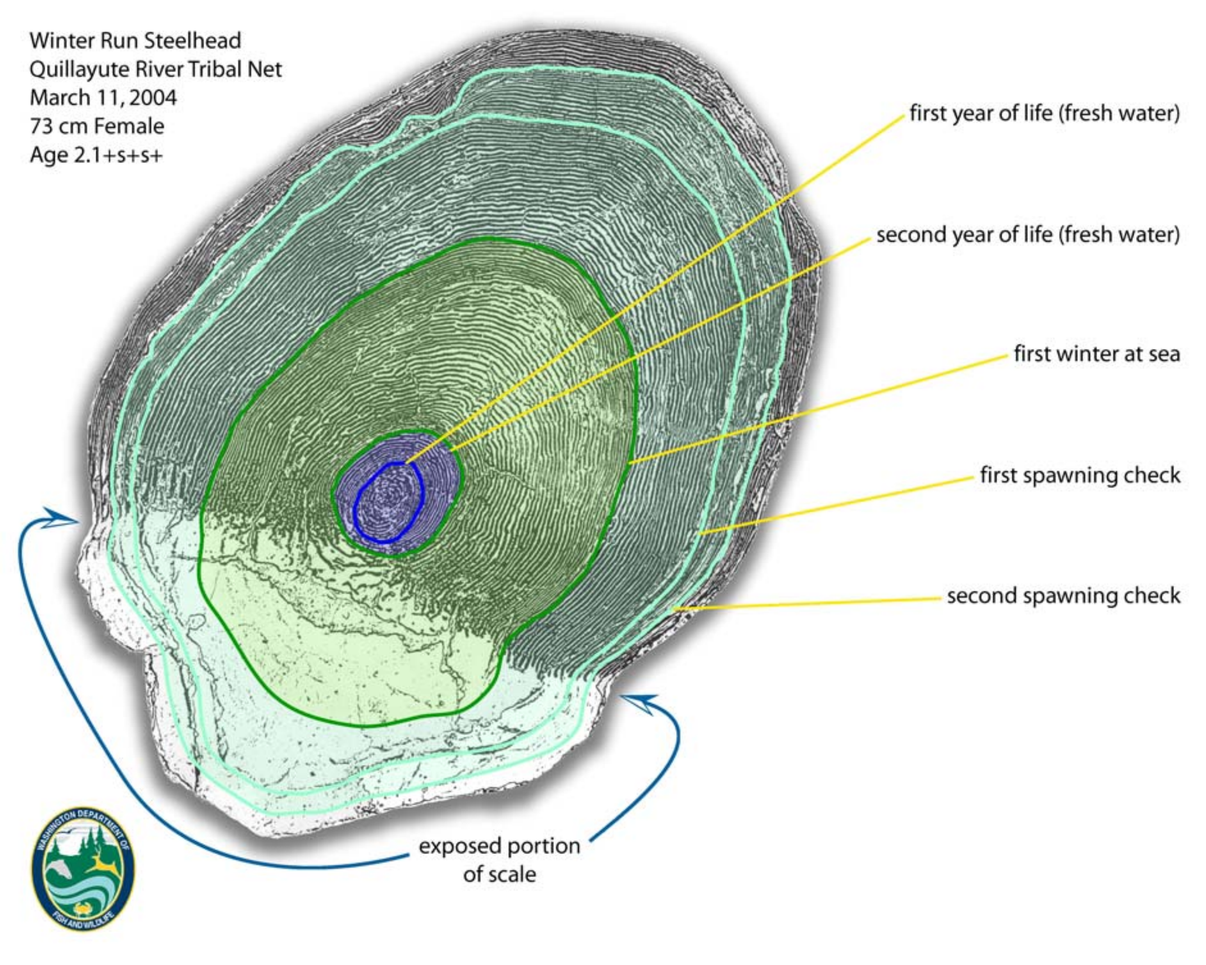
Watershed (sampling method)	Geographic location	Life history patterns		Source (years)
		Primary (%)	Secondary (%)	
Summer Steelhead				
Kalama (weir)	Lower Columbia	2.2 (61%)	2.1 (12%)	Hulett (pers. comm.) (1975-1976 through 1997-1998)
Yakima (weir)	Middle Columbia	2.2 (43%)	2.1 (26%)	Hockersmith et al. (1995) (1989-1990 through 1992-1993)
Touchet (weir)	Middle Columbia	2.1 (40%)	2.2 (35%)	Bumgarner et al. (2004) (1993-1994 through 2004-2005)
Wenatchee (weir)	Upper Columbia	2.2 (38%)	2.1 (30%)	Murdoch (pers. comm.) (1997-1998 through 2004-2005)
Methow & Okanogan (weir)	Upper Columbia	2.1 (42%)	2.2 (39%)	Murdoch (pers. comm.) (1997-1998 through 2004-2005)
Tucannon (weir)	Snake	2.1 (43%)	2.2 (31%)	Bumgarner et al. (2004) (1999-2000 through 2004-2005)
Winter Steelhead				
Skagit (sport catch)	Puget Sound	2.1+ (44%)	2.2+ (26%)	WDFW unpublished data[1] (1978-1979 through 1992-1993)
Green (sport catch)	Puget Sound	2.1+ (52%)	2.2+ (13%)	Meigs and Pautzke (1941) (1939-1940 through 1940-1941)
Green (sport catch)	Puget Sound	2.1+ (45%)	2.2+ (38%)	Cropp (pers. comm.)[2] (1977-1978 through 1989-1990)
Snow Creek (weir)	Puget Sound	2.1+ (66%)	2.2+ (9%)	Johnson (pers. comm.) (1976-1977 through 2004-2005)
Hoh (sport catch)	Olympic Peninsula	2.1+ (75%)	2.2+ (14%)	Larson and Ward (1954) (1948-1949 through 1949-1950)
Quillayute (sport catch)	Olympic Peninsula	2.1+ (48%)	2.2+ (33%)	WDFW unpublished data (1979-1980 through 1992-1993)
Chehalis (sport catch)	Washington Coast	2.1+ (66%)	2.2+ (15%)	Larson and Ward (1954) (1947-1948)
Cowlitz (sport catch)	Lower Columbia	2.1+ (58%)	2.2+ (22%)	Larson and Ward (1954) (1946-1947 through 1947-1948)
Kalama (weir)	Lower Columbia	2.1+ (51%)	2.2+ (28%)	Hulett (pers. comm.) (1976-1977 through 1998-1999)

[1] 1982-1983, 1983-1984, and 1991-1992 seasons excluded because fishery closed prior to the end of March.

[2] 1983-1984 and 1984-1985 seasons excluded because fishery closed prior to the end of March.

Box 2-1. Ageing Steelhead

The age of a steelhead is often determined from the pattern of rings, or circuli, observed on a scale (see picture below). The circuli are laid down on the scale as the fish grows, with closely spaced circuli corresponding to periods of slow growth. During the winter, the prolonged period of reduced growth results in an area on the scale, termed the annulus, with a substantial number of closely spaced circuli. Counting the number of annuli provides a means to determine the age of the fish from which the scale was removed. The return and residence of adults in freshwater results in a loss of body mass and resorption of the edge of the scale. The number of times a fish has previously returned to freshwater can be determined from the number of areas of resorption.



Box 2-1. Ageing Steelhead (continued)

The Washington Department of Fish and Wildlife uses a modified version of the Narver and Withler (1971) scale aging method to age steelhead scales. This ageing method for steelhead consists of chronological arrangements of the following symbols:

“.” = initial saltwater entry.

Arabic numerals = number of consecutive winters in freshwater or in saltwater. To qualify for a numeral the annulus must be followed by more widely spaced circuli (i.e.: spring or summer growth).

“+” = used for winter-run steelhead only, indicates less than one year in salt or freshwater, usually denotes spring and/or summer circuli but may include some winter circuli (after a period (“**.**”) a “+” denotes saltwater existence).

“S” = spawning check, represents approximately 1 to 6 months for winter-run fish or 6 to 12 months for summer-run fish.

“+S” = one chronological year for winter-run steelhead.

“W” = Wild designation, used to identify natural-origin steelhead that smolted and entered saltwater after one year in freshwater.

Combinations of freshwater age, total age, and the corresponding WDFW age designation for winter steelhead are illustrated in the table below.

Freshwater winter(s)	**Total age (years)**				
	2	**3**	**4**	**5**	**6**
1	W1.+	W1.1+	W1.2+	W1.3+	
			W1.1+S+	W1.1+S+S+	W1.1+S+S+S+
				W1.2+S+	W1.2+S+S+
2		2.+	2.1+	2.2+	2.3+
			2.+S+	2.+S+S+	2.+S+S+S+
				2.1+S+	2.1+S+S+
					2.2+S+

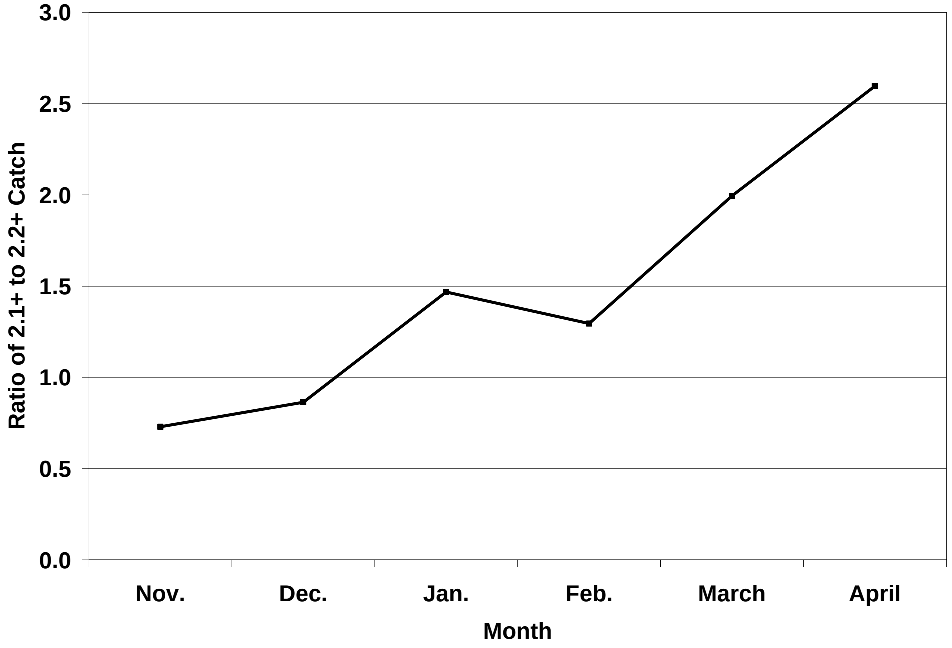


Figure 2-5. Average ratio of age 2.1+ to age 2.2+ natural-origin winter steelhead in the Quillayute River sport fishery, 1981-1982 through 1992-1993 seasons.

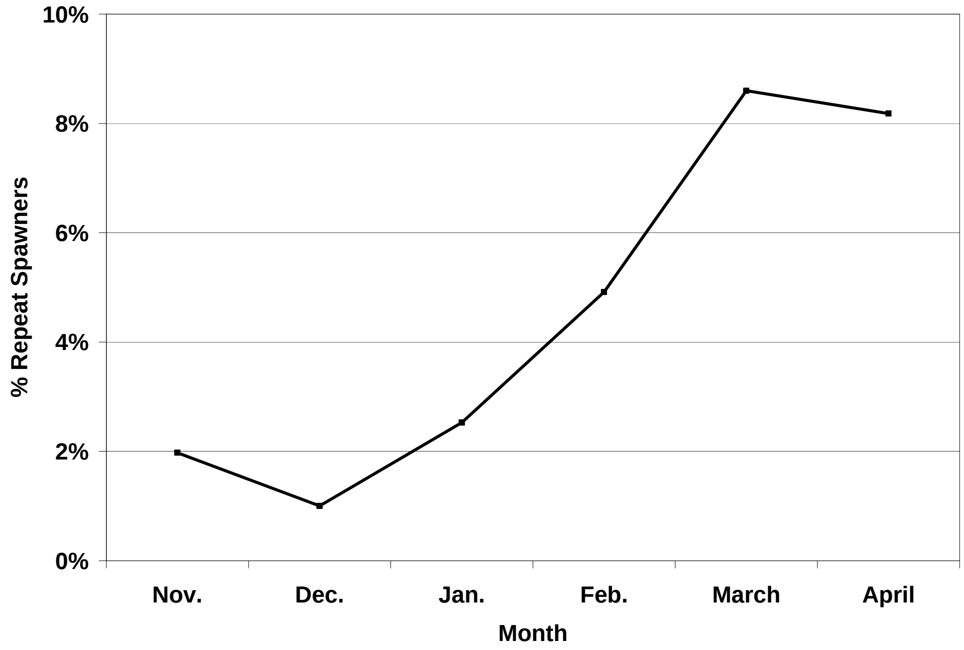


Figure 2-6. Average percentage of the Quillayute River sport catch of natural-origin winter steelhead comprised of repeat spawners, 1981-1992 through 1992-1993 seasons.

2.5 Discussion

O. mykiss displays a wide range of life history diversity that enables the species to persist in highly variable environments. The diversity of life history characteristics expressed by *O. mykiss* include the potential presence of resident and anadromous forms, varying periods of freshwater and ocean residency, summer and winter adult return timing to freshwater, and plasticity of life history between generations. The emphasis on life history diversity as a strategy for persistence contrasts with some other species of anadromous *Oncorhynchus*, such as pink salmon, that exhibit relatively small variation in life history characteristics.

Our review of the biological characteristics of *O. mykiss* suggests that maintenance of diversity, or increasing diversity where losses have occurred, should be a key consideration in the development of management plans. As the population of Washington State expands, and the potential for habitat degradation increases, this diversity provides O. mykiss with the potential to maintain viable populations. Broad-scale modifications of habitat, such as might result from global warming, further reinforce the importance of maintaining the diversity of *O. mykiss*. Similar considerations led the RSRP (2004) to conclude that "recovery plans for *O. mykiss* ESUs listed under the Endangered Species Act should place a high priority on the maintenance and restoration of naturally occurring life-history diversity, including the restoration of extirpated anadromous runs." The current diversity of steelhead populations in Washington, and monitoring needs, is discussed further in Chapter 6, Diversity and Spatial Structure.

Theoretical analyses and empirical data suggest that shifts in the relative abundance of the anadromous and resident life history types may occur in response to habitat or fishery perturbations. If reductions in the abundance of steelhead are partially or completely compensated for by an increase in the abundance of rainbow trout, assessments that evaluate trends in the abundance of steelhead, without consideration of the resident life history type, may not accurately portray the status of *O. mykiss*. The population viability analyses presented in Chapter 7 (Abundance and Productivity), for example, relies only on the escapement of steelhead. Estimates of extinction risk resulting from this analysis are likely to have a positive bias for populations comprised of both steelhead and rainbow trout.

2.6 Findings and Recommendations

Finding 2-1. *O. mykiss* **displays a wide range of life history diversity that enables the species to persist in highly variable environments.** The diversity of life history characteristics expressed by *O. mykiss* include the presence of resident (rainbow or redband trout) and anadromous (steelhead) forms , varying periods of freshwater and ocean residency, summer and winter adult return timing to freshwater, and plasticity of life history between generations. The emphasis on life history diversity as a strategy for persistence contrasts with some other species of anadromous *Oncorhynchus*, such as pink salmon (*Oncorhynchus gorbuscha*), which exhibit relatively small variation in life history characteristics.

> *Recommendation 2-1.* Pursue opportunities to preserve and restore population structure, spatial structure, and within-population diversity through careful review of harvest, hatchery, and habitat management and implementation of improved strategies.
>
> *Recommendation 2-2.* Develop improved tools that relate environmental factors (e.g., climate, water temperature, stream flow) and the physiological status (e.g., length, growth rate) of juvenile *O. mykiss* to the diversity, spatial structure, abundance, and productivity of steelhead populations.

Finding 2-2. The diverse life histories of steelhead introduce management complexity. Juvenile *O. mykiss* observed in freshwater may have originated from resident or anadromous parents, and anadromous parents may be of summer or winter return-timing. This diversity can make the collection and interpretation of juvenile genetic or abundance data difficult.

The adult run of steelhead may be comprised of fish with multiple return-timing (summer and winter), a variable number of years of freshwater and marine residence, and adults that previously spawned. Understanding the effects of the environment and the number of spawners on the dynamics of the population requires age and run-timing specific estimates of fishing mortality and escapement. In some populations, further management complexity may be introduced by the contribution of resident *O. mykiss* to the production of steelhead.

Finding 2-3. The complex reproductive and ecological interactions between anadromous and resident forms of O. mykiss may necessitate a holistic assessment of management actions. Initial research suggests that extensive reproductive and ecological interactions can exist between resident and anadromous *O. mykiss* in some watersheds. These interactions can include breeding between resident and anadromous forms and the production of anadromous progeny from one or more resident parents.

Where substantial interactions occur, predicting or understanding the response of the population to management actions will require a holistic assessment of resident and anadromous *O. mykiss*.

> *Recommendation 2-3.* Build on studies in the Cedar River, Yakima River, and other locations to develop a better understanding of the relationship of resident and anadromous *O. mykiss*. From these studies, develop improved tools to assess the potential effects of management actions and enhanced management strategies that effectively address resident and anadromous life history forms.

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Chapter 3
Artificial Production

Key Questions:

- a) *What are the potential benefits of artificial production programs?*
- b) *What are the types of hatchery programs currently operated for steelhead in Washington and what has been the survival rate for the juveniles released?*
- c) *What is the fitness (or adult-to-adult survival) of naturally-spawning steelhead of hatchery-origin relative to the indigenous population?*
- d) *What are the potential genetic and ecological effects of artificial production on natural populations? How do hatchery facilities, hatchery effluent, or the release of diseased fish affect natural populations?*

3.1 Introduction

Over 9.1 million juvenile steelhead were released from artificial production programs in Washington in 2000, a nearly four-fold increase from 1960 (Fig. 3-1). In this chapter we evaluate the economic and conservation benefits of hatchery programs as well as the potential risks they may pose to natural populations.

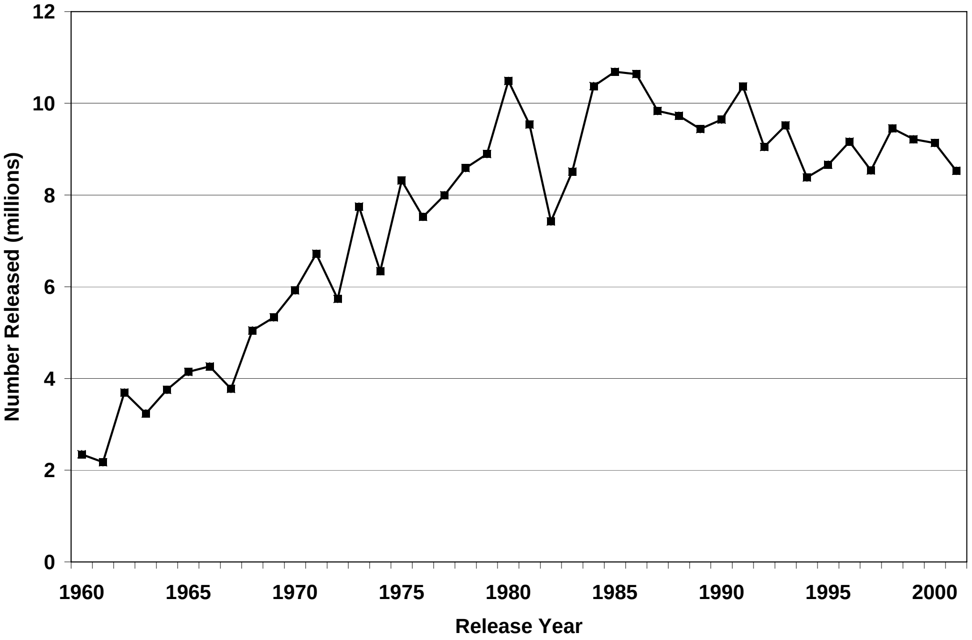

Figure 3-1. Tribal, federal, and state releases of summer and winter steelhead smolts in Washington.

3.2 Artificial Production Programs

3.2.1 Programs Types and Benefits

The primary objectives of hatchery programs are to enhance harvest opportunities or to provide recovery, or conservation benefits. Hatchery-origin steelhead provide substantial recreational and economic benefits to Washington State residents and comprise the vast majority of the recreational fishery harvest of steelhead (96% of recreational fishery harvest in 2003-2004). In the nine seasons from 1995-1996 through 2003-2004, recreational anglers harvested an average of 99,300 hatchery-origin steelhead. With an estimated expenditure of $999 per fish caught, (see Box 3-1, Economic Analysis), the average total expenditures associated with hatchery-origin steelhead was approximately $99 million. The total economic impact of this catch is estimated at over $188 million. The average annual production of steelhead from hatcheries in Washington during this time period was 8.8 million fish. With an estimated production cost of about $0.50 per fish, the cost of steelhead released exceeds $4.4 million per year but provides a benefit:cost ratio of more than 40:1 for recreational fisheries alone.

Photo 3-1. The total economic impact of the catch of hatchery-origin steelhead in recreational fisheries is estimated at over $188 million annually. Photo source: unknown.

Hatchery programs can also have significant conservation benefits. According to the NMFS "Policy on the Consideration of Hatchery-Origin Fish in Endangered Species Act Listing Determination for Pacific Salmon and Steelhead" (70 FR 37204), hatchery-origin fish can positively affect the status of an ESU by:

1) "contributing to increasing abundance and productivity of the natural populations in the ESU";
2) "improving spatial distribution";
3) "serving as a source population for repopulating unoccupied habitat"; and
4) "conserving genetic resources of depressed natural populations in the ESU".

Hatchery programs, although quite diverse in details, can be simply classified by management objective and reproductive strategy used to achieve the objective

Box 3-1. Economic Analysis of Recreational Harvest of Steelhead

The economic analysis of the recreational harvest of steelhead is derived from a survey conducted by the U.S. Census Bureau in 2001. Detailed information on sampling procedures, response rates, and survey results can be found in U.S. Department of the Interior et al. (2003) and Southwick and Associates (2003).

We assessed the annual expenditures and economic benefit of the recreational harvest of steelhead in Washington using the following five steps: 1) estimate the average expenditures per day of steelhead fishing in the western states; 2) estimate the total expenditures of steelhead fishers in Washington; 3) estimate the expenditures per steelhead caught by recreational fishers; 4) estimate the economic output per steelhead caught by recreational fishers; and 5) estimate the average expenditures and economic output associated with the catch of hatchery-origin steelhead.

Step 1. Average Expenditures Per Day of Steelhead Fishing

The average expenditure per day of steelhead fishing was estimated from data in Southwick and Associates for steelhead fishers in the western states.

Expenditures	$327,088,084	Southwick and Associates, page 186
Days Fished for Steelhead	4,911,643	Southwick and Associates, page 89
Expenditures per Day	$67	

Step 2. Total Expenditures by Steelhead Fishers in Washington

We estimated the total expenditures by steelhead fishers in Washington by multiplying the total estimated days of steelhead fishing by the average expenditures per day computed in Step 1. This assumes that steelhead fishers in Washington expend the same amount of money per day of fishing as the average steelhead fisher in the western states.

Expenditures per Day	$67	Step 1
Days Fished for Steelhead	2,483,000	U.S. Department of Interior et al. (2003), Table 7
Total Expenditures	$166,361,000	

Step 3. Expenditures per Steelhead Caught by Steelhead Fishers

We estimated the expenditures per steelhead caught by dividing the total expenditures computed in Step 2 by the total catch of steelhead in the 2001 calendar year.

Total Expenditures	166,361,000	Step 2
2001 Calendar Year Catch	166,453	WDFW catch estimates
Expenditures per Steelhead Caught	$999	

Box 3-1 (continued).

Step 4. Economic Output per Steelhead Caught
We estimated the economic output per steelhead caught by multiplying the expenditures per steelhead caught by an economic output multiplier. The economic multiplier estimates the ripple effect of how each dollar spent by a fisher "increase another person's income, enabling the person (or business) to spend more, which in turn increases income for someone else" (ASA 2002). We assumed that the economic multiplier computed for the aggregate of all types of sport fishing in Washington was applicable to steelhead fishers.

Expenditures per Steelhead Caught	$999	Step 3
Economic Multiplier	1.9	ASA (2002)
Economic Benefit per Steelhead Caught	$1,898	

Step 5. Average Expenditures and Economic Output
We estimated the average expenditures and economic output associated with the catch of steelhead of hatchery origin by multiplying the average catch in the 1995-1996 through 2003-2004 seasons by the expenditures (Step 3) and economic output (Step 4) per steelhead caught. All economic analyses are in 2001 dollars.

Region	Average catch hatchery-origin steelhead	Recreational fisher expenditures	Economic output
Puget Sound & Strait of Juan de Fuca	13,981	$14.0 million	$26.5 million
Washington Coast	12,625	$12.6 million	$24.0 million
Columbia Basin	72,657	$72.6 million	$137.9 million
Total	99,263	$99.2 million	$188.4 million

The estimated expenditures by recreational fishers associated with the catch of hatchery-origin steelhead is approximately $99 million, with an estimated economic output of $188 million.

(Table 3-1). The two primary management objectives for hatchery programs are recovery/conservation or harvest. Programs with a harvest objective are often mitigation for production lost through the construction of dams or other anthropogenic factors. For example, the Lower Snake River Compensation Plan is a congressionally authorized mitigation program that is intended to compensate for natural production lost as a result of the construction of dams in the Snake River basin. The two reproductive strategies used to achieve the objective, integrated or isolated, differ in the degree of reproductive interaction between natural and hatchery-origin adults in the hatchery and natural spawning areas. Integrated programs intend fish of natural- and hatchery-origin to be reproductively connected to represent a single population. This requires natural-origin adults in the hatchery broodstock, and hatchery-origin adults in the natural spawning areas. Isolated programs (called segregated in HSRG 2004) intend for the hatchery population to be a distinct and reproductively isolated from naturally-spawning populations. Strategy selection is program- and watershed-specific, and depends on the status of the natural population, the quality of the habitat, the ability to collect natural-origin broodstock, the ability to control the number of hatchery-origin adults in natural spawning areas, and the objectives of the program.

Table 3-1 Artificial production strategies and their primary uses (from PSTT and WDFW 2004).

Primary Management Objective	Reproductive Strategy	
	Integrated Production	**Isolated Production**
Recovery	• Prevent extinction • Increase natural origin recruits using the local stock • Reintroduction • Research	• Prevent extinction • Create 'reserve' population in case other recovery options fail • Gene banking until reintroduction • Research
Harvest	• When isolated approach is not feasible • Maintaining local stocks • During rebuilding • Mitigation • Research	• Create new or enhance existing fishing opportunities • Mitigation • Allocation • Research

Many of the steelhead programs with a recovery objective are located in the Snake River and Upper Columbia basins. In the Upper Columbia River region, steelhead programs operated from Eastbank and Wells hatcheries produce summer steelhead with release sites that include the Wenatchee River and its tributaries, the Methow River and its tributaries, and the Okanogan River and its tributaries. In the biological opinion for this program, the NMFS (2002) concluded that: "Overall, the artificial propagation programs provide a benefit to the endangered UCR steelhead ESU by boosting the population abundance, while maintaining or increasing the genetic diversity, and spatial distribution."

At broodstock collection sites in Washington, there are 33 facilities that gather brood stock for isolated harvest programs, 4 sites for integrated harvest, 1 site for integrated recovery, 8 sites for integrated harvest and recovery, 2 sites for integrated harvest and research, and 2 sites for integrated recovery and research (Table 3-2).

Isolated artificial production programs for steelhead in western Washington rely almost exclusively on broodstock that originated from one of two sources – Chambers Creek winter steelhead or Skamania summer steelhead. The Chambers Creek winter steelhead (South Puget Sound) program was initiated in 1945 at the South Tacoma Hatchery and the Skamania summer steelhead (lower Columbia River) program in 1956 (Crawford 1979). Both stocks were developed to produce smolts in a one-year rearing program compared to the typical two year freshwater residence of steelhead rearing in the natural habitat of Washington (Pautzke and Meigs 1940; Larson and Ward 1954; Crawford 1979). The Chambers Creek stock was selected for early spawn timing; maturity in adults was further accelerated in the warm (55-58° F) water at Chambers Creek Hatchery and nearby South Tacoma Hatchery. Consequently, adult return timing advanced from March-May to December-January, with most spawning completed by the end of January. The Skamania Hatchery summer steelhead stock was started with broodstock from the Washougal and Klickitat rivers. Skamania steelhead were also selected for early spawn timing and adult fish now typically spawn in December-January compared to February-April for wild fish (Crawford 1979).

Programs that use an isolated reproductive strategy can use eggs (or juveniles) that originate from either adults returning to the facility, other facilities within the watershed, or facilities outside of the watershed. Historically, the latter approach was often used in western Washington because of the operational simplicity, flexibility, and cost. Eggs were imported from a few centrally located facilities (e.g., South Tacoma Hatchery) with adequate water temperatures to assure development was accelerated to meet a one-year release schedule. Alternatively, if broodstock are collected onsite, additional costs may be incurred for spawning and incubation, and fishery management may have to be adjusted to ensure sufficient adults return to the facility to meet broodstock requirements. To reduce out of watershed transfers and accelerate early growth and development to achieve optimum release size of juvenile steelhead within 12 to 16 months, heated water systems ($5,000 capital, $2,500 annual operating costs) have been installed at some hatcheries.

Table 3-2. Steelhead broodstock collection sites, broodstock origin, run timing, program strategy, and program objective. (Run timing is defined as W for Winter or S for Summer).

Geographic Location	Facility	Broodstock Origin	Run Timing	Strategy	Objective
Puget Sound Hood Canal	Kendall Creek	Chambers	W	Isolated	Harvest
	Marblemount	Chambers	W	Isolated	Harvest
	Barnaby Slough	Chambers	W	Isolated	Harvest
	Whitehorse Ponds	Chambers	W	Isolated	Harvest
	Reiter Ponds	Skamania	S	Isolated	Harvest
	Tokul Creek	Chambers	W	Isolated	Harvest
	Palmer Ponds	Chambers	W	Isolated	Harvest
	Palmer Ponds	Skamania	S	Isolated	Harvest
	Soos	Chambers	W	Isolated	Harvest
	Soos[1]	Local	W	Integrated	Recovery
	Puyallup	Chambers	W	Isolated	Harvest
	Hamma Hamma [2]	Local	W	Integrated	Recovery & Research
Strait of Juan de Fuca	Dungeness	Chambers	W	Isolated	Harvest
	Lower Elwha [3]	Chambers	W	Isolated	Harvest
	Hoko [4]	Chambers	W	Isolated	Harvest
Olympic Peninsula	Makah NFH [5]	Quinault	W	Isolated	Harvest
	Snider Creek	Local	W	Integrated	Harvest
	Bogachiel	Chambers	W	Isolated	Harvest
	Bogachiel	Skamania	S	Isolated	Harvest
	Quinault NFH [5]	Unknown	W	Isolated	Harvest
	Lake Quinault [6]	Local	W	Integrated	Harvest
Grays Harbor	Humptulips	Chambers	W	Isolated	Harvest
	Lake Aberdeen	Chambers	W	Isolated	Harvest
	Lake Aberdeen	Local	W	Integrated	Harvest
	Lake Aberdeen	Skamania	S	Isolated	Harvest
	Bingham	Local	W	Integrated	Harvest & Recovery
	Skookumchuck	Local	W	Integrated	Harvest
	Eight [7]	Local	W	Integrated	Harvest & Recovery

[1] Program operated by Muckleshoot Tribe.

[2] Cooperative program with Long Live the Kings and NOAA.

[3] Program operated by Lower Elwha Klallam Tribe.

[4] Program operated by the Makah Tribe.

[5] Program operated by the Fish and Wildlife Service.

[6] Program operated by the Quinault Indian Nation.

[7] Cooperative program with the Upper Chehalis Fisheries Enhancement Group.

Table 3-2 (continued). Steelhead broodstock collection sites, broodstock origin, race, program strategy, and program objective. (Run timing is defined as W for Winter or S for Summer).

Geographic Location	Facility	Broodstock Origin	Run Timing	Strategy	Objective
Willapa Bay	Forks Creek	Chambers	W	Isolated	Harvest
	Naselle	Chambers	W	Isolated	Harvest
Lower Columbia	Elochoman	Chambers	W	Isolated	Harvest
	Cowlitz Trout	Local	W	Integrated	Harvest & Recovery
	Cowlitz Trout	Chambers	W	Isolated	Harvest
	Cowlitz Trout	Skamania	S	Isolated	Harvest
	Kalama Falls	Chambers	W	Isolated	Harvest
	Kalama Falls	Local	W	Integrated	Harvest & Research
	Kalama Falls	Skamania	S	Isolated	Harvest
	Kalama Falls	Local	S	Integrated	Harvest & Research
	Merwin	Chambers	W	Isolated	Harvest
	Merwin	Skamania	S	Isolated	Harvest
	Skamania	Chambers	W	Isolated	Harvest
	Skamania	Skamania	S	Isolated	Harvest
Middle Columbia	Cle Elum	Local	S	Integrated	Recovery & Research
	Lyons Ferry	Local (Touchet)	S	Integrated	Harvest & Recovery
Upper Columbia	Eastbank	Wenatchee	S	Integrated	Harvest & Recovery
	Wells	Local (Methow/ Okanogan)	S	Integrated	Harvest & Recovery
	Cassimer Bar[1]	Local (Okanogan)	S	Integrated	Harvest & Recovery
Snake River	Cottonwood	Wallowa	S	Isolated	Harvest
	Lyons Ferry	Wallowa Wells	S	Isolated	Harvest
	Lyons Ferry	Local (Touchet)	S	Integrated	Harvest Recovery

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[1] Program operated by the Confederated Tribes of the Colville Reservation.

An integrated program requires collection and spawning of natural-origin steelhead brood stock throughout the protracted return and spawn. In addition, heated incubation water and higher protein diets may be necessary for progeny to achieve the optimal release size for survival. Replacing a 150,000 juvenile steelhead isolated program with an integrated late brood stock program may cost about $5,000 in initial capital, and $12,000 in annual operating costs ($4,000 energy, $8,000 in feed costs). Additional costs would be incurred to collect natural-origin broodstock based upon specific hatchery needs to include traps, holding structures, transport trucks for broodstock collected through angling efforts during the protracted adult return, etc.

A relatively new method for increasing the abundance of natural-origin adult steelhead, which takes advantage of their iteroparity nature, has been the reconditioning of spawned out adults (kelts). This is especially important on the Columbia River, where repeat spawning is complicated by survival through the dams (Wertheimer and Evans 2005). However, the dams also afford the opportunity to collect steelhead kelts for reconditioning (Evans and Beaty 2001). On the Yakima River, kelts are captured at the Chandler Canal and directed into the adjacent Yakama Nation hatchery in Prosser. The kelts are treated for parasites and pathogens and restarted on feed to regain body condition. Some fish are reconditioned for a short time (one to three months) and then transported for release downstream of Bonneville Dam to return to the ocean. Others are held and released the following winter in the Yakima River to spawn. In 2004, survival of kelts from capture to release for short-term reconditioning was 79%, while long-term reconditioning was 40% (Hatch et al. 2004; Branstetter et al. 2005). Reconditioned fish radio-tagged and released in the Yakima River have subsequently been detected in spawning tributaries (Branstetter et al. 2005). Reconditioning efforts require cool well water, adult holding areas, labor and special diet, but the increase to natural production could be relatively high through a minimally invasive manner.

3.2.2 Survival Rates of Hatchery Fish

Factors Affecting Survival Rates

One important performance measure for programs with either a harvest or recovery objective is the survival rate, or the number of adult fish that return per juvenile released. Research indicates that hatchery steelhead have the highest survival rate when released at 75-90 grams (Larson and Ward 1955; Royal 1973; Wagner et al. 1963; Buchanan 1977; Tipping et al.1995; Tipping 1997) with a condition factor of 0.90-0.99 (Tipping et al. 1995; Tipping and Byrne 1996) starting in mid-April through mid-May (Wagner 1968; Royal 1973; Gearheard 1981). In addition, rearing fish in semi-natural rearing ponds enhances post-release survival (Tipping 1998a; 2001a), forced releases outperform volitional releases (Wagner 1968; Evenson and Ewing 1992) and seasonally cool water temperatures appear to increase post-release survival (Bjorn 1984). Juvenile steelhead are generally indifferent to rearing factors such as density and loading (Tipping et al. 2004), stress from trucking (Columbia River Transportation Ad Hoc Review Group 1992; Tipping 1998b), hand- versus demand- feeding (Tipping 2001b), exercise (Evenson and Ewing 1993), and acclimation (Kenaston et al. 2001) in the range of conditions typically encountered in WDFW facilities. Precocity, an undesired by-product of hatchery rearing (McMichael et al. 1997), increases with growth rates and may be hatchery specific (Tipping et al. 2003).

NATURES and Semi-Natural Rearing

Natural rearing systems (NATURES) rearing involves adding materials or altering culture methods so juvenile salmonids are exposed to a more natural environment that also increases their adult survival. Since wild fish commonly have greater adult survival than hatchery fish, naturalizing the hatchery environment has potential to increase adult survival of hatchery fish. Obviously, if NATURES rearing increased adult survivals, great economic benefit would result at relatively little expense. Earthen/gravel rearing ponds are commonly used semi-natural hatchery vessels that generally produce better quality smolts than fish reared in concrete raceways (Piper et al. 1992).

Maynard et al. (1995) reviewed semi-natural culture strategies for enhancing survivals of anadromous salmonids. These included rearing fish over natural substrates for proper cryptic coloration, training fish to avoid predators, exercise to enhance the fish's ability to escape predation, supplementing with live food to improve foraging ability, and reducing rearing densities. General results from these studies are summarized below:

1) Survival of subyearling Chinook salmon is usually improved with NATURES enhancements that include camouflage covers, structure (suspended evergreen trees) and substrate. Of these, substrate may be the most important factor as it improves cryptic coloration of fish and thereby reduces predator detection.
2) Yearling Chinook and coho salmon survival is usually not improved with NATURES enhancements. Yearling smolts are silvery in color and exhibit rapid emigration compared to subyearling Chinook salmon.
3) Adult salmonid survival is enhanced when fish are reared in semi-natural earthen ponds versus concrete raceways, even when fish are placed in the pond for a short time prior to release.

Several studies have been conducted on the effects of the rearing environment on survival rates of steelhead and cutthroat smolts. An experiment was conducted at the Cowlitz Trout Hatchery to determine relative adult survivals to steelhead by adding structure to a semi-natural earthen pond (Tipping, unpublished). About 5,000 denuded evergreen trees were added to one 5-acre pond while a second similar pond was used as a control. Similar numbers of fish were reared and released from both ponds and fish were released in 1996-1998. Adult fish recoveries were similar, 0.43% and 0.44% for control and NATURES fish, respectively.

An ongoing experiment at Marblemount Hatchery involves steelhead reared in an earthen pond while a second similar pond is asphalt lined (Tipping, unpublished). Adult returns from the first two of three releases were significantly greater for fish reared in the earthen pond than the asphalt pond. The 2-salt recoveries from the last release also had significantly more fish recovered from the earthen pond than the asphalt pond.

In an experiment at the Cowlitz Trout Hatchery, adult survival of sea-run cutthroat trout reared in a semi-natural rearing pond was 60% greater than that of fish reared in concrete raceways (Tipping 1998a). A subsequent study found fish placed in a semi-natural pond for four to seven months before release had 160% greater adult survival than raceway-reared fish, while fish reared for only one month in the semi-natural pond prior to release had 98% greater adult survival than raceway-reared fish (Tipping 2001a). So, even a one-month exposure to the pond environment nearly doubled adult survival. Possible reasons for the improved survival of semi-natural pond fish included 1) reduced rearing density; 2) reduced condition factor (K), which has been associated with migrating versus non-migrating steelhead smolts (Ewing et al. 1984; Tipping et al. 1995); 3) possible cryptic coloration differences which might help fish avoid predation (Donelly and Whoriskey 1991; Maynard et al. 1995); and 4) increased exposure to natural feed organisms which thrive in mud bottoms and may help fish in post-release foraging ability (Savino et al. 1993; Maynard et al. 1996).

Regional and Temporal Trends in Survival Rates

We computed survival rates for a number of hatchery programs throughout the state to evaluate regional and temporal trends. In general, we attempted to select hatchery programs with consistent rearing methods and where estimates of the escapement were available. However, in most cases, the estimates are indices rather than survival rates as not all returning fish are enumerated. Also, in some cases, adults may be counted a second time after return to the hatchery, release to the river, and subsequent capture by an angler. Survival rates were typically computed by dividing the total return (all age classes) of hatchery-origin steelhead by the number of steelhead smolts released two years earlier. For example, smolts from the 1974 brood of winter steelhead were released in the spring of 1975 and predominantly contributed to catch in the winter of 1976-1977.

Datasets used in the analysis are summarized below:

> Puget Sound. Winter steelhead smolt release, catch, escapement data were used from the Skagit River, the Elwha River, and the Puyallup River.

Olympic Peninsula. Winter steelhead smolt release, catch, escapement data were used from the Quillayute River and the Quinault River.

Southwest Washington. Winter steelhead smolt release, catch, and escapement data were used from the Humptulips River and the Elochoman River.

Lower Columbia River. Winter steelhead smolt release, catch, and escapement data were used from the Kalama River and the Washougal River. Summer steelhead smolt release, catch, and escapement data were used from the Kalama River.

Middle Columbia River. Survival rates were computed based on coded-wire-tag recoveries for steelhead released from the Touchet Acclimation Pond (WDFW 2005a)

Upper Columbia River. Survival rates were computed based on age specific returns to the Wells Hatchery (WDFW 2002a; C. Snow, pers. comm.).

Snake River. Survival rates were computed based on coded-wire-tag recoveries for steelhead released from the Lyons Ferry Hatchery (2005b).

Survival rates for juvenile steelhead released varied substantially between regions and years but some consistent patterns were evident (Fig. 3-2). Juveniles released from programs on the Olympic Peninsula (4.4% for 1995 through 1998 broods) and in Southwest Washington (3.3% for 1995 through 1998 broods) always had the highest survival rates. Survival rates for steelhead released from hatcheries in the Upper Columbia and Snake River programs were generally the lowest (< 1%). Perhaps most surprising, however, was the collapse in the survival rates for programs in Puget Sound. In the first 10 years of the analysis, the average survival rates for steelhead released from these programs was in the range of 3 to 4.5%. In the most recent four years, the average survival rate was 0.4%, the lowest of all regions in Washington.

The pattern in survival rates was similar for the winter steelhead programs in each of the three rivers in Puget Sound (Skagit River, Puyallup River, and Elwha River) (Fig. 3-3). Survival rates were variable but relatively high for the 1975 through 1981 broods, reaching a maximum of 7% on average for the 1982 brood. A precipitous decline in survival rates occurred subsequently and by the 1995 brood the average survival rate had dropped to 0.2%. Average survival rates have ranged from 0.2% to 0.5% since that time.

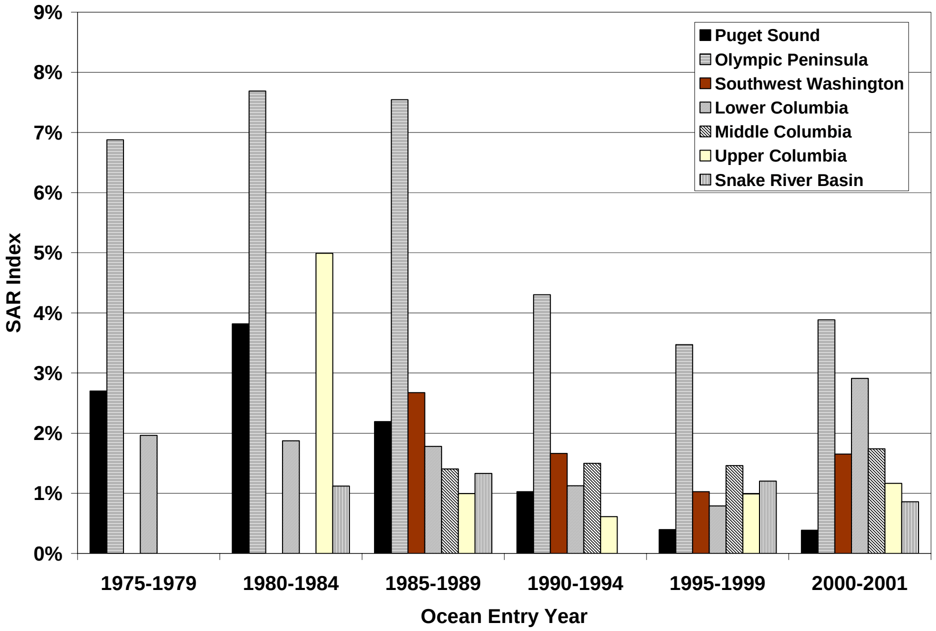

Figure 3-2. Average survival indices for steelhead released from artificial production programs in Washington.

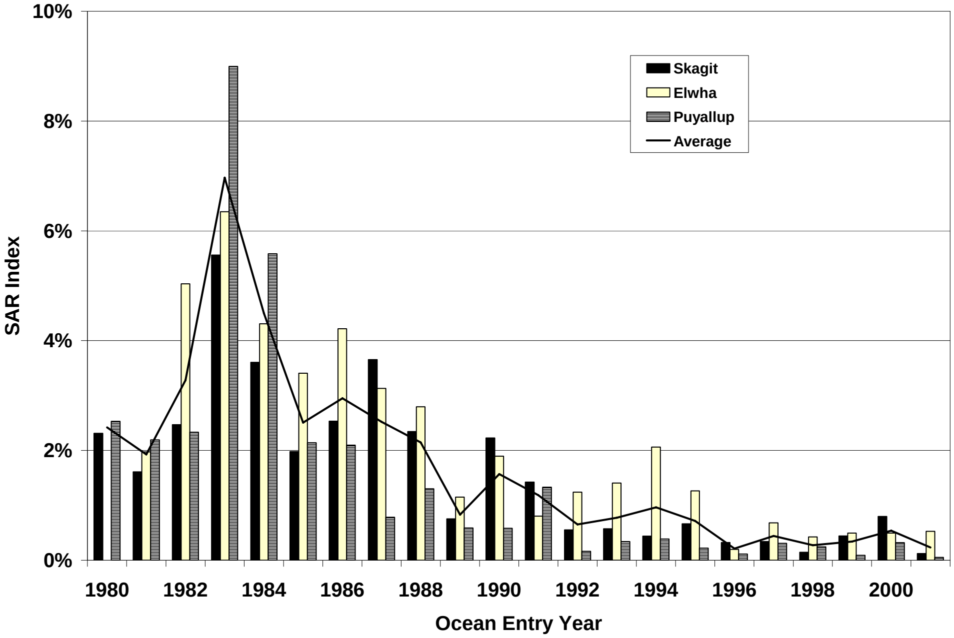

Figure 3-3. Survival rate indices for winter steelhead released from three artificial production programs in Puget Sound.

Although a number of hypotheses exist for the reduction in survival rates for the Puget Sound steelhead programs, the most likely explanation is a shift in oceanic conditions affecting early marine survival. Welch et al. (2000) found substantive declines after 1990 in survival rates for steelhead from rivers entering Georgia Strait, but no change or increased recruitment for steelhead from the west coast of Vancouver Island and northern British Columbia. Although the exact functional mechanism remains unknown, Welch et al. (2000) suggested that anomalous atmospheric circulation patterns in 1989 resulted in a sharp change in oceanic conditions and reductions in the survival rates for many stocks. Potential explanations for the reduction in survival rates for Puget Sound steelhead are discussed further in Chapter 7.

3.3 Genetic Effects on Natural Populations

Royal (1973) was perhaps the first to raise questions regarding the effectiveness of hatchery steelhead production programs in Washington and their potential impacts on natural steelhead populations. In response to such concerns for ecological and genetic risks of hatchery production on wild populations, research on fitness of hatchery fish spawning naturally and their interactions with wild stocks was initiated in the mid-1970s. Until recently, most research involved assessment of isolated hatchery stocks of non-local origin. Recently, there has been increased interest in integrated hatchery programs that use broodstock of local-origin. The risks and benefits of integrated versus isolated programs are discussed in this chapter and in Chapter 4, where tradeoffs are evaluated in concert with harvest management strategies and habitat productivity.

3.3.1 Overview of Genetic Risk

Genetic hazards posed to salmonid populations by hatchery operations fall into four main categories: 1) extinction, 2) loss of within population diversity, 3) outbreeding depression and loss of among-population diversity, and 4) domestication (Busack and Currens 1995). Extinction risk differs significantly from the others in that it typically has nongenetic causes, and is fairly easily controlled by good hatchery design, management, and equipment. The other three hazards are potential risk factors in all hatchery operations, though there is considerable uncertainty about the severity and permanence of their impacts (Busack and Currens 1995; Campton 1995).

Gene Flow between Hatchery-Origin and Natural-Origin Steelhead

To understand how steelhead programs in Washington may genetically affect natural populations and natural spawning components of composite populations, it is important first to have a clear conceptual picture of gene flow from hatchery-origin to natural-origin steelhead and vice versa. Fig. 3-4 shows all possible gene flow paths between a group of hatchery fish and a natural spawning group. At this point, these can either be considered separate populations or two components of the same population (which is biologically more correct in many cases). The diagram shows the two spawning components of the population (or two populations) and four groups of fish. The smaller arrows show hatchery-origin fish spawning in the hatchery (called hatchery-origin broodstock [HOB]) and natural-origin fish spawning in the wild (called natural-origin spawners [NOS]). The larger arrows depict fish spawning in the environment opposite the one they came from: natural-origin fish spawning in the hatchery (called natural-origin broodstock [NOB]) and hatchery-origin fish spawning in the wild (called hatchery-origin spawners [HOS]). If a fish spawning in the hatchery doesn't come from the wild it must have come from the hatchery, and if a fish spawning in the wild doesn't come from the wild it must have come from the hatchery.

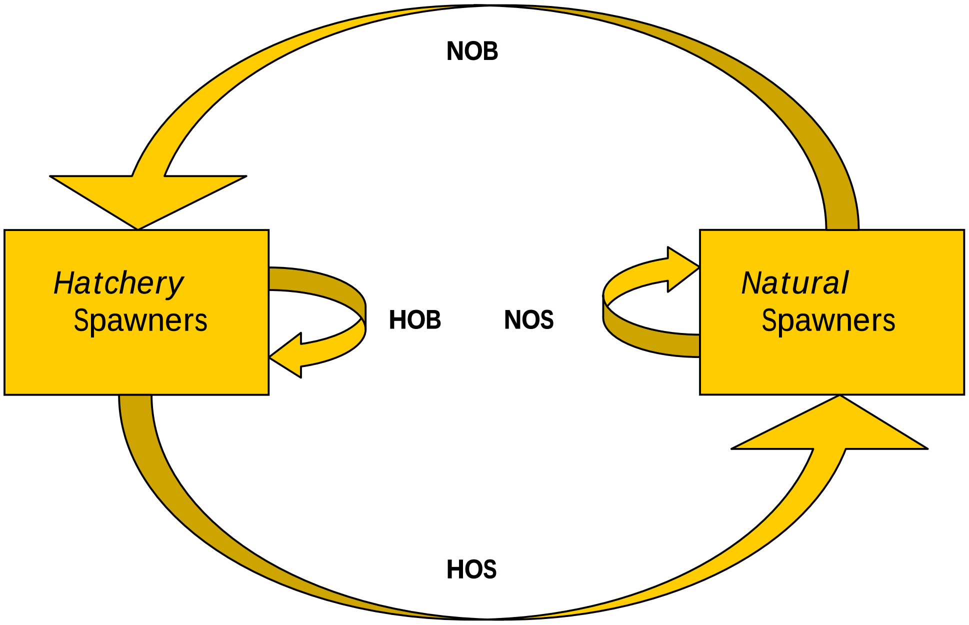

Figure 3-4. Schematic of reproductive interactions between natural and hatchery subpopulations in an integrated production program (from Lynch and O'Hely, 2001).

As discussed in section 3.2.1, hatchery programs use either an isolated or integrated reproductive strategy. In isolated programs, the intent is to keep hatchery and natural fish genetically separate. Gene flow is not desired, especially from hatchery to natural, as depicted in Fig. 3-5. The diagram clearly shows that spawning of the two groups is isolated. The dotted arrow represents unintentional gene flow from the hatchery population to the natural population. In isolated programs hatchery and natural fish are managed as two separate populations.

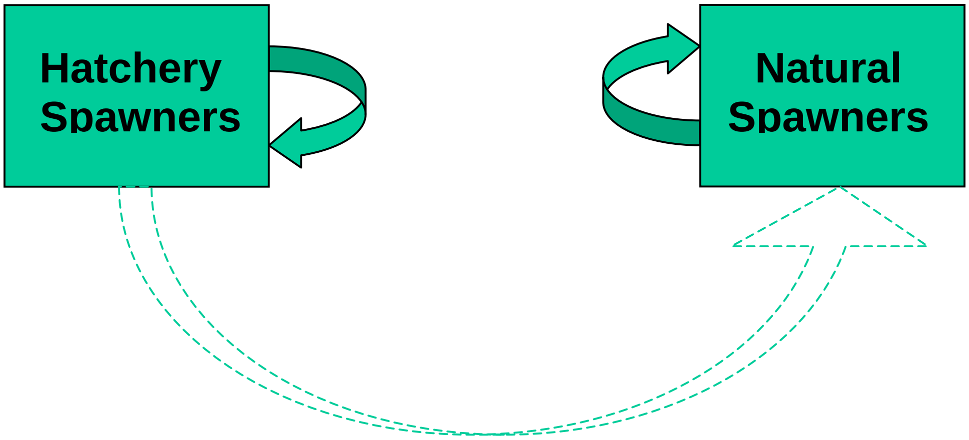

Figure 3-5. Schematic of a Isolated hatchery program interacting with a natural population. Dotted arrow represents low levels of gene flow.

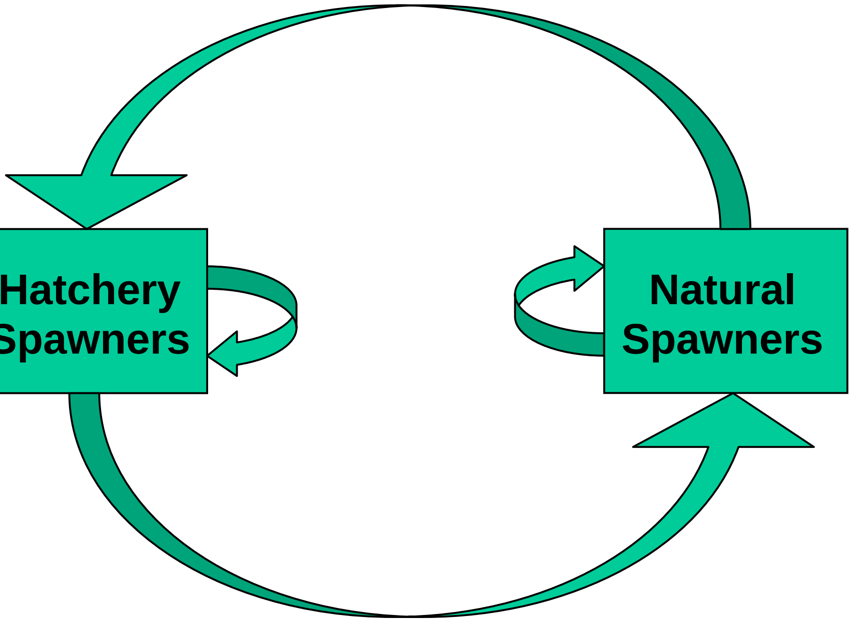

Figure 3-6. Schematic of an integrated hatchery program interacting with a natural population.

In integrated programs, interbreeding between the hatchery and natural fish, and vice versa, is intended (Fig. 3-6). This differs from the way many biologists and resource managers have traditionally thought about hatchery fish on the natural spawning grounds and prompts a refined definition of “stray”. In general, all hatchery fish on the natural spawning grounds were considered “stray” since they were not removed through harvest, nor returned to the hatchery of origin. Thus, although a program may have been in place for years with hatchery fish commonly spawning in the natural environment and perhaps some natural-origin fish contributing to the hatchery broodstock, the perception was there were two discrete populations. However, it is highly probable most of the natural-origin fish had at least one hatchery origin parent.

Modeling and initial genetic analysis suggest that even limited gene flow can unite the groups genetically. Therefore, in these situations, it’s better to view this as a single population that spawns in two environments rather than two populations. Genetic distinctions between the hatchery and natural origin fish when they commingle in spawning are often small and temporary, reflected mostly by the additional generation in the hatchery environment for hatchery fish. The situation could be compared with a single population that spawns in two streams.

Loss of Within-Population Diversity

Loss of within-population diversity in salmonid hatchery operations has been widely documented (Hindar et al. 1991). The causes are primarily sampling the population inadequately for inclusion as hatchery broodstock, using too few fish as broodstock, or a combination of the two. The result is that some genetic variation present in the source population is lost. Waples (1999) argues that loss of some diversity is inevitable.

Loss of within-population diversity is often determined by the effective size of the population. Effective size is one of the preeminent concepts in conservation biology. In a genetically ideal population, all parents have an equal probability of contributing to the next generation and there are equal numbers of males and females. The effective size of a population is the size of a genetically ideal population that loses genetic diversity at the same rate as a given population. Thus, in a genetically ideal population the effective size and census size is the same, but the more the sex ratio deviates from 1:1 and the more fish vary in reproductive potential, the smaller the effective size becomes relative to the census size. The expected loss of diversity per generation is $1/2N_e$, where N_e is the effective population size. Effective sizes of a few hundred to a few thousand are considered necessary for adequate conservation of genetic variability (Lande and Barrowclough 1987; Lande 1995). These analyses assume totally isolated populations, however. Gene flow can significantly increase the true effective size of a local population (Whitlock and Barton 1997; Tufto and Hindar 2003). Because of this phenomenon, the importance of effective size as a risk factor is under review by geneticists evaluating populations of salmon and steelhead in the Pacific Northwest.

Concerns about loss of variability due to sampling error, such as exclusion of life history types, remain.

A great concern in integrated hatchery programs, especially those used for conservation, is the Ryman-Laikre effect (Ryman and Laikre 1991, Ryman et al. 1995). Because survival of hatchery juveniles to adulthood is often considerably higher than that of natural-origin juveniles, the contributions of individual hatchery fish to the next generation can be considerably higher than the contributions of natural-origin fish, depressing effective size.

Outbreeding Depression and Loss of Among-Population Diversity

Outbreeding depression and loss of among-population diversity are considered a single hazard because they both result from gene flow among populations. Some gene flow among salmonid populations is natural and healthy, and is an important force in maintaining genetic diversity in populations. Estimates of gene flow are rarely available for natural populations of steelhead, but the percentage of spawners originating from nonlocal populations has occasionally been estimated. Shapolov and Taft (1954), for example, estimated that about 2% of the population in two small California streams originated from other streams.

A potential concern is that excessive gene flow from nonnative hatchery fish spawning with native natural-origin spawners will cause a loss of fitness called outbreeding depression (Templeton 1986; Emlen 1991; Roff 1997). Although outbreeding depression has recently been well demonstrated by hybridizing largemouth bass from neighboring states (Philipp et al. 2002), evidence in salmonids is scant. Bams (1976) demonstrated that hybrid pink salmon do not home to natal streams as well as pure local stock. Gharrett and Smoker (1991) found significant outbreeding depression in crosses of odd-year and even-year pink salmon and their work is often cited as evidence of outbreeding depression. However, these two groups of pink salmon for all practical purposes are distinct species. Most of the concern about outbreeding depression in salmonids is indirect, based on the vast amount of local adaptation that seems evident (Taylor 1991). Reisenbichler (1988), for example, showed that the return rate success of coho salmon varied inversely with the distance between release point and hatchery of origin. A NOAA Fisheries- sponsored workshop on the effects of gene flow through straying was held at Seattle in 1995 (NMFS 1997). The conclusion of the panel, based on outbreeding depression arguments, was that significant losses might occur at gene flow rates (measured as proportion of recipient population) less than 5%, so that rates as high as 5% are not justifiable.

The concern about gene flow may seem odd because of the common public perception, based on agriculture, that hybridization is a positive thing. It is important to consider that plants and animals under, in many cases, centuries of culture are quite inbred, so the phenomenon of “hybrid” vigor is not surprising because the hybridization causes a large increase in genetic variability in the population. There is little, if any, evidence of hybrid vigor in crosses of natural animal populations.

The above material treats gene flow from only one perspective, that of its ability to reduce fitness. There is another more subtle risk posed by gene flow from exogenous sources, that of loss of *among-population* diversity. If two locally adapted populations exchange genes, they will both have increased levels of within-population diversity, but the genetic differences between them will decrease, so among-population diversity is decreased. This is a loss in biodiversity whether or not there is a fitness consequence to the interbreeding.

Domestication

Domestication is the adaptation of organisms to anthropogenic environmental changes. In hatcheries, the concern is that fish will become genetically more adapted to the hatchery “lifestyle” of incubation and early rearing in the hatchery followed by later life in the wild and less adapted to the purely wild life. This will be true not only of “hatchery stocks” but also true to a more limited extent of “natural stocks” with which hatchery fish regularly interbreed or into which they stray. This is probably the single most controversial and least understood topic in the general debate about hatchery risk. For this reason, the theory behind the concern requires some careful explanation.

Our prevailing model of natural selection is that the environment is constantly working to genetically refine an organism. Thus, we consider wild fish to have become well adapted to their environments. If we spawn and rear fish in the hatchery for part of their lives, for that portion of their lives they will experience a much different set of selection pressures than they would in the wild. The hatchery-reared progeny of wild fish taken into the hatchery for broodstock can be expected to differ genetically slightly from their parents. If these fish return as adults and are themselves used as broodstock, their progeny will differ slightly genetically from them, and so on, each generation changing slightly in the direction that the selective forces imposed by the hatchery environment. If hatchery fish sometimes spawn in the hatchery and sometimes in the wild, the proportionate selective effects of the hatchery and natural environments will determine how much the population changes (Ford 2002; Lynch and O’Hely 2001).

There are three popular arguments for the viewpoint that domestication should not be a real concern in salmonid hatchery programs. First, that hatchery programs relax selection more than they change selection regimes. For example, the hatchery provides a much less selective incubation environment than the wild. Theorists would agree, but this relaxation is part of domestication, and in theory can cause considerable genetic change (Lynch and O’Hely 2001). Second, that hatcheries can’t be selective because survival rates of juveniles from the hatchery are so high. While it is true, that the high juvenile survival rates do occur, in all salmonid populations a huge percentage of the fish die before they get a chance to spawn. If the survivors are a different genetic mix than they would have been had they not been produced by the hatchery, then domestication has occurred. Third, that releasing the fish into the wild counteracts any selection that might have occurred in the hatchery. This may happen to some extent, but there is scientifically no basis for expecting it to cancel out the hatchery effects.

Empirical evidence for domestication in salmonids is abundant. Berejikian and Ford (2004) comprehensively reviewed both published and unpublished information regarding the relative fitness of hatchery and natural salmon and steelhead. Much of the relative fitness work that has been done has been conducted on steelhead, and mostly in Washington and Oregon. The majority of the studies compared the natural reproductive success (measured as offspring produced per spawner) of transplanted (non-local origin) hatchery stocks to that of natural-origin fish spawning in the same streams (Leider et al. 1990; Hulett et al. 1996; Blouin 2003; Kostow et al. 2003; McLean et al. 2003, 2004). One study in Oregon (Blouin 2003) also compared the reproductive success of hatchery and natural-origin steelhead when the hatchery stock was spawned from a local natural stock.

Some of the data from these studies are summarized in Table 3-3, organized relative to the type of broodstock.

Domesticated, Nonlocal Broodstock
The summer steelhead studies conducted with domesticated broodstock each involve a derivative of the Skamania hatchery stock. Fitness is compared to three natural populations: 1) Kalama River summer steelhead (Leider et al. 1990); 2) Clackamas River (Oregon) winter steelhead (Kostow et al. 2003); or 3) Hood River (Oregon) summer steelhead (Blouin 2003).

Two of the studies of domesticated stocks of winter steelhead involve a derivative of the Chambers Creek stock: 1) Beaver Creek Hatchery stock (Chambers Creek origin) compared to the Kalama winter-population (Hulett et al. 1996); and 2) the Bogachiel Hatchery stock (Chambers Creek origin) compared to the winter-run steelhead of natural-origin in Forks Creek (Willapa River) (McLean et al. 2003, 2004). The third domesticated winter-run stock studied was the Big Creek Hatchery (Oregon) stock (Lower Columbia origin) compared to the natural, winter-run population in the Hood River (Blouin 2003).

Collectively, the available data convincingly demonstrate that the reproductive success of domesticated, non-locally derived hatchery steelhead stocks is likely to be low relative to natural-origin spawners in the same streams (Table 3-3). In the summer steelhead studies, the hatchery spawners averaged only 28-30% as many smolt offspring and 9-37% as many adult offspring as did the natural-origin spawners. Findings from the winter steelhead studies were qualitatively similar. Relative reproductive success to the smolt stage was low (4-7% of that of natural-origin fish) in Forks Creek, but was higher and much more variable in the Kalama study. Hatchery-origin adults produced an estimated 284% as many smolts as natural-origin adults in the Kalama one brood year, but only 33% and 61% as many as natural-origin adults the other two years. Relative reproductive success to the adult stage was low in both the Kalama and Forks Creek studies (hatchery adults averaged 7-8% as productive as natural-origin adults), and somewhat higher (34% of that of natural-origin adults) in the Hood River study.

Table 3-3. Reproductive success estimates of hatchery steelhead spawning in natural streams in the presence of natural-origin steelhead. Relative fitness is expressed as the number of offspring per hatchery spawner divided by that of the natural-origin spawners, for the smolt and returning adult stages of naturally produced offspring.

Location	**Relative Fitness**		**Citation**
	Smolts	**Adults**	
Summer Steelhead, Domesticated, Nonlocal Broodstock			
Kalama River Washington	0.30 (0.12-0.53)	0.16 (0.12-0.21)	Leider et al. (1990) [1]
Clackamas River Oregon	0.28 (0.18-0.37)	0.09 (0.04-0.13)	Kostow et al. 2003)
Hood River Oregon	NA	0.37 (0.17-0.54)	Blouin (2003)
Winter Steelhead, Domesticated, Nonlocal Broodstock			
Kalama River Washington	1.26 (0.33-2.84)	0.08 (0.0-0.21)	Hulett et al. (1996) [1]
Forks Creek Washington	0.06 (0.04-0.07)	0.07 (0.02-0.11)	McLean et al. (2003) McLean et al. (2004)
Hood River Oregon	NA	0.34	Blouin (2003)
Winter Steelhead, Local Natural-Origin Broodstock			
Hood River Oregon	NA	0.91 (0.85-1.08)	Blouin (2003)

[1] The data presented here for the two Kalama studies differ somewhat from those reported in Leider et al. (1990) and Hulett et al. (1996) because of unpublished changes in methods to calculate reproductive success. These changes include elimination of the Leider et al. (1990) procedure to standardize production to potential egg deposition, instead estimating production on a per spawner basis (consistent with other studies reported here). The earlier published data and those provided here lead to the same conclusions.

Natural Origin, Local Broodstock

The Hood River study (Blouin 2003) is the only one to have reported lifetime (adult to adult) reproductive success of first generation hatchery steelhead spawned from local, natural-origin broodstock compared to natural-origin spawners of the same stock (Table 3-3). Averaging male and female success across the three brood years (1996-1998), the hatchery adults produced 91% as many adult offspring as did the natural-origin adults (per spawner). Individual brood year values ranged from 85-108% for females and 85-90% for males.

At least two studies shed light on the fitness of hatchery stocks that were founded with wild spawners but had more than one generation of hatchery production spawned from returning hatchery adults. Reisenbichler and McIntyre (1977) conducted controlled crosses of wild adults and hatchery adults that had been cultured for two generations since being founded by wild fish in the Deschutes River, Oregon. Relative survival of embryos stocked in streams from hatchery crosses was 91% of that of wild crosses to the emergence stage, 81% to age-0, and 79% to age-1. Intermediate survival was observed from hybrid crosses of hatchery females spawned with wild males (92%, 85% and 87% to emergent fry, age-0 and age-1, respectively). In parallel experiments conducted in a hatchery environment, the hatchery offspring survived better. Because of the controlled nature of the experiment, these results are regarded as representing genetic differences not confounded by environmental effects. However, there are no data on the survival of the experimental fish beyond age-1, so the lifetime fitness under this scenario is unknown.

Preliminary data from another local origin, multi-generation hatchery stock are available from a study conducted on Little Sheep Creek in NE Oregon (Moran, pers. comm.). As reported by Berejikian and Ford (2004), Moran found that naturally spawning hatchery females produced about 40% as many parr offspring as did natural females and 33% as many parr as natural males.

Other Studies

In other species, apparent effects of domestication have been noted in reproductive success (Fleming and Gross 1992; Fleming and Gross 1993; Petersson and Jarvi 1993), morphology (Fleming and Gross 1989; Hard et al. 2000; Swain et al. 1991; Taylor 1986), agonistic behavior (Berejikian et al. 1996; Swain and Riddell 1991), and assorted life-history traits (Kallio-Nyberg and Koljonen 1997; Petersson et al. 1996).

The literature, although plentiful, leaves a lot to be desired. Most domestication studies involve comparisons of populations that have had heavy hatchery impacts with those that have not, so there is always the possibility of differences between populations not related to hatchery rearing being confused with domestication. Many studies also don’t clearly distinguish between phenotypic effects of hatcheries, differences that may be caused solely by the fish being reared in a hatchery and that may be nongenetic, and true genetic differences. Most importantly for the discussion in the next section, virtually no research has been done on integrated programs, programs in which there is substantial gene flow between the hatchery and natural components of the population. Therefore, important questions as to the severity and permanence of domestication impacts and our ability to reduce impacts remain unanswered (Busack and Currens 1995; Campton 1995). However, echoing Busack and Currens (1995), we are unaware of any study looking for domestication that did not find it. The combination of evidence and theory make a compelling case for domestication being a concern in populations affected by hatchery operations. A number of regional scientific panels have underscored these concerns (e.g. Indepependent Scientific Advisory Board (ISAB) 2003; Independent Multidisciplinary Science Team (IMST) 2001).

3.3.2 Genetic Risks of Isolated Hatchery Programs

As stated earlier, in an isolated program the hatchery fish and the natural fish with which they may interact are considered two separate populations. Limiting interactions between the two groups controls the risks of these programs. In practical terms this means limiting gene flow from the hatchery-origin fish into the natural spawners, and limiting the ecological interactions between the two.

The gene flow issue is both a domestication risk and an outbreeding depression/loss of among population diversity risk. Both problems stem from the stock used for the hatchery releases, which is invariably domesticated and typically of nonlocal origin. Isolated steelhead programs often involve release of fish from a small number of centralized hatchery stocks, typically Chambers Creek winter steelhead, Skamania summer steelhead, and localized derivatives of the one of the two. The localized derivatives may have some additional ancestry from other populations, but the essential feature of these stocks is a long history of domestication directed at producing a one-year smolt (Crawford 1979). Thus, not only have the fish been subjected to generalized domestication, there has been artificial selection for early run-timing and spawning. Except for the occasional inclusion of wild fish, these are closed populations that do not spawn in the wild. Thus, the push-pull of hatchery and natural selective forces has been strongly in the hatchery direction. It is reasonable to assume these fish have been heavily domesticated for 50 years.

The Chambers Creek stock originated in south Puget Sound, and the Skamania stock originated in the lower Columbia (Crawford 1979). These two stocks and their local derivatives (e.g. Bogachiel) are widely planted all over western Washington, especially the Chambers Creek stock. They are almost always nonnative fish where they are planted. Thus, in addition to the domesticating effect of gene flow from a highly domesticated source, isolated programs include a risk of outbreeding depression/loss of among-population diversity. The risk varies with the degree of nonlocality and with the possible local adaptation that the domesticated stock may have developed. For example, there is more outbreeding depression risk from Chambers Creek stock released into north coastal streams than there would be from Chambers Creek stock released into a Puget Sound tributary. However, there would be less outbreeding depression risk from the Bogachiel derivative of the Chambers Creek stock being released into a north coastal stream than Chambers Creek stock from a Puget Sound hatchery, because the Bogachiel stock has had time to develop some level of local adaptation.

The risk due to this gene flow depends on the domestication level of the stock used, the degree of nonlocality of the stock used, the level of gene flow the population has already undergone (a stock that has already had a certain level of gene flow will be less impacted incrementally than one that has had less), and the level of gene flow. Gene flow depends on the relative abundance of hatchery and wild spawners on the spawning ground, their temporal and spatial overlap, and the relative success of the three types of matings (hatchery x hatchery [HxH], hatchery x natural [HxN], and natural x natural [NxN]). Fig. 3-7 shows the situation with regard to mating structure. There are three regions on the figure, each representing a different mating scenario. In region A, only hatchery-origin fish are present, so only HxH matings take place.

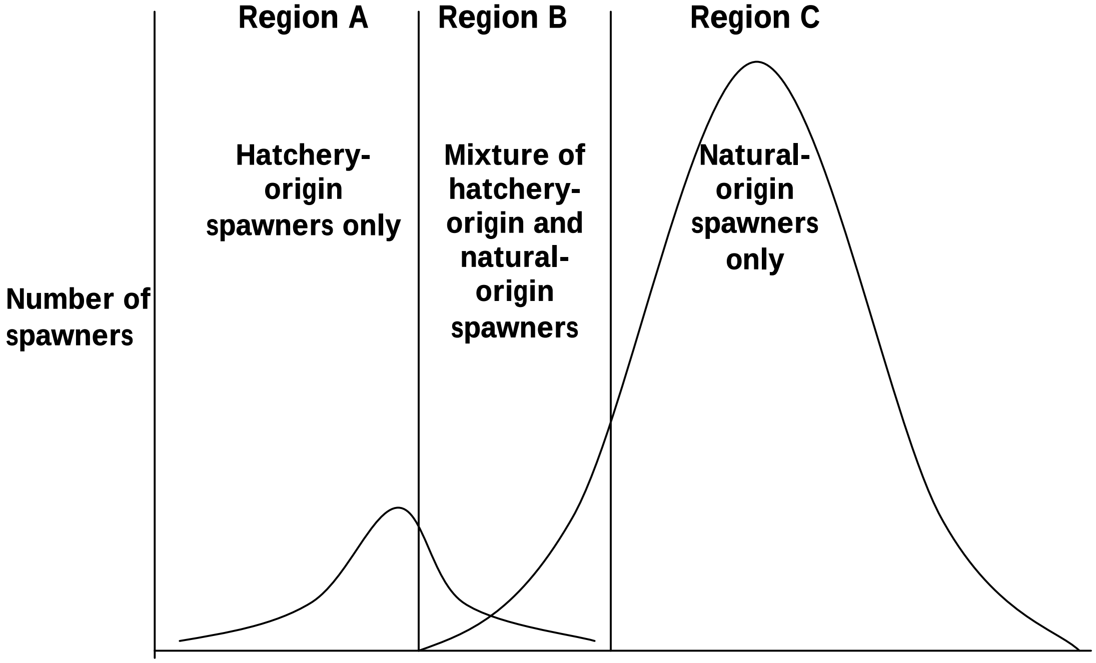

Figure 3-7. Schematic of temporal spawning overlap between early-run hatchery-origin winter steelhead and natural-origin winter steelhead. The shape, sizes, and placement of curves does not represent any particular real situation.

In region C, only natural fish are present, so all matings are NxN. In region B, both types of spawners are present. Assuming fish mate at random and assuming single-pair mating, there will be p^2 HxH matings, $2p(1-p)$ HxN matings, and $(1-p)^2$ NxN matings, where p is the proportion of hatchery-origin fish present in region B. For example, if during the time the two runs overlap the proportion of hatchery-origin fish is 10%, the expected frequency of the three types of matings will be 1% HxH, 18% HxN, and 81% NxN.

The level of gene flow to be expected from the scenario depicted in Fig. 3-7 is (see also derivation in Appendix 3-A):

$$Gene\ \ flow = \frac{b}{b + a(1-q)(1-o_N) + (1-q)^2 o_N{}^2}, where$$

$$a = o_N + q(o_H - o_N)$$
$$b = k_1(aq(1-o_H) + q^2 o_H{}^2) + k_2 q(1-q) o_N o_H$$

and k_1 and k_2 are the fitnesses of HxH and HxN matings relative to NxN, respectively; q is the proportion of hatchery fish among all spawners (regardless of overlap), o_h is the proportion of the hatchery spawners that are in the overlap region, and o_n is the proportion of the natural-origin spawners that are in the overlap region. For example, assume 1) there are 150 natural-origin spawners, and 20 hatchery-origin spawners present; 2) 10% of the natural-origin spawners overlap with 5% of the hatchery-origin spawners; and 3) the fitnesses of HxH and HxN matings relative to NxN are 0.5 and 0.75, respectively. Here q=20/170=0.118, o_H=0.05, o_N=0.1, k_1=0.5, and k_2=0.75, so the gene flow is 6.4%.

Note that the expected gene flow rate can be much lower than the “stray” rate. In a well run Isolated program, the level of gene flow should be quite low for three reasons: 1) the numbers of hatchery-origin fish that have escaped harvest should be low compared to the number of natural-origin fish present; 2) the reproductive success of the hatchery-origin fish can be expected to be low (Leider et al. 1990; Kostow et al. 2003; McLean et al. 2003; McLean et al. 2004); and 3) spawning overlap may be low.

As previously mentioned, there is no consensus on the impacts of gene flow from non-native sources (NMFS 1997). There is also no way to predict the impact of doses of domestication delivered this way, although some insights might be gained by contrasting this discussion with the discussion of integrated programs below. We can make some predictions based on basic population genetic theory of the balance between selection and migration. The genetic material in a population is maintained by selection coefficients, symbolized by *s*. The selection coefficients can basically be thought of as defending the population from the inflow of nonadaptive genetic material. The basic idea is that if the gene flow rate (also called migration rate) exceeds the selection coefficient, the immigrant genetic material will over time replace the native material (NMFS 1997). Selection coefficients in nature for single traits are thought to be low (Endler 1986; Hoekstra et al. 2001; Kingsolver et al. 2001),

It does not take much migration to replace native (or less domesticated) genetic material with immigrant genetic material. Because we really don't know what the selection coefficients are, a detailed analysis using a variety of selection coefficients is not much more informative than the general statements just presented. It is important to gain some sense of how fast this replacement can take place. For varying levels of constant gene flow, the rate at which the genetic difference between a donor and recipient population decreases for selectively neutral genetic material (i.e., that is not selected against) is given by:

$$Decrease\,in\,Genetic\,Difference = 1-(1-m)^t$$

where m is gene flow and t is generations (Hedrick 1983). Examples of this kind of variation are the neutral protein and DNA markers that are used to describe differences among fish populations. With a gene flow rate of 2% for 14 generations (~50 yr), about 25% of the difference will be lost (Fig. 3-8). This graph represents the maximum rate at which native genetic material can be replaced by immigrant material. Genetic differences under selection will decrease more slowly, but those under low levels of selection (which may be quite common) will decrease almost as rapidly. This forms the basis of the general findings of the 1995 straying workshop (NMFS 1997), and the general guideline of the Hatchery Scientific Review Group (HSRG) that the stray rate of hatchery-origin fish onto the spawning grounds should not exceed 5% (HSRG, WDFW, and NWIFC 2004).

The decay of genetic differences between the hatchery stock and natural populations impacted by isolated programs may be of interest in its own right as a loss of among-population diversity, but the impact on current fitness is more relevant to immediate management and stewardship concerns. There is no way at present, to quantify the risk to fitness over either the long- or short term.

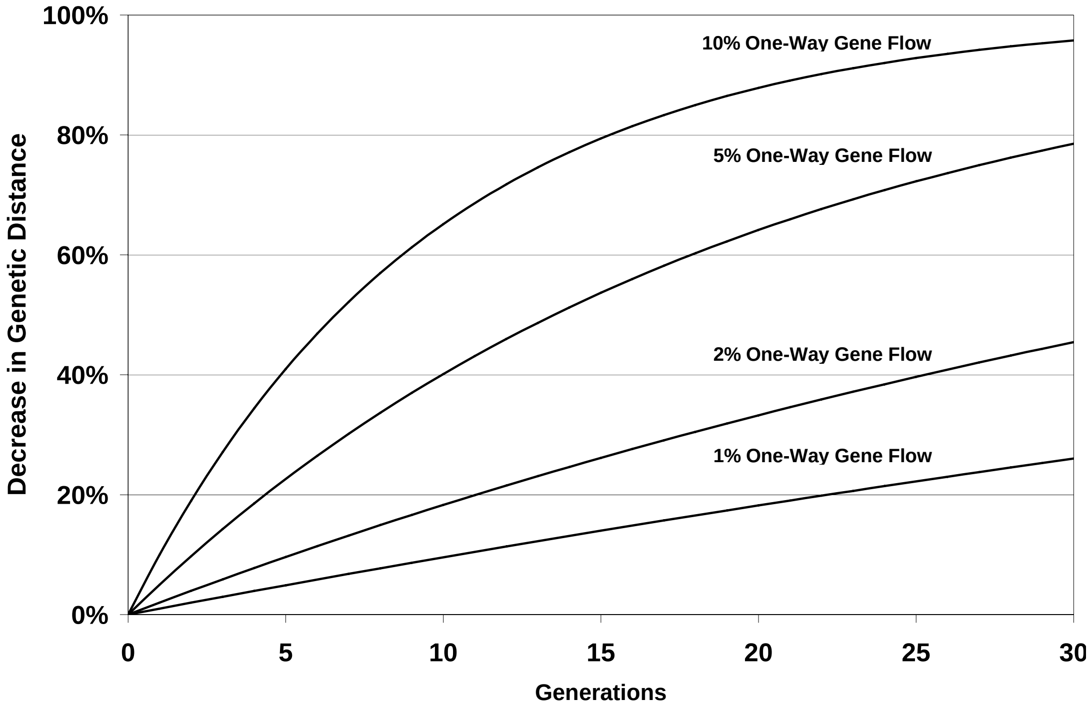

Figure 3-8. Decay of selectively neutral genetic differences between a donor and recipient population under varying levels of one-way gene flow

3.3.3 Genetic Risks of Integrated Programs

There are few integrated steelhead hatchery programs in Washington. Some began from native stock, others from conversion of isolated programs using mixed somewhat nonlocal stocks. Because hatchery-origin and natural-origin fish are managed as a single population in an integrated program (which indeed they are), these programs avoid the ecological-genetic risks discussed above for isolated programs. The major genetic risk in integrated programs is domestication, but there is also risk of outbreeding depression/loss of among population diversity if the program is begun with nonnative hatchery fish. As we saw in the discussion of isolated programs using nonnative hatchery fish, insufficient information exists to predict how much fitness loss will be suffered due to the introduction of nonnative genetic material. This risk can be minimized, however, by avoiding use of a distantly related hatchery stock, and by ceasing use of the nonnative stock as soon as possible.

Recent work on domestication by regional scientists has developed theory that helps a great deal in understanding the risk and in developing risk containment measures.

Integrated programs involve regular gene flow from the hatchery into the natural spawning component, and from the natural spawning component into the hatchery (Fig. 3-6). The domestication risk depends largely on these two levels of gene flow, and risk containment almost always requires regulating them. The key is a concept called *proportionate natural influence* (PNI). This concept is based on modeling by Lynch and O'Hely (2001). Mathematically,

$$PNI = \frac{pNOB}{pNOB + pHOS}$$

where *pNOB* is the proportion of natural-origin fish in the hatchery broodstock and *pHOS* is the proportion of hatchery-origin fish on the spawning grounds. The concept involves the assumption that these proportions are constant over time. Real programs, obviously, will vary, so these proportions can be thought of as means. Biologically, PNI is a measure of the proportion of time the population spawns in the wild, where it is subjected entirely to natural forces. Not at all obvious from this equation is the fact that any given PNI value represents a particular *pNOB/pHOS* ratio. For example, a PNI of 50% (.5) is achieved when *pNOB/pHOS = 1* (i.e., when the proportion of natural-origin fish in the broodstock is the same as the proportion of hatchery-origin fish spawning in the wild. A PNI of 60% (or 0.6) is achieved when *pNOB/pHOS = 1.5*.

The idea of taking natural-origin fish into the hatchery to control domestication may seem counterintuitive. Biologists concerned with limiting the effects of hatcheries on natural production are accustomed to trying to keep natural-origin fish out of the hatchery, so the idea of putting them into the hatchery in a big way may seem like lunacy, but it makes sense genetically. Putting natural-origin fish into the hatchery retards domestication because the hatchery environment can't affect natural-origin fish as effectively as it can hatchery-origin fish. Keeping them out, and at the same time allowing hatchery-origin fish to spawn in the wild in large numbers actually makes domestication work faster.

The PNI concept can be displayed to good advantage on a "NOB-HOS" diagram (Fig. 3-9). This is a powerful diagram, both conceptually and practically. The triangular region below the 50% line represents combinations of pNOB and pHOS that result in PNI values greater than 50%. The triangular region to the left of the 50% represents combinations of pNOB and pHOS that result in PNI values less than 50%. With this graph you can see at a glance (without calculations) the kinds of pNOB/pHOS ratios that would be needed for any specified PNI. This graph can also be used to track programs. Any integrated program can be plotted on this graph if the pNOB and pHOS values can be estimated with reasonable accuracy; averages can be plotted, or the program can be plotted year to year. Programs can also be characterized by PNI value alone. Any integrated program will have a PNI value between 0 and 1, and the PNI obviously tells you immediately the proportionate natural influence.

PNI, as might be expected, has a direct relationship to domestication, as illustrated by a model by Ford (2002). This model considers the change in a single trait (such as fecundity) in a population as it goes from being wild to being part of an integrated hatchery program. As explained earlier, in such a population, natural selective forces are pushing the population's traits toward the natural optimum, but hatchery selective forces are trying to pull the traits toward a hatchery optimum. The hatchery optimum is the trait value the population would eventually go to if it were never allowed to spawn in the wild. What the Ford (2002) model tells us is that at equilibrium, under assumptions of equal heritabilities and selection pressures in the natural and hatchery environments, the trait value on the line between the hatchery optimum and wild optimum is the PNI. A PNI of more than 50% leads to the population reaching an equilibrium state where its characteristics are more like those of a pure natural population than a pure hatchery population in that setting.

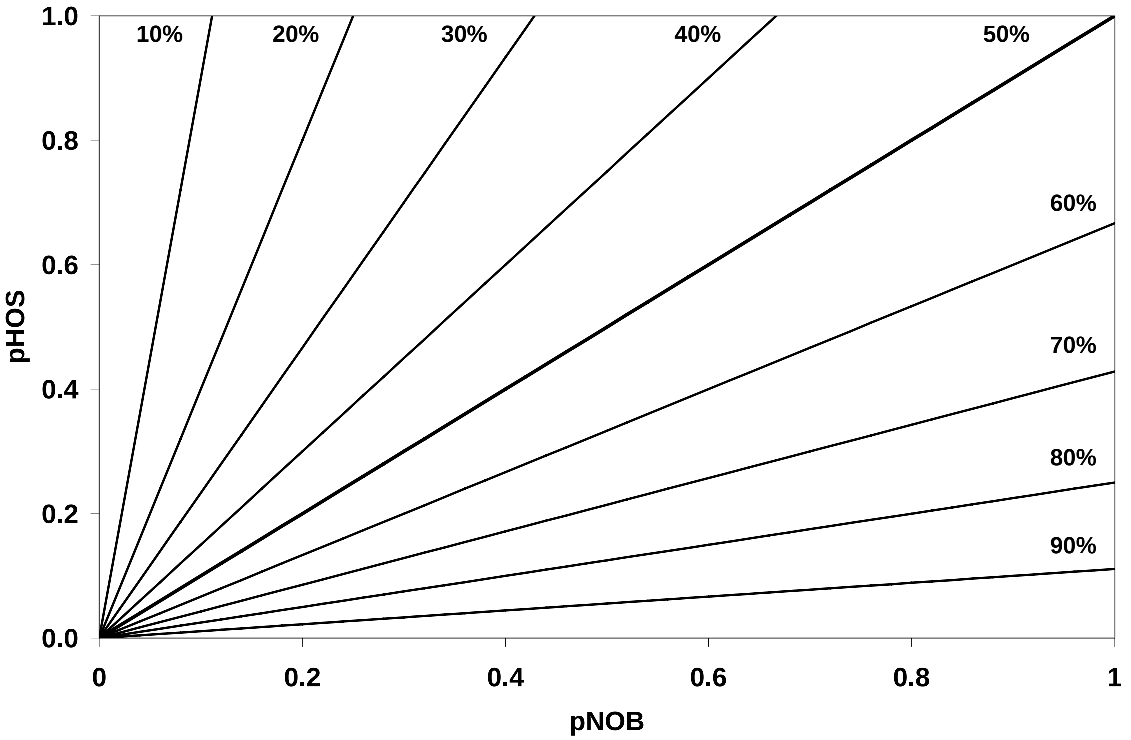

Figure 3-9. Proportionate natural influence in integrated hatchery programs as a function of pNOB and pHOS.

PNI is one important component of domestication risk. The other is the selective intensity of the hatchery environment; i.e., how it differs from the natural environment. For a given hatchery program, and given PNI, the genetic change the population undergoes will depend on this difference in environments. Thus, even with genetically conservative PNI values, making the hatchery environment more like the wild environment can lessen domestication. This means that hatchery operation modifications that make hatchery fish morphologically, behaviorally, and physiologically similar to wild fish may pay off in terms of lessening domestication.

Although we can use the PNI principle in concept to get some idea of relative risk of different programs, there is still much that we don't know biologically. Throughout this discussion we have treated domestication as if it were a single trait. It is several interacting traits, and we don't have an understanding of the exact genetic mechanisms behind them. Most importantly, we don't understand the relationship between PNI and fitness. The relationship between a change in trait mean and change in fitness is nonlinear. The actual fitness loss depends on the intensity of selection and how far the trait is moved from its wild optimum, neither of which is apparent from PNI.

3.3.4 Comparison of Genetic Risks of Isolated and Integrated Programs

Isolated and integrated hatchery programs can be evaluated relative to the risks they pose to among-population diversity and domestication. The fundamental distinction between a typical isolated program using a nonlocal hatchery stock and an integrated program using native stock is that the first involves low levels of gene flow from a highly domesticated and nonlocally adapted source into an otherwise "wild" stock, whereas the other deliberately puts the population through a program of adaptation to a mixed hatchery-natural environment. Programs using nonlocal stock potentially pose a risk to among-population diversity because of the different geographical origins of the two stocks; programs using local stock do not pose this type of risk. Thus, isolated programs, as currently operated with nonlocal stocks potentially pose a type of biodiversity risk that integrated programs based on a local stock do not.

The contrast between isolated and integrated programs in terms of domestication impacts can be stated quite simply. Well run isolated programs involve minor levels of gene flow from highly domesticated sources, whereas well run integrated programs involve higher levels of gene flow from less domesticated sources. Simplifying the difference in program types in this way suggests it may be possible to model the relative fitness impacts of the program types using the model of Ford (2002).

Ford (2002) evaluated quantitative genetic change at a single trait in populations with gene flow from hatchery to natural component and from natural component to hatchery component using a simple model based on Lande (1976) and Bulmer (1985). Under this model, the mean of the trait in the natural component is given as

$$\bar{z}'_w = p_w\left\{\bar{z}_w + \left[\frac{\bar{z}_w\omega_w^2 + \theta_w\sigma^2}{\omega_w^2 + \sigma^2} - \bar{z}_w\right]h^2\right\} + (1 - p_w)\left\{\bar{z}_c + \left[\frac{\bar{z}_c\omega_w^2 + \theta_w\sigma^2}{\omega_w^2 + \sigma^2} - \bar{z}_c\right]h^2\right\},$$

the mean of the trait at time t+1 in the hatchery component is

$$\bar{z}'_c = p_c\left\{\bar{z}_c + \left[\frac{\bar{z}_c\omega_c^2 + \theta_c\sigma^2}{\omega_c^2 + \sigma^2} - \bar{z}_c\right]h^2\right\} + (1 - p_c)\left\{\bar{z}_w + \left[\frac{\bar{z}_w\omega_c^2 + \theta_c\sigma^2}{\omega_c^2 + \sigma^2} - \bar{z}_w\right]h^2\right\},$$

where the $\bar{z}$ values are trait means in the natural (w) and hatchery (c) components of the population in generation t, and the $\bar{z}$ ' values are the corresponding trait means in generation $t+1$, p_w and p_c are the proportions of the fish that originated in the natural or hatchery environment, the ω values are the range of trait values with high fitness, the θ values are trait optima in the two environments, σ^2 is the phenotypic variance of the trait, and h^2 is the heritability of the trait. Note that the value of θ in the hatchery environment may be affected by cultural practices (e.g., natural rearing channels versus standard concrete raceways).

The relative mean fitness of a population component in a particular environment is given by

$$\overline{W} \propto \exp\left(\frac{-(\bar{z} - \theta)^2}{2(\omega^2 + \sigma^2)}\right)$$

(Lande 1976).

There are a number of assumptions inherent in use of the Ford model in general, and in this form:

1) that selection actually operates in this way, moving the population toward optima rather than simply directionally;
2) that trait values are normally distributed;
3) that the heritability is the same in the two environments;
4) that the genetic change does not involve loss of genetic material (change is completely reversible).

In using the Ford model to evaluate the fitness loss potential of typical nonnative stock segregated hatchery programs relative to integrated native stock programs, we made a number of additional simplifying assumptions, similar to assumptions made by Busack et al. (2005):

5) it is reasonable for our purposes here to model domestication, which is actually a composite of many correlated traits, possibly with widely differing heritabilities, as a single trait with heritability 0.5
6) ω is the same in the two environments
7) using the above equations without incorporation of demographic features does not appreciably distort results.

We modeled typical segregated programs by use of the equations above, setting p_c to 1.0, and varying p_w from 0.98 to 0.80, which corresponds to gene flow from returning hatchery-origin fish into the natural spawning population of 2 to 20%. We assumed strength of selection (ω), expressed as standard deviation units, could vary from 2σ to 3σ, based on Hard (2004). For assumptions about the distance in optima between natural production and the domesticated hatchery stocks, we attempted to calibrate using the Forks Creek data of McLean et al. (2003; 2004), in which the relative fitness of the hatchery stock in the wild was 0.07, and the Hood River data of Blouin (2003), in which the relative fitness of the hatchery stock in the wild was 0.37 (see section 3.3.1 for a discussion of these studies). For each study we found the optimum value, assuming strength of selection of 2σ and 3σ that would yield the empirically observed fitness. Finally, we considered that despite several years of domestication, that the hatchery stock may have not reached its optimum, so modeled it at 0.33, 0.67, and 1.0 of its optimum, but ended up deciding this was too minor a factor to include so we modeled the hatchery stocks at their optima. Finally, we used fitness in the wild of the natural component after 20 generations as the simulation endpoint.

In modeling integrated programs we set p_c to 0.5 and varied p_w to simulate a proportionate natural influence (PNIs) of 0.5. We assumed the same range of strength of selection and range of optima as in the segregated modeling, but assumed that the integrated program could have a hatchery optimum that is considerably lower than a corresponding segregated program. We simulated programs with 25%, 50%, 75%, and 100% of the difference in optima not nearly as a much less distant from the natural optimum. In simpler terms, we considered that culture practices in a same-stock integrated program may be only 25%, 50%, or 75% as domesticating as the culture practices that created the Chambers Creek stock, as well as considering that they might be just as domesticating.

We summarized results as integrated/segregated fitness indices. The indices are ranges of fitness under integrated programs divided by the fitness under corresponding (same ranges of strength of selection and optima) isolated programs. The indices are presented in Fig. 3-10. The figure is divided into four panels, each representing a different level of hatchery optima in the integrated program relative to the isolated program, and the levels are (from left to right) 25%, 50%, 75%,and 100%. Consider the results depicted in the 25% panel (far left). Results here assume that the hatchery optimum realized in the integrated program is 25% as distant from the original wild optimum as the hatchery optimum in a isolated program. A level of 1 on the y-axis (marked with a dark dotted line) indicates the point at which isolated programs conserve fitness as well as integrated programs. Above a level of 1, isolated programs do better at conserving fitness than integrated programs, and below they do worse. In the first (25%) panel we see then that segregated programs with a 2% gene flow rate can do almost as well (~96-99%) in conserving fitness as integrated programs, but isolated programs with gene flow rates of 20% do considerably worse (20-67%).

Three overall patterns are very clear from the figure. First, in general, integrated programs are generally better at conserving fitness than isolated programs, but isolated programs with low gene flow levels can be nearly as good or better. Second, the relative advantage of integrated programs over isolated programs depends on how domesticating the integrated program are. The 100% panel shows that if the integrated program is just as domesticating as the isolated program is, an isolated program may actually be better if gene flow can be controlled. This is logical. If the integrated program is essentially creating a local Chambers Creek or Skamania stock, an isolated program may be less harmful because gene flow will be better controlled. Third, the relative advantage of integrated over isolated programs depends on the gene flow rate achieved in the isolated program. The ability to conserve fitness relative to the integrated programs drops off rapidly as gene flow increases beyond a few percent.

The overall conclusion from this work is that if gene flow rates can be held to very low rates, isolated programs should be approximately equivalent or slightly better at conserving fitness loss due to domestication than integrated programs, but only if the gene flow can actually be constrained to those low rates (i.e., in Fig. 3-10, the isolated/integrated fitness index is greater than or equal to 1.0 at a 2% rate of gene flow in panels B, C, and D). Otherwise, integrated programs are superior for maintaining the fitness of the natural population.

In considering these results, three caveats need to be considered. First, the model deals only with domestication, not with the other genetic threat an isolated program may impose, outbreeding depression/loss of diversity due to the geographical source of the hatchery population. Second, the modeling deals only with relative, not absolute fitness. Our modeling tools and empirical data are simply too limited to make solid inferences at this point about actual fitness loss. Finally, this is a preliminary analysis.

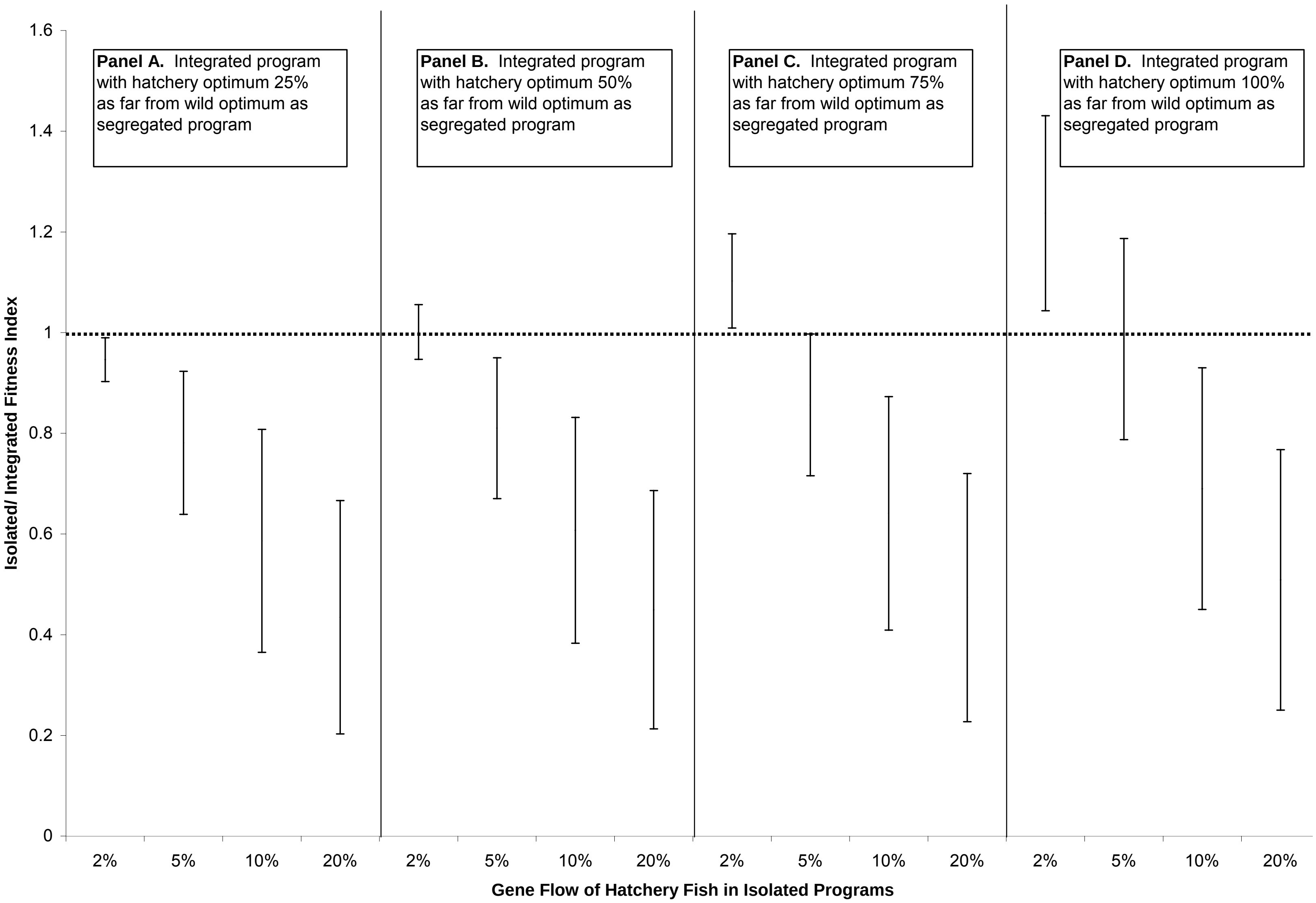

Figure 3-10. Comparison of the relative performance of isolated and integrated programs. Index values of <1.0 indicate that an integrated program operating under those conditions will preserve more of the fitness of a natural program than an isolated program.

The results seem clear and logical enough that we are reasonably confident that the general conclusions will hold over any parameter space we would explore, but we cannot be certain of this until we do additional modeling and until this work is more broadly reviewed.

3.3.5 Empirical Studies of Changes in Genetic Characteristics

In theory, the effects of hatchery steelhead on the genetic characteristics of naturally spawning populations of steelhead could be easily addressed. Samples could be taken from the population before and after the release of hatchery-origin fish to see whether or not the 'after release' populations of naturally spawning fish had become more similar to the hatchery population than the 'before release' populations. However, there are several complicating factors that make rigorous comparisons difficult or impossible. Samples of naturally spawning populations must exist so that initial genetic effects can be investigated. Enough loci must be screened to provide reasonable sensitivity to detect genetic change. Sample sizes must be large enough to provide adequate power to detect differences, if they occur. Genetic changes attributable to genetic drift or other factors must be distinguishable from those resulting from hatchery releases. Finally, a failure to detect change at the gene loci screened does not mean that changes have not occurred at other loci.

Which genetic characteristics should be evaluated? Many people would argue that genes encoding selectively important traits (e.g., life history variation, growth characteristics, reproductive performance) are the most important to monitor. However, many of these phenotypic characteristics have both environmental and polygenic components and are difficult and expensive to study. As a result, such data do not presently exist for addressing the question.

Another approach is to monitor enzyme-coding genes (investigate allozyme variation by electrophoretic analysis) and/or individual DNA segments that may or may not even have a coding function (e.g., mtDNA control region, microsatellite DNAs). This approach presumably provides a sensitive measure of gene flow (effective interbreeding) because the traits being monitored are selectively neutral (or nearly so). However, by definition, this approach does not directly evaluate possible changes in genetic traits that affect survival or performance.

Phelps et al. (1997) attempted to address the question by comparing steelhead allozyme data for the Chambers Creek Hatchery strain and various naturally spawning populations collected by Allendorf in the early 1970s (Allendorf 1975) with data collected by the WDFW Genetics Laboratory more recently (1993-1996). They reasoned that, if there had been substantial interbreeding and genetic introgression of the

Chambers Creek Hatchery strain into local, naturally spawning populations, the genetic distances between the hatchery strain and the various naturally spawning populations should have decreased over time. Genetic distance data (between the Chambers Creek Hatchery strain and the naturally producing local stock) for the seven rivers with data from the early 1970s and the early 1990s (from Table 4-1 of Phelps et al. 1997) are plotted in Fig. 3-11. This plot does not reveal a consistent pattern between the 1970s data and the 1990 data. In some cases, the collections from the 1970s have larger genetic distances (from the Chambers Creek Hatchery strain) than do the collections from the 1990s (e.g., Stillaguamish, Hoko, Twin, and especially Pysht) but in others the reverse is true (Sol Duc, Sauk, and SF Nooksack). Furthermore, in nearly all cases, the distances for the 1970s collections and those for the 1990s collections are of similar magnitude.

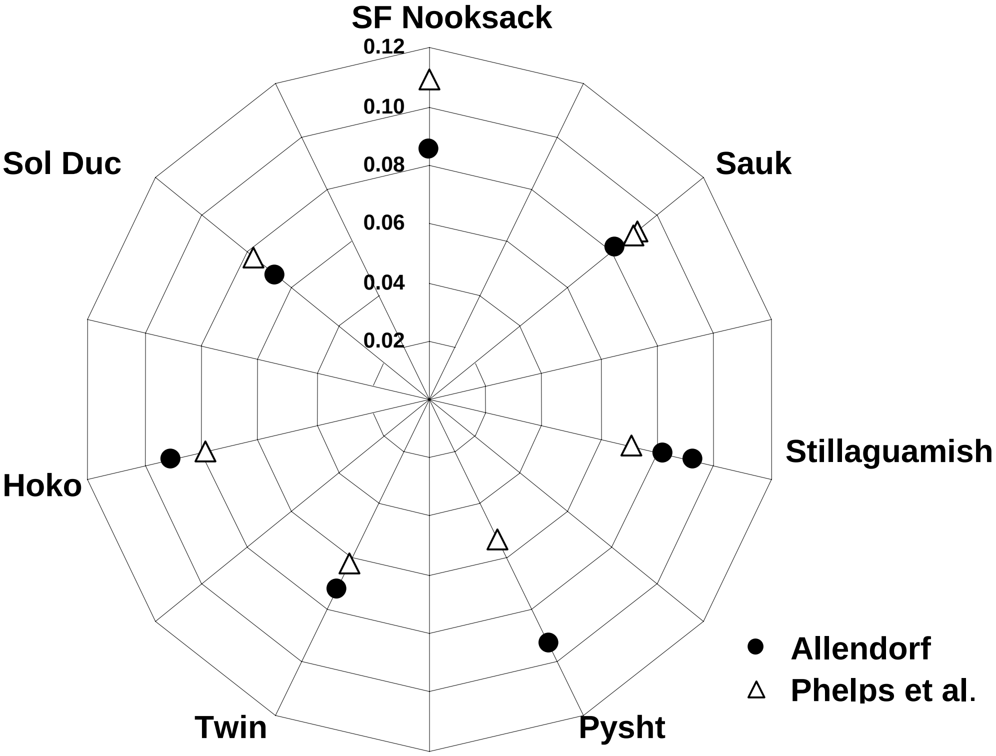

Figure 3-11. Cavalli-Sforza and Edwards (1967) chord distances using seven loci between the Chambers Creek Hatchery strain and selected naturally spawning steelhead populations in Washington. In this graph, the distance from the center of the graph to the data point represents the genetic distance between the Chambers Creek Hatchery strain and the listed stock. The seven loci in common between the two data sets are : *ADH; G3PDH-1; sIDHP-2; LDH-B2; sMDH-B1,2; PGM-2*; and *sSOD-1*. Where necessary, alleles in the Phelps et al. (1997) data set were pooled to ensure compatibility of the data with the data from Allendorf (1975).

Currens (pers. comm.) also evaluated changes in the genetic characteristics of the Pysht River Winter and Hoko River Winter steelhead populations from the data presented in Phelps et al. (1997). Currens computed the probability that changes in the genetic distance were simply due to genetic drift. The probabilities were based on simulated genetic drift from baseline allele frequencies at genetically effective population sizes, N_e., of 50 and 500. Comparing samples from 1975 and 1994, Currens concluded that the magnitude of the change was "extremely unlikely" to have resulted only from genetic drift alone (Table 3-4). "Although we cannot predict the direction of change due to genetic drift in any samples, the magnitude of the change, and the stronger similarity of Chambers Creek steelhead to Strait of Juan de Fuca samples than southern Puget Sound samples, it is highly likely that changes in these populations is due to interbreeding with Chambers Creek steelhead."

Table 3-4. Changes in Pysht and Hoko River populations due to interbreeding with Chambers Creek steelhead. Table from Currens (pers. comm.)

Population	Genetic Distance to Chambers Creek Stock		Probability Due to Gene Drift		Estimated Gene Flow
	Early 1970s	Current	$N_e = 50$	$N_e = 500$	
Pysht River	0.03387	0.00534	< 5%	< 5%	11-27%
Hoko River	0.04382	0.00996	< 5%	< 5%	6-21%

What are the limitations of these analyses? First, the Chambers Creek Hatchery strain was established in 1945 (Crawford 1979) and WDFW records indicate that hatchery fish were planted into some streams as early as 1948 (Puyallup River). Between 1950 and 1973, over 15,500,000 hatchery winter steelhead smolts were planted into western Washington streams (WDFW unpublished steelhead stocking records). The numbers of hatchery winter steelhead smolts planted into the seven streams in the analysis are shown in Table 3-5, and range from just under 4,000 in East and West Twin rivers to over 1,000,000 in the Stillaguamish River. These data strongly suggest that the collections made in the early 1970s did not necessarily represent samples taken prior to possible hatchery effects. Thus, if there had been genetic effects during the first 5-25 years, they could have already been represented in the 1970s data used in the analysis. Furthermore, the test had limited power because only seven loci were common to the 1970s and the 1990s data sets, the collections from each location were generally small (N = 35 - 56; see Table 3-5), and the genetic characteristics of the Chambers Creek Hatchery strain (for the seven loci screened) had changed enough between 1975 and

1993 that the two collections were significantly different at $p < 0.01$ (Phelps et al. 1997).

Clearly, it would be desirable to extend this temporal analysis to earlier collections (prior to the early 1970s) to try to determine the 'before' hatchery genetic characteristics of naturally spawning populations. While no tissue samples suitable for allozyme analysis from earlier time periods are likely to exist, an attempt was made to locate archived scale samples that might allow DNA-based genetic analyses. Unfortunately, no such samples were found after talking with relevant WDFW staff. At this time it seems unlikely that a direct test of the issue involving 'before' as well as 'after' collections is possible.

Although the Phelps analysis shows that evidence of continued introgression from Chambers Creek stock is apparent (and we should pay attention to that) in some populations, it is also not as widespread or pronounced as one might expect, considering the numbers and distribution of hatchery stocking and resulting adult escapements of Chambers Creek stock that have gone on for the two decades between these two sampling events. This could occur either because our ability to assess the effects is poor, or that that native populations may have some level of resistance to introgression from the hatchery stocks (see Utter 2000 for a review of the factors that appear to affect the relative vulnerability or resistance to introgression).

Table 3-5. Details of the collections used for the 1970s vs. 1990s comparison and approximate numbers of hatchery smolts released into these streams between 1950 and 1973. Information on the 1970s samples is not available.

Stream	**1990s collections**			**# Hatchery Smolts**
	Year	**N**	**Collection Code**	
Chambers Creek Hatchery	1993	50	93CD	Na
SF Nooksack River	1995	35	95CL	67,500
Sauk River	1994	55	94AT	210,400
Stillaguamish River	1993	56	93CI	1,194,171
East & West Twin River	1995	56	95CF	3,700
Pysht River	1994	50	94CT	213,000
Hoko River	1994	53	94BB	66,464
Sol Duc River	1994	52	94CO	156,780

3.4 Competition

Intraspecific competition occurs indirectly when two or more individuals from the same species use the same resources when those resources are in short supply (exploitative competition), or directly when access to a critical resource is prevented (interference competition) (Pianka 1988). The resources that hatchery and wild steelhead may compete for include space, food, and access to mates. Competition may occur in freshwater rearing areas, the migration corridor, estuary, ocean, and spawning grounds. Interference and contest competition might be most prevalent in freshwater where territorial behavior is advantageous. Exploitative and scramble competition may be most prevalent in marine environments. Combinations of all types of competition may be expressed in the migration corridor and estuary, where temporary interference and exploitative competition may occur.

In hatchery programs that release smolts, competition with wild steelhead can occur when hatchery steelhead actively migrate as smolts, when they residualize, and when hatchery steelhead return to freshwater as adults. An actively migrating smolt is defined as a fish that emigrates to the ocean prior to a specified time (i.e., usually determined by the completion of the co-occurring wild steelhead smolt emigration). A residual is a juvenile steelhead that fails to emigrate within a specified time (Viola and Schuck 1995). In fact, residuals may never migrate to the ocean and instead become stream residents (Peven et al. 1994). In some instances, wild progeny of steelhead may become residuals, however the percentage of juvenile wild steelhead that residualize is unknown. For example, some adult resident rainbow trout in the Babine River, British Columbia, have been found to be offspring of maternal steelhead (Zimmerman and Reeves 2000).

Hatchery managers have traditionally attempted to efficiently produce smolts that actively emigrate to sea and later return as adults to provide harvest opportunities. However, residuals create inefficiencies and are an undesirable byproduct of many hatchery steelhead programs (Tipping et al. 1995; Viola and Schuck 1995; Busby et al. 1996). Residuals can form a significant percentage of hatchery steelhead releases, with estimates ranging between 3 and 52% (Seelbach 1987; Evenson and Ewing 1992; Martin et al. 1993; Tipping et al. 1995; Viola and Schuck 1995). Most steelhead hatcheries release smolts in the spring at age 1, despite the propensity for most wild steelhead smolts to emigrate at age 2 or older (Withler 1966; Peven et al. 1994; Busby et al 1996). The impetus to migrate may be a combination of genetic and physiological factors (Peven et al. 1994; Pearsons et al. in press). The life histories of some wild steelhead may lead them to not emigrate at all and these fish are referred to as rainbow trout. Residualized steelhead are considered to present such a substantial risk to wild fish in some areas (e.g., in areas with populations listed under the ESA) that innovative strategies have been developed to minimize the numbers of residuals that are introduced into streams (Viola and Schuck 1995; McMichael et al. 1999).

During freshwater rearing, salmonids in hatcheries and rivers use different methods to acquire food. River environments are heterogeneous (e.g., patchy) with respect to food and habitat quality. Salmonids rearing in streams primarily feed on drifting invertebrates as they maintain energetically profitable stream locations (Fausch 1984). Dominant fish secure the most food and grow the fastest (Metcalfe 1986). These fish use a variety of agonistic interactions, such as nips, butts, chases, and threats to defend territories that have predictably high levels of food (Chapman 1962; Grant and Kramer 1990; McMichael et al. 1999). This type of interference interaction is referred to as contest competition. In contrast, salmonids in hatchery raceways live in homogenous environments where positions are equally viable. Fish in hatcheries frequently use shoaling or schooling behaviors and acquire food from the water surface. Thus, agonistic interactions prior to food interactions is wasted energy but with little immediate consequences in hatchery environments where food is plentiful. Fish that are in the right place at the right time and that swim rapidly towards the food are the most successful. This type of interaction is referred to as scramble competition.

The more similar the ecology of two organisms, the stronger the potential for competition. When individuals are of the same species, competition is likely to be most intense when they are of the same size. Competition is also hypothesized to increase as densities of fish increase, particularly as carrying capacity is reached. The carrying capacity of a watershed is one of the main factors in determining whether supplementation is a viable technique of increasing natural production. For example, supplementing a stock that is near carrying capacity will not produce a large increase in naturally produced fish. Carrying capacity in aquatic systems is defined as the maximum number of fish at their most demanding life-stage that can be supported by the available habitat.

Studying an indirect interaction such as competition is challenging and yet extremely important because of the impact that competition can have in structuring communities (Connell 1983; Schoener 1983). Controlled field experiments are the best way to test competition, but logistically impractical when considering multiple species in a variety of ecological conditions during many years. Historically, resource overlap has been used as an indication or demonstration of competition (Colwell and Futuyma 1971). The use of resource overlap indices during the 1970’s led many scientists to conclude that competition was extremely prevalent in natural communities. However, without additional information, such as resource availability or behavioral interactions, overlap indices can be ambiguous (Colwell and Futuyma 1971; Sale 1974; Ross 1986). For example, high resource overlap between sympatric species is a good indication of competition only if resources are relatively scarce and important to the well being of the organisms. Conversely, low resource overlap is a good indication that significant competition is not occurring only when it can be demonstrated that the lack of overlap is due to innate differences in preferences and not interactive segregation.

There are relatively few studies that have explicitly tested whether hatchery steelhead competitively impact the growth or abundance of wild steelhead (Weber and Fausch 2003), however mechanisms of competition have been demonstrated. Residualized hatchery steelhead have been observed to impact the growth of wild *O. mykiss* in stream enclosures (McMichael et al. 1997). However, in a larger scale experiment, impacts to growth or abundance were more equivocal (McMichael et al. 2000; Pearsons, pers. communication). Bjornn (1978) reported that stocking hatchery steelhead fry reduced the abundance of resident rainbow trout through competition. "Differences in behavior, physiology, and morphology that potentially affect competitive ability have been studied more than direct tests of competition" (Weber and Fausch 2003). McMichael et al. (1999) found that hatchery steelhead smolts interacted agonistically with *O. mykiss*, which caused wild *O. mykiss* to be displaced from presumably preferred locations.

Hatchery fish generally dominate wild fish in behavioral contests (Rhodes and Quinn 1998; McMichael et al. 1999). Dominance among salmonids has been demonstrated to be most consistently associated with fish size (Abbott et al. 1985; Berejikian et al. 1996; McMichael et al. 1999), but prior residence, prior winning experience, genetics, aggressiveness, and hatchery rearing also influence dominance (Huntingford et al. 1990; Berejikian et al. 1996; Rhodes and Quinn 1998). Differences in aggression are related to metabolic rate (Metcalfe et al. 1995), genetics (Taylor and Larkin 1986; Rosenau and McPhail 1987), and rearing experience (Berejikian et al. 1996; Rhodes and Quinn 1998).

Domestication selection has been shown to alter the aggressiveness and dominance of hatchery fish. Domestication has been implicated as increasing and decreasing aggressive and schooling behavior in fish (Ruzzante 1994). Berejikian et al. (1996) found that offspring of wild steelhead trout were more aggressive and dominant (87.5%) than size matched offspring of parents that had been in hatchery culture for 4 to 7 generations. However, when hatchery fry had a 3.0-4.5% size advantage, they dominated wild fish in 68% of encounters. Swain and Riddell (1990) found that domesticated coho were more aggressive than those of natural origin from nearby streams. Hatchery reared chinook salmon dominated smaller wild chinook salmon and altered wild fish behavior (Peery and Bjornn 1996). Farrell (2003) found that wild spring chinook salmon from the Yakima Basin were competitively dominant to descendents of first generation local origin hatchery fish in contest competition trials.

Despite the limited reproductive success of some domesticated hatchery-origin spawners, the sheer number of hatchery-origin spawners can result in substantial numbers of juvenile progeny. This scenario creates a mechanism for detrimental competitive effects of the offspring of hatchery fish on rearing juvenile wild fish (Leider et al. 1990; Kostow et al. 2003; McLean et al. 2004). This could be expected to cause some level of depression of productivity in the wild population as long as the competition continues. Each of the domesticated hatchery stocks reported on here have earlier spawn timing than the local wild stocks. Thus any of the hatchery offspring that do survive to emerge will do so much earlier than most wild fish and would be expected to have both a size-related and prior residence-related competitive advantage that may reduce the cumulative effects of other mal-adaptive traits that confer their lower observed fitnesses.

In conclusion, there is sufficient theoretical and empirical data to indicate that hatchery steelhead could potentially pose a competitive risk to wild steelhead. However, risks could range from low to high, and our ability to accurately assess these risks is still lacking empirical data.

3.5 Predation

Both hatchery steelhead juveniles and adults have the potential to prey on juvenile salmonids. Although research on the subject has been somewhat limited, predation on stocks of low abundance is of most concern and thus, predation on juvenile Chinook salmon has been the focus of most investigations.

Based on the only two studies found on the subject, adult steelhead consumption of juvenile salmonids in freshwater is infrequent; Burns (1974) reported that 95% of adult steelhead contained food items in two tributaries of the Sacramento River in California but that no juvenile fish were found. Vander Haegen et al. (1998) examined the stomach contents of adult summer steelhead on the Cowlitz River. Of 1,041 stomachs examined, 11% contained food items but only two stomachs (0.2%) contained the remains of four juvenile salmonids.

Juvenile hatchery steelhead (smolts) are relatively large (170-230 mm) and usually released with spatial and temporal overlap to allow predation on Chinook salmon fry. However, most evidence suggests minimal predation on juvenile Chinook salmon. Even though Martin et al. (1993) found that hatchery steelhead had consumed Chinook salmon juveniles up to 108 mm in fork length and averaged 35% of their body length, Martin et al. (1993), Cannamela (1993) and Jonasson et al. (1995) found low rates of predation, with 0.00% to 0.18% of hatchery steelhead smolts containing juvenile Chinook salmon. On the Green River for 2003 and 2004 combined, 1,134 hatchery steelhead stomachs were examined (Topping, pers. communication). Most (78.8%) hatchery steelhead smolts contained insects, 20.5% of stomachs were empty and 3 (0.3%)

contained chum salmon fry. In 2003, an additional five fish contained salmonid fry but all prey were either alive or freshly killed and thought to have been consumed in the trap, so they were not counted. All prey fish were identified as chum salmon fry with no Chinook salmon juveniles present. Mean length of hatchery steelhead smolts having consumed fry was 191 mm (range 176-205 mm). On the Deschutes River, Washington, 1,407 hatchery steelhead smolts were captured in a fish trap and 91 fish were captured by angling, a total of 1,498 fish. Gastric lavage sampling indicated that 69% of hatchery steelhead smolts contained insects and 31% were empty; no salmonid fry were found (Sharpe, pers. communication).

Further, an ongoing study (Kraemer, Tipping, and Busack, in preparation) found that egg-to-migrant survival of Chinook salmon juveniles remained unchanged in the Skagit River even when hatchery steelhead smolt numbers trebled from 196,000 to 583,000 fish.

An outlier to the above research is the study on the Lewis River by Hawkins and Tipping (1999) who reported that 232 hatchery steelhead stomachs contained 58 Chinook salmon juveniles, an average of 0.25 fry/steelhead. However, the high predation rates on the Lewis River are probably due to the great abundance of Chinook fry and the late spawning time of the adult fish. In the Martin et al. (1993) study on the Tucannon River, spawning escapement was estimated at 259 Chinook salmon in 1991 (WDFW records), representing an egg density of 7,600 eggs/km, based on a spawning access of 84 km, an assumed 45% of the population being female and a fecundity of 5,500 eggs/female. On the Lewis River, Chinook salmon spawner abundance typically averages about 11,000 fish, resulting in about 27,225,000 eggs for 31 km of accessible river, 878,200 eggs/km, 115 times greater than that on the Tucannon River.

In addition, Chinook salmon in the Lewis River spawn in November whereas most Chinook salmon in Washington spawn in late September and early October. The late spawning time is probably due to the river temperature profiles resulting from the dams on the river. Thus, peak juvenile emigration occurs in late June and early July on the Lewis River (McIsaac 1990), 4 to 6 weeks later than most other streams. Most Chinook salmon juveniles were probably present on the Lewis River when hatchery steelhead were released from mid-April to early May whereas many had emigrated by that time on other rivers. Therefore, not only was there a much higher density of Chinook salmon juveniles present in the Lewis River than on other streams when hatchery steelhead were released, but the Chinook salmon juveniles were smaller in size, probably making them more susceptible to predation.

Obviously, the predation opportunity of hatchery steelhead is influenced by their spatial and temporal overlap with wild salmonid juveniles. Migration travel rates of hatchery steelhead have been documented at around 20 miles per day (Dawley et al. 1984; Harza

1998). However, substantial smolt losses have been frequently documented before fish exit the river. A 20% loss was observed in 4.7 km of travel on Snow Creek (Tipping et al.1995), 40-50% loss in a series of releases with 9.9-17.2 km of travel on two coastal streams (Tipping and Byrne 1996), 42.0-42.7% loss over 10 km of travel on a stream in British Columbia (Ward and Slaney 1990), and 36% loss over 11 km of travel in the Yakima River (McMichael et al. 1992).

Factors that affect emigration rates of hatchery steelhead smolts include length and condition factor at release (Tipping et al. 1995). Smolts less than 190 mm and fish with a condition factor greater than 1.0 had substantially lower emigration rates. Ongoing research on the Kalama River suggests that residualism rates are higher rates for hatchery fish spawned from wild brood stock. Many rearing parameters that affect residualism rates are probably inverse to those mentioned in section 3.2.2 that affect survival.

Commonly, 5-10% of a hatchery steelhead population fails to emigrate from rearing vessels after release. Voila and Shuck (1995), in a study on summer steelhead in eastern Washington, found that in one year, many non-migrants were precocious males and they recommended not releasing them so that the number of residuals would be reduced. However, in a recent study on the Washington coast, adult returns of hatchery steelhead that were forced from a raceway (7% of population) after volitional opportunity had similar survival as volitional emigrants.

Current methods employed by WDFW to reduce predation risk by hatchery steelhead smolts on juvenile salmonids include delayed release timing and downstream transport. At the Dungeness Hatchery, hatchery steelhead smolts are not released until June 1 in years following pink salmon spawning so that pink salmon fry can clear the system before steelhead are present. At Merwin Hatchery on the Lewis River, hatchery steelhead smolts are trucked for release below the juvenile Chinook salmon rearing area.

3.6 Facility Effects and Disease

Hatchery facilities have potential to impair wild fish. Upstream and downstream passage barriers may exist, intake screens may impinge juveniles or allow their passage into the hatchery, effluent water quality may be degraded, wild fish adults may enter adult ponds and be inadvertently destroyed during handling of hatchery fish, and diseases may be amplified.

Current hatchery facility passage and screening criteria include NOAA Fisheries' Anadromous Salmonid Passage Facility Guidelines and Criteria, WDFW's Fish Protection

Screen Guidelines for Washington State and Fishway Guidelines for Washington State. In fall 2004, water intakes in Puget Sound and Coastal anadromous hatcheries were assessed for screening and passage by WDFW engineers and a consultant. Nearly every hatchery needed some corrective action to be compliant with the guidelines; estimated costs were about $22 million.

However, hatchery barriers on streams have aided management of adult wild fish by allowing wild fish to be counted and hatchery fish numbers passed upstream to be controlled. Such barriers exist at Kalama Falls Hatchery on the Kalama River, the Cowlitz Salmon Hatchery on the Cowlitz River and at Minter Creek Hatchery.

Effluent from hatcheries has the potential to degrade water quality for wild fish and the habitat in which wild fish rear. Poor water quality with high biotic loads or chemicals from treatments could slow growth of wild fish or increase their susceptibility to disease while the discharge of sediments could result in stream siltation, reducing fish rearing habitat. The Clean Water Act set water quality standards for all contaminants in surface waters. The Act made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions. Environmental monitoring is conducted at WDFW hatcheries to ensure the facilities meet requirements of the National Pollution Discharge Elimination Permit administered by the Washington Department of Ecology. Monitoring parameters include total suspended solids, settleable solids, in-hatchery water temperatures, and in-hatchery dissolved oxygen. To comply with the Clean Water Act and the National Pollution Discharge Elimination Permit, recent and ongoing assessments of WDFW Puget Sound and Coastal facilities have identified needed corrective actions. Construction or upgraded of pollution abatement facilities at WDFW facilities will cost $5 to 10 million; corrective actions are currently underway at some facilities and planned for the rest.

When handling large numbers of hatchery brood stock, hatchery staff may inadvertently kill wild fish that are in the pond due to repeated handling or other means. Such destruction of wild fish can be minimized with improved hatchery design during renovations and acquisition of fish friendly equipment. For example, wild fish can often be excluded from the hatchery brood stock with a sorting tower and flume like those found at Minter and Cowlitz Salmon hatcheries.

There is potential that disease organisms can be amplified in hatcheries and then discharged to infect wild fish. Although this has received limited study and there have been no documented cases in Washington, hatchery personnel work closely with Fish Health staff to minimize the incidence of disease within hatcheries, and thus, the discharge of disease should also be minimized. Reporting and control of fish pathogens are conducted in accordance with the co-managers Fish Disease Control Policy and include protocols on fish and egg movements, therapeutic and prophylactic treatments, and sanitation. Hatchery protocol calls for mortalities to be removed from the water and disposed of properly.

3.7 Discussion

Hatchery-based production is a tool that can be used to increase fishing opportunities, conserve at-risk natural populations, or facilitate research, monitoring, and evaluation. Use of the tool is not without risks. Possible impacts can include reductions in the diversity and fitness of natural populations, deleterious ecological interactions with natural populations and other species, and migration impediments resulting from the construction of hatchery facilities.

Hatchery reform is the ongoing, systematic application of scientific principles to improve hatcheries for recovering and conserving naturally spawning populations and supporting sustainable fisheries (HSRG 2004). The roots of hatchery reform can be traced back at least to the late-1980s, but an influential report published by the National Academy of Sciences in 1996 may have been the first to promote a broad discussion of a new paradigm for hatchery programs. That report, *"Upstream: Salmon and Society in the Pacific Northwest"* (National Research Council 1996), concluded that hatcheries had generally failed to compensate for habitat degradation and recommended a broader, ecosystem perspective for hatchery management:

> *"Hatcheries can be useful as part of an integrated comprehensive approach to restoring sustainable runs of salmon, but by themselves they are not an effective technological solution to the salmon problem."*

The concept of hatchery reform has subsequently been refined (Brannon et al. 1999; ISG 2000; Williams et al. 2003; HSRG 2004) and, in this chapter, new tools have been developed to evaluate artificial production programs for steelhead.

Drawing on these efforts, we discuss below seven considerations to effectively use artificial production programs as a tool to achieve conservation and fishery objectives.

1) Healthy Habitat Provides Greatest Biological Certainty. *Productive natural habitat is essential for healthy, harvestable salmon populations. However, restoring and protecting habitat to the extent necessary to achieve population restoration and harvest goals is often a long-term process and social, economic, or funding constraints may make it infeasible for some populations.*

Four alternative types of habitat management strategies are to protect, restore, rehabilitate, or substitute (NRC 1992). As the strategy moves from protection to substitution (including hatchery production), the certainty of achieving viable salmonid populations declines because of the complex interaction between the environment and salmonid populations and our limited ability to predict the effects of anthropogenic intervention (NRC 1992; 1996). Although protection and restoration strategies provide the greatest biological certainty, habitat within the range of listed species of salmonids is typically substantially degraded and the restoration of natural processes may not be feasible within a 10-20 year time frame. In some watersheds, social, economic, and funding constraints may limit our ability to provide the habitat conditions necessary to meet fishery and conservation objectives (see for example, NMFS' consideration of economic impacts in the proposed rule for critical habitat, 69 FR 74572; December 14, 2004).

2) Ecosystem Perspective Promotes Improved Performance. *Hatcheries designed, operated, and evaluated in an ecosystem perspective are more likely to provide harvest and conservation benefits with reduced risks to natural populations.*

A fundamental change from the historical paradigm for hatchery programs is required to achieve conservation and fishery objectives. Rather than viewing a hatchery as an isolated fish production factory, numerous scientific reviews have recommended that hatchery programs should be evaluated as part of the environmental and ecological systems in which they operate (NRC 1996; Brannon et al. 1999; HSRG 2004). Viewing a hatchery as a tributary to a watershed expands hatchery assessments from a simple examination of fish culture practices to a broad investigation of demographic, ecological, evolutionary, and fishery interactions (Williams et al. 2003).

3) Successful Programs Achieve Watershed Specific Objectives. *A hatchery program is "successful" when it provides more benefits than risks when evaluated relative to watershed-specific objectives. The characteristics of a successful program will differ among watersheds because of the varying status of natural populations and policy decisions regarding the rapidity and extent of habitat protection and recovery.*

Hatchery programs can provide substantial economic, cultural, and conservation benefits, but potentially they can also pose risks to natural populations of salmon and steelhead. Often, hatchery programs focused on preventing extinction and promoting recovery must consider tradeoffs between different biological risks in the short-term to achieve long-term recovery. The risks and benefits of a hatchery program should be evaluated relative to the ability of the habitat to support viable natural populations and meet other policy objectives – currently and in the future. This evaluation should take into account the abundance, productivity, diversity, and spatial structure of the population, and how the hatchery program affects these population characteristics.

As habitat improves to levels that support viable natural populations, hatchery programs can often be modified to reduce potential risks while maintaining harvest and conservation benefits. A hatchery program may be visualized as following a trajectory from the current operation to the expected operation at recovery (Fig. 3-12). The speed and direction of the trajectory will depend on the current conservation value of the population, the current productivity of the habitat, and policy decisions that define region-wide recovery.

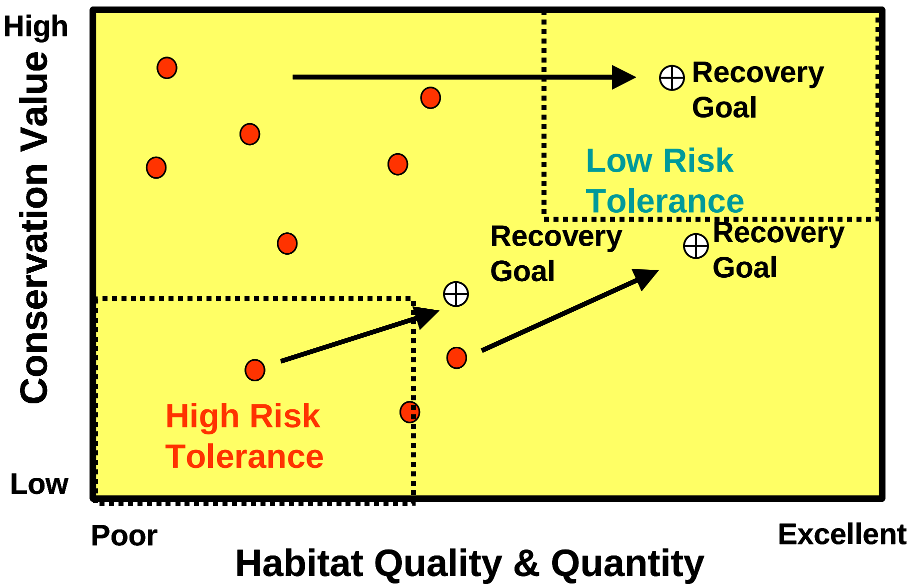

Figure 3-12. Conceptual representation of relationship between habitat quality and quantity, population conservation value, and risk tolerance for hatchery programs (revised from Currens and Busack, In Prep.).

4) Goal and Strategy Drive Program Protocols. *The design of a successful program begins with the careful selection of either an integrated or an isolated hatchery strategy. Integrated hatchery programs can be operated to increase the number and distribution of natural spawners, increase the productivity of the composite population, and provide fishing opportunities. Isolated hatchery programs can be operated to provide fishing opportunities while minimizing interactions with natural populations.*

Strategy selection is program and watershed specific, and depends on the status of the natural population and habitat, the ability to collect natural-origin broodstock, the ability to control the number of hatchery-origin adults in natural spawning areas, and other factors. Hatchery operating protocols should be consistent with the management objective and the strategy. The protocols describe the daily operation of the hatchery program, and include the program size, broodstock source and collection procedures, rearing conditions, and time, size, and location of release.

5) Productive Habitat is Essential. *Habitat quality and quantity remain essential, regardless of the hatchery strategy, if hatchery programs are to be successfully implemented. In watersheds where social, economic, or funding constraints limit the feasibility of meeting conservation and harvest objectives strictly through habitat restoration and protection, hatchery programs using an integrated strategy and complementary habitat actions ("balanced portfolio" approach) could be implemented and tested.*

An outgrowth of the new, ecosystem paradigm for hatchery operations is the renewed recognition of the critical importance of habitat. Hatchery programs can only be successful if habitat conditions are conducive to the survival of salmon throughout their entire life cycle. This is particularly true for programs relying on an integrated strategy, since natural-origin broodstock must be incorporated into the hatchery in each generation. This means that the risks and benefits of a program of fixed size will be directly related to the productive capacity of the natural habitat.

In watersheds where social, economic, or funding constraints limit the feasibility of meeting conservation and harvest objectives strictly through habitat restoration and protection, hatchery programs using an integrated strategy and complementary habitat actions could be implemented and tested. Where applied, this "balanced portfolio" approach should be carefully designed, monitored, and evaluated during the next 10-20 years. Scientific decision support tools developed by the comanagers, HSRG, and other can help identify scientifically defensible combinations of habitat improvement, harvest constraints, and hatchery program size that are consistent with policy objectives and constraints.

6) Relationship Among Hatcheries, Harvest, and Habitat. *The effectiveness of hatchery programs is likely to increase if they are developed and evaluated as part of an integrated harvest, hatchery, and habitat strategy for conservation and sustainable fishing opportunities.*

The complex interaction of harvest, hatchery, and habitat is discussed further in Chapter 4, Management.

7) Manage Hatchery Programs for Success. *Hatchery management improves through adaptive management - or making changes based on learning by doing. Adaptive management is enhanced by carefully defining and monitoring performance measures.*

Continued review, evaluation, and modification of hatchery programs is essential to assure that fishing-related economic and cultural benefits are maximized and region-wide conservation objectives achieved. Adaptive management is a process that allows managers to make informed decisions while operating in the face of uncertainty, including future circumstances and consequences. It is likely to be most effective if it is driven by clearly defined goals and objectives, performance measures are identified and monitored, and results are readily available, communicated, and evaluated in a defined decision making framework.

The HSRG (2006) provided broad recommendations for steelhead programs in Puget Sound and the Washington Coast. The recommendations were premised on the assumption that integrated harvest programs are not currently a viable alternative in most watersheds in Puget Sound because the natural steelhead populations are not sufficiently abundant and productive to provide the necessary number of natural-origin broodstock. Key points of these recommendations are summarized below.

> Wild Steelhead Management Zones (WSMZs). The HSRG suggested selecting "a balance of large and small streams and habitat types in each region that are not planted with hatchery fish and are instead managed for native stock. Fishing for steelhead in these streams would not be incompatible with this approach, but no hatchery-produced steelhead should be introduced."
>
> Locally Adapted, Early Run Timing Broodstock. Outside of the WSMZs, the HSRG recommended using locally adapted broodstock and to reduce reliance on outside sources of broodstock to backfill shortages in the locally adapting hatchery stock. The hatchery stock should be managed to "maintain its early spawn timing and reduced the likelihood of interaction with naturally-spawning steelhead."
>
> Adult Collection Capability. To minimize reproductive interactions with natural-origin spawners, the HSRG recommended that an adult capture facility should be in place in every location where juveniles from an isolated program are released.
>
> Program Size. The number of juveniles released from a hatchery program should be established "in a manner that achieves harvest goals with minimal impact on wild populations."
>
> Size of Juveniles at Release. "Release hatchery yearling steelhead smolts between April 15 and May 15 at target size of six fish to the pound, and a condition factor of less than 1.0."

Monitoring and Evaluation. The HSRG recommended that monitoring and evaluation should be a "basic component" of the management of artificial production programs. In addition, a specific recommendation was to "investigate the reasons for the recent decline in adult winter steelhead returns, formulate a working hypothesis for the decline and take appropriate actions."

The WDFW expects that the general recommendations of the HSRG will be used in conjunction with this report and others to develop improved artificial production strategies for steelhead. However, specific program modifications will need to be developed on a population specific basis, with consideration of conservation and fishery objectives, the biological characteristics of the natural population, the productivity of the habitat, and the potential for implementation of alternative harvest management strategies. Rather than a simple mixture of isolated, early-timed hatchery programs and WSMZs, a wider variety of artificial production programs will likely need to be considered. Kelt reconditioning, integrated conservation programs, integrated harvest programs, and isolated harvest programs are all strategies that, when thoughtfully implemented, may help achieve conservation and fishery objectives.

3.8 Findings and Recommendations

Finding 3-1. The recreational fishery for hatchery-origin steelhead provides substantial fishing opportunities and economic benefits. In the nine seasons from 1995-1996 through 2003-2004, recreational anglers harvested an average of 99,300 hatchery-origin steelhead. The estimated expenditures by recreational fishers associated with the catch of hatchery-origin steelhead were approximately $99 million dollars per year, with an economic output (includes revenues generated indirectly) of $188 million dollars per year.

Finding 3-2. Hatchery programs using Chambers Creek Winter or Skamania River Summer steelhead coupled with an isolated strategy comprise over 68% of the broodstock collection programs in western Washington. Over 68% (28 of 41) of the steelhead broodstock collection programs in Puget Sound, the Olympic Peninsula, Southwest Washington, and the Lower Columbia regions collect broodstock of either Chambers Winter or Skamania Summer origin. Juveniles from these programs are generally released in watersheds where these stocks are not indigenous. The programs are operated with an isolated (also called segregated) reproductive strategy with the intent that little or no gene flow will occur between the natural and hatchery population. In contrast, hatchery programs in eastern Washington primarily rely on an integrated strategy with broodstock of local origin (5 of 7 or 71% of broodstock collection sites).

Finding 3-3. Naturally spawning adults originating from hatchery programs using the Chambers Creek Winter or Skamania River Summer stock have low reproductive success. Six empirical studies in Oregon and Washington demonstrated that returning adults from these programs have low reproductive success in natural spawning areas. In these studies, highly domesticated hatchery-origin spawners have have been found to have only 7% to 37% of the success of natural-origin spawners in the same river.

Finding 3-4. Chambers Creek Winter and Skamania river Summer steelhead programs pose a high potential genetic risk. Although each returning adult of Chambers Winter and Skamania Summer origin may on average have low reproductive success, substantial production of juveniles can still result from the spawning of a large number of hatchery-origin adults. When considered together with the previous two findings, this suggests that the Chambers Winter and Skamania Summer steelhead hatchery programs could pose a substantial risk to both the among-population diversity and the fitness of natural steelhead populations. Direct empirical evidence for loss of diversity is limited because genetic samples were generally not collected from natural populations before hatchery programs were initiated and the power of tests that can be applied is limited by the small number of loci (7) evaluated. Despite these limitations, 2 of the 7 (29%) natural populations sampled had significant introgression by Chambers Winter type fish during the time period evaluated.

Finding 3-5. Integrated programs are likely to be more effective at maintaining population fitness for rates of gene flow >2%. Theoretical analysis calibrated with field studies indicates that integrated programs using a local source of broodstock will be more effective than isolated programs in maintaining the fitness of natural populations when the rate of gene flow from adults of hatchery-origin to the naturally-spawning population exceeds 2% per year.

> *Recommendation 3-1.* Evaluate the potential range of gene flow from returning adults to natural populations in all watersheds where Chambers Winter or Skamania Summer type steelhead are released. Where risks are inconsistent with policy objectives for the natural population, implement one or more of the following actions: 1) release steelhead juveniles from isolated programs only at locations where returning adults can be captured; 2) adjust the size of the program, release location, fishery harvest rate, or other factor to achieve an acceptable rate of gene flow; or 3) replace the isolated program with an integrated program developed from local broodstock.

Recommendation 3-2. Design and initiate a program to monitor the genetic characteristics of steelhead populations. Prioritize the collection of samples from watersheds with both a hatchery program and a significant natural population to assess the potential loss of diversity associated with hatchery programs.

Recommendation 3-3. Support and expand research to link changes in genetic markers to the abundance and productivity of the population. Current genetic monitoring typically assesses changes in the frequency of neutral alleles, or alleles that are not believed to have a functional effect on fitness. If we could identify genetic markers that were related to fitness, we could provide an improved assessment of what changes in the frequency of these markers mean to population productivity and other characteristics.

Recommendation 3-4. Submit for publication in a peer-reviewed journal a paper describing the methods developed to compare the potential fitness loss associated with integrated and isolated artificial production programs. These methods may be of broad interest in the evaluation and management of artificial production programs.

Finding 3-6. Progeny from Chambers Creek Winter and Skamania River Summer adults that spawned naturally pose a potential risk of competition to the indigenous natural population. Despite the limited reproductive success of some domesticated hatchery-origin spawners, the sheer number of hatchery-origin spawners in natural spawning areas can result in substantial numbers of juvenile progeny. Competition may occur with indigenous natural populations, but the potential magnitude of the effects is extremely difficult to quantify.

Recommendation 3-5. Evaluate the potential effects of competition when considering the relative risks and benefits of isolated programs, particularly if conservation concerns exist. Where risks are inconsistent with policy objectives for the natural population, implement one or more of the actions described in Recommendation 3-1.

Finding 3-7. Integrated artificial production programs can increase the number of natural spawners and improve the productivity of the composite population, but the long-term effectiveness of these programs has not been conclusively demonstrated. Successful implementation of an integrated program requires careful consideration of the number and characteristics of natural-origin broodstock, the incidence of hatchery-origin adults in natural spawning areas, and the juvenile release strategy (location and time of release; size and smolting status of juveniles at release). While integrated programs have proven effective in increasing the abundance and productivity of the composite population in the short-term, long-term impacts on diversity, spatial structure, and the potential loss of productivity associated with domestication have not been thoroughly evaluated. Long-term effectiveness also depends on maintenance and improvement of the productivity of natural habitat. Interactions between habitat, hatchery, and harvest are discussed further in Chapter 4.

> *Recommendation 3-6.* Evaluate the potential effects of integrated programs on the diversity, spatial structure, abundance, and productivity of the indigenous natural population. Carefully consider the size of the program and characteristics of the release strategy (location, time, size of fish) to assure that potential genetic and ecological risks are consistent with policy objectives.

Finding 3-8. Survival rates for steelhead released from Puget Sound programs are currently the lowest of any region within the state. Survival rates for winter steelhead released from hatchery programs in Puget Sound dropped to an average of <0.4% for the 1995 through 1998 brood years. The survival rates are currently the lowest of any region within the state, including the Upper Columbia River and the Snake River, and appear to have resulted from a significant shift in the conditions encountered during early marine rearing in Puget Sound and the Georgia Basin.

> *Recommendation 3-7.* Develop a “population rescue” reference document that discusses the conditions under which a hatchery conservation program may be warranted and the key questions that should be addressed during the development of the program. (Chapter 3, Recommendation 7)

> *Recommendation 3-8.* Evaluate the fishery and economic benefits of isolated hatchery programs in Puget Sound relative to those of hatchery programs for other salmonid species and the potential benefits of conservation programs for natural steelhead populations. If necessary, adjust programs to provide enhanced economic and conservation benefits.

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Appendix 3-A. Derivation of Gene Flow Equation

The spatio-temporal distribution of spawners in a stream with an isolated hatchery program is shown in Fig. 3-7. Region A represents the distribution of natural-origin spawners, Region C the distribution of hatchery-origin spawners, and Region B represents the overlap of the two distributions.

Let N_N be the number of natural-origin spawners, N_H be the number of hatchery-origin spawners, o_N be the proportion of natural-origin spawners in region B, and o_H be the proportion of hatchery-origin spawners in region B. The number of spawners in the three regions is then:

$$A: \;\; N_N(1-o_N)\,, \;\; B: \;\; N_N o_N + N_H o_H\,, \;\; C: \;\; N_H(1-o_H)$$

We assume that the proportion of total matings in each region are the same as the proportions of fish in each region. At this point we remove the absolute fish numbers and rescale as proportions, letting *q* be the proportion of total spawners that are hatchery-origin fish and *1-q* be the proportion of total spawners that are natural-origin fish. Now the proportions of matings in each region are:

$$A: \; (1-q)(1-o_N)\,, \;\; B: \; (1-q)o_N + qo_H\,, \;\; C: \; q(1-o_H)$$

Matings within region A are NxN only, matings within region C are HxH only, but matings within region B are NxN, HxN, NxH, and HxH. To calculate the proportions of the various mating types, it is necessary to calculate the proportions of natural-origin and hatchery-origin spawners within region B. Let these two proportions be p_N and p_H, respectively.

$$p_N = \frac{(1-q)o_N}{(1-q)o_N + qo_H}, \qquad p_H = \frac{qo_H}{(1-q)o_N + qo_H}$$

To simplify algebra for the time being, let $X = (1-q)o_N + qo_H$

Assuming fish mate randomly and ignoring the distinction between NxH and HxN matings, total mating proportions are:

NN: $(1-q)(1-o_N) + p_N^2 X$

HN: $2p_N p_H X$

HH: $q(1-o_H)+p_H^2 X$

Substituting for p_N and p_H, these proportions become:

NN: $(1-q)(1-o_N)+\dfrac{(1-q)^2 o_N^2}{X}$

HN: $\dfrac{2q(1-q)o_N o_H}{X}$

HH: $q(1-o_H)+\dfrac{q^2 o_H^2}{X}$

Gene flow equals the proportion of alleles in the population that are from immigrants. This is a function of the mating proportions, the success of each mating type, and the relative contribution of each mating type. Here we assume that immigrant alleles come only from HxN matings and HxH matings with Region B, and that the entire gene pool is produced by fish in Regions A and B. Each fish from a HxN mating brings half as many immigrant alleles into the population as an HxH mating. Let w be the relative fitness, and f be the relative frequency of a mating type. Gene flow can then be expressed as:

$$GeneFlow=\frac{f(HH)w(HH)+f(NH)w(NH)(0.5)}{f(HH)w(HH)+f(NH)w(NH)(0.5)+f(NN)w(NN)}$$

Now let w(HH), w(NH), and w(NN) be k_1, k_2, and 1, respectively. Substituting from equations above for f(HH), f(NH), and f(HH):

$$f(NN)w(NN)=(1-q)(1-o_N)+\frac{(1-q)^2 o_N^2}{X}$$

$$f(NH)w(NH)=k_2\left[\frac{q(1-q)o_N o_H}{X}\right]$$

$$f(HH)w(HH)=k_1\left[q(1-o_H)+\frac{q^2 o_H^2}{X}\right]$$

Substituting these expressions into the gene flow equation yields:

$$GF = \frac{k_1\left[q(1-o_H) + \frac{q^2 o_H^2}{X}\right] + k_2\left[\frac{q(1-q)o_N o_H}{X}\right]}{k_1\left[q(1-o_H) + \frac{q^2 o_H^2}{X}\right] + k_2\left[\frac{q(1-q)o_N o_H}{X}\right] + \left[(1-q)(1-o_N) + \frac{(1-q)^2 o_N^2}{X}\right]}$$

Multiplying through by X/X to remove X terms from denominators, we get:

$$GF = \frac{k_1\left[q(1-o_H)X + q^2 o_H^2\right] + k_2\left[q(1-q)o_N o_H\right]}{k_1\left[q(1-o_H)X + q^2 o_H^2\right] + k_2\left[q(1-q)o_N o_H\right] + \left[(1-q)(1-o_N)X + (1-q)^2 o_N^2\right]}$$

Finally, substituting $o_N + q(o_H - o_N)$ for *X*, we arrive at the equations provided in the text:

$$a = o_N + q(o_H - o_N)$$
$$b = k_1(aq(1-o_H) + q^2 o_H{}^2) + k_2 q(1-q)o_N o_H$$
$$Geneflow = \frac{b}{b + a(1-q)(1-o_N) + (1-q)^2 o_N{}^2}$$

Chapter 4
Management

Key Questions:

- a) *What is the legal framework under which fishery management operates?*
- b) *What are trends in the catch and effort in steelhead fisheries?*
- c) *What are angler preferences for gear and regulations?*
- d) *What strategies and tools are available and used to manage steelhead fisheries?*

4.1 Introduction

In an appeal for a new era in fisheries management, Walters and Martell (2004) suggest that "the central objective of modern fisheries science should be to clearly expose trade-offs among conflicting objectives, and the central objective of fisheries management should be to develop effective ways to decide where to operate along the trade-offs, and how to operate successfully."

> *"…the central objective of modern fisheries science should be to clearly expose trade-offs among conflicting objectives, and the central objective of fisheries management should be to develop effective ways to decide where to operate along the trade-offs, and how to operate successfully."*
>
> *Carl J. Walters & Steven J.D. Martell*
> *Fisheries Ecology and Management*

In this chapter, we strive to apply these concepts to Washington steelhead. We begin by describing the legal framework under which fisheries are managed, the catch and effort in sport and tribal fisheries, and angler preferences for regulations and gear. We then explore the trade-offs between objectives of fishery management as embodied in the comanagers goal statement, alternative fishery management strategies, and fishery regulation tactics. Finally, we identify several remaining technical questions related to fishery management that will be broadly discussed in the final version of this report and more specifically addressed in subsequent fishery management plans.

4.2 Value of Fisheries

4.2.1 Value of Recreational Fishery

Perhaps no better icon of the Pacific Northwest exists than steelhead (*Oncorhynchus mykiss*). Their sleek bodies, their preference for swift water, and their habit of returning to even the most remote mountain streams have resulted in Northwest lore that is rich with stories of recreational fishing trips in search of the elusive and explosive steelhead.

Recreational fisheries for steelhead also provide significant economic benefits withl an estimated economic benefit of over $200 million dollars to Washington State (see Box 3-1 for summary of economic analysis). During the 1995-1996 through 2003-2004 seasons, the estimated economic output associated with recreational fisheries for summer steelhead was $133.2 million dollars, with the greatest output ($119.8 million dollars) associated with fisheries in the Columbia River basin. The estimate economic benefit of recreational fisheries for winter steelhead was $68.1 million dollars.

Photo 4-1. Recreational fisheries for steelhead result in an annual economic benefit to the State of Washington of over $200 million dollars. Photo source: unknown.

Table 4-1. Approximate economic output associated with the catch of natural- and hatchery-origin steelhead in Washington sport fisheries.

Geographic Region	**Summer Steelhead**	**Winter Steelhead**	**Total**
Strait of Juan de Fuca & Puget Sound	$9.8 million	$19.5 million	$29.3 million
Washington Coast	$3.7 million	$27.3 million	$30.9 million
Columbia River Basin	$119.8 million	$21.3 million	$141.1 million
Total	$133.2 million	$68.1 million	$201.3 million

4.2.2 Importance to Tribal Culture

The importance of salmon and steelhead to the northwest Native American culture has been extensively documented (cf., Ballard 1927; Ballard 1929; Gunther 1950; Swindell 1942). This cultural role is reviewed in NMFS (2004) from which the following summary is drawn.

> "Salmon is ubiquitous (omnipresent) in Indian culture within the action area {Puget Sound}. It is regularly eaten by individuals and families, and served at gatherings of elders and to guests at feasts and traditional dinners. Salmon is treated ceremoniously by Indians throughout the action area at present as it has been for centuries. Salmon is of nutritional, cultural, and economic importance to tribes. To Indians of the action area, salmon is a core symbol of tribal identity, individual identity, and the ability of Indian cultures to endure. It is a constant reminder to tribal members of their obligation as environmental stewards. Traditional Indian concepts stress the relatedness and interdependence of all beings including humans within the action area. Thus, the survival and well-being of salmon is seen as inextricably linked to the survival and well being of Indian people and the cultures of the tribes. Many Indian people within the action area share traditional stories that explain the relationship between mountains, the origins of rivers, and the origins of salmon that inhabit the rivers (Ballard 1929). In traditional stories, even the humblest of creatures play important roles in sustaining life and balance in the ecological niche that has supplied food for Indian people for generations (Ballard 1927). Stories recount the values Indian people place on supporting healthy, welcoming rivers and good salmon runs. Salmon is also a symbol used in art and other representations of tribal identity."
>
> "The availability of salmon as an economic base and a cultural, ceremonial, and religious staple has provided for enhanced social cohesion and promoted cultural vitality among Puget Sound tribes. Its centrality to the Indian culture has been reaffirmed by court cases like U.S. v. Washington. Some refer to it as "a calling back home." In many instances, Indian people came back to live with relatives and friends on reservations because there was economic opportunity. The enhanced fisheries opportunities demanded that new generations of fishermen and women be trained. The core group of elders and fishermen who had local knowledge of the waters, the currents, the tides, the habits of fish, and the requirement of habitat came forward to train others in this specialized cultural knowledge. New technologies were learned and taught along with the guidance of local, traditional knowledge. Indian people express a holistic relationship to the land and the waterways, as well as to the salmon and other creatures dependent upon the health of the land and environment.

Little differentiation is made between and among spirit, nature, and culture when they speak of their obligations. Tribal people characterize their relationship to salmon as a dynamic and demanding one. The relationship draws upon indigenous teachings and insights. The obligation to salmon articulated by Indian people is one concerned with renewal, reciprocity, and balance. Salmon is of economic importance to Indian people, and it embodies cultural, ceremonial, and social dimensions of their lives to the degree that it is a significant symbol of Indian and tribal identity. Tribal identity is realized and expressed in the many daily acts in which they engage. For the Indian people within the Puget Sound Action Area, many of those acts involve or include salmon. Tribal people have a strong present connection with salmon, and share a passionate concern for the future of salmon in the marine waters, rivers, lakes, and streams in the action area."

Photo 4-2. Salmon and steelhead are of economic importance to Indian people, and it embodies cultural, ceremonial, and social dimensions of their lives to the degree that it is a significant symbol of Indian and tribal identity. Photo Source: University of Washington.

4.3 Legal Framework

4.3.1 Native American Fishing Rights

Many of Washington’s steelhead fisheries are comanaged with Native American tribes in a unique government-to-government relationship defined by treaties, court decisions, and legislation. Since the management of steelhead in many areas of Washington depends to a substantial extent on this relationship, we have included a fairly extensive description of Native American fishing rights to provide context for the subsequent discussion of management strategies and tools. This description is adapted from a paper by Woods (2006) who also provided a listing of Treaty tribes (i.e., entitled to exercise treaty rights), federally recognized non-treaty tribes, and non-treaty tribes that are not federally recognized (Appendix 4-1).

Indian Treaties

Congress created Washington Territory in 1853 out of a portion of Oregon Territory. It encompassed what is now Washington and parts of Idaho and Montana. In 1854 and 1855, at the direction of the Indian Office in Washington, D.C., Isaac Stevens and Joel Palmer (superintendents for Indian Affairs in the Washington and Oregon territories, respectively), concluded eleven treaties with Indian tribes in Washington Territory and adjacent parts of Oregon Territory.[1] Stevens was instructed to clear title to the lands, and to collect the Indians on reservations, where they would be taught farming and trades. Ten of the treaties he and Palmer concluded contain a provision substantially similar to the following:

> **The right of taking fish, at all usual and accustomed grounds and stations, is further secured to said Indians, in common with all citizens of the Territory, and of erecting temporary houses for the purpose of curing, together with the privilege of hunting, gathering roots and berries, and pasturing their horses on open and unclaimed lands:**

Medicine Creek Treaty, art. III, 10 Stat. at 1133.

Some Indian groups in Washington Territory did not sign treaties, but obtained reservations through other federal actions. One group of tribes, the Colville Tribes, has off-reservation hunting and fishing rights in an area that was once part of the Colville

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[1] Treaty With Nisquallys (Treaty of Medicine Creek), 10 Stat. 1132 (Dec. 26, 1854) (http://www.nwifc.wa.gov/pdf_public/Treaty_of_Nisqually.pdf); Treaty With the Dwámish Indians (Treaty of Point Elliott), 12 Stat. 927 (Jan. 22, 1855) (http://www.nwifc.wa.gov/pdf_public/Treaty_of_Dwamish.pdf); Treaty With the S'Klallams (Treaty of Point No Point), 12 Stat. 933 (Jan. 26, 1855) (http://www.pnptc.org/treaty_of_point_no_point.htm); Treaty With the Makah Tribe (Treaty of Neah Bay), 12 Stat. 939 (Jan. 31, 1855) (http://www.nwifc.wa.gov/pdf_public/Treaty_of_the_Makah_Tribe.pdf); Treaty With the Walla-Wallas, 12 Stat. 945 (June 9, 1855) (http://www.umatilla.nsn.us/treaty.html); Treaty With the Yakamas, 12 Stat. 951 (June 9, 1855) (http://www.critfc.org/text/yaktreaty.html); Treaty With the Nez Percés, 12 Stat. 957 (June 11, 1855) (http://www.ccrh.org/comm/river/treaties/nezperce.htm); Treaty With the Tribes of Middle Oregon, 12 Stat. 963 (June 25, 1855) (http://www.warmsprings.com/Warmsprings/Tribal_Community/History__Culture/Treaty__Documents/Treaty_of_1855.html); Treaty With the Qui-Nai-Elts (Treaty of Olympia), 12 Stat. 971 (July 1, 1855) (http://www.nwifc.wa.gov/pdf_public/Treaty_of_Quinaielt.pdf); Treaty With the Flatheads (Treaty of Hell Gate) (http://digital.library.okstate.edu/kappler/Vol2/treaties/fla0722.htm), 12 Stat. 975 (July 16, 1855); Treaty With the Blackfoot Indians, 11 Stat. 657 (Oct. 17, 1855) (http://digital.library.okstate.edu/kappler/Vol2/treaties/bla0736.htm). Attorneys in Washington may also have occasion to address claims under the Treaty With the Shoshonees and Bannacks (Treaty of Fort Bridger), 15 Stat. 673 (July 3, 1868) (http://digital.library.okstate.edu/kappler/Vol2/treaties/sho1020.htm).

Indian Reservation (the "North Half"), under a Congressionally-ratified agreement.[2] The Colville and Spokane Tribes have statutory fishing, hunting, and boating rights in a portion of Lake Roosevelt (the reservoir behind Grand Coulee Dam).[3] No other non-treaty tribe has off-reservation rights in Washington that are different from those of the general public at this time.

Court Interpretation of the Treaties: Key Concepts and Cases

Dozens of court decisions have interpreted the treaty "right of taking fish". Key concepts in these decisions are summarized below.

- **The Treaties Secure Rights that are Different From Those of the General Public**

Outside of Indian reservations, Indians are presumed to be subject to nondiscriminatory state law absent express federal law to the contrary.[4] A treaty or statute may be such express federal law.[5] "An ethnic Indian who is not a member of a tribe with reserved fishing rights is in the same position with respect to Washington fish and game laws as any other citizen of the state."[6]

The first published court decision construing the treaty "right of taking fish" in the Stevens/Palmer treaties was an 1887 decision of the Washington Territorial Supreme Court. The United States sought to enjoin a settler who was restricting Yakama Indians' use of a traditional fishing site adjacent to his land. The Court rejected the settler's argument that, because Indians were not then citizens of the United States, the treaty language securing rights "in common with citizens" meant that Indians were guaranteed

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[2] *Antoine v. Washington*, 420 U.S. 194 (1975), *rev'g State v. Antoine*, 82 Wn.2d 440, 511 P.2d 1351 (1973).

[3] 16 U.S.C. § 835d.

[4] *Mescalero Apache Tribe v. Jones*, 411 U.S. 145, 148-49 (1973); *United States v. Washington*, 520 F.2d 676, 684 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976); *People v. Patterson*, 5 N.Y.3d91, 96, N.E.2d 223, 800 N.Y.S.2d 80 (2005)("Absent a treaty fishing right, the State enjoys the full run of its police powers in regulating off-reservation fishing"), cert. denied, 126 S.Ct. 1045 (2006); *see State v. Quigley*, 52 Wn.2d 234, 324 P.2d 827 (1958) (Chinook Indian was subject to state hunting laws). *See also Wagnon v. Prairie Band Potawatomi Nation*, 126 S. Ct. 676, 6688 (2005).

[5] *Cree v. Waterbury*, 78 F.3d 1400, 1403 (9th Cir. 1996) (Yakama Treaty public highways clause); *United States v. Washington*, 520 F.2d 676, 684 (9th Cir. 1975) (treaty fishing clause), *cert. denied*, 423 U.S. 1086 (1976); *see Antoine v. Washington*, 420 U.S. 194 (1975) (statute); *Puget Sound Gillnetters Ass'n v. Moos*, 92 Wash.2d 939, 951, 603 P.2d 819, 825 (1979) (treaty fishing clause).

[6] *Puget Sound Gillnetters Ass'n v. U.S. District Court*, 573 F.2d 1123, 1130 (9th Cir. 1978), *vacated on other grounds*, *sub. nom Washington v. Wash. State Commercial Passenger Fishing Vessel Ass'n*, 443 U.S. 658 (1979).

the same rights as citizens. The Court held that the Yakama Treaty preserved rights that the Indians had exercised before the treaty was executed, rights that were different from those of citizens.[7] Most courts since then have applied the same principle.[8]

- **Tribes and Non-Indian Sovereigns Hold the Treaty Rights. The Rights are Not the Property of Individuals**

The Indians' rights under the treaties belong to tribal groups, not to individual persons of Indian ancestry.*[9]* Only tribal members may exercise treaty rights; others may not exercise a treaty right on a tribal member's behalf.*[10]*

As the holders of the treaty rights, Tribes have authority to regulate their members who take fish at the Tribe's off-reservation usual and accustomed places.[11] Tribal regulations do not preempt state law [12], though, as discussed below, the treaties do preempt state law to a large extent. It is not double jeopardy under the state double jeopardy statute to prosecute an Indian for violating state law when the defendant's tribe

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[7] *United States v. Taylor*, 3 Wash. Terr. 88, 13 P. 333 (1887), *enforced*, 44 F. 2 (C.C.D. Wash. 1890).

[8] *E.g.*, *United States v. Winans*, 198 U.S. 371 (1905); *Tulee v. Washington*, 315 U.S. 681, 684 (1942); *Washington v. Wash. State Commercial Passenger Fishing Vessel Ass'n*, 443 U.S. 658, 673-9 (1979); *Puget Sound Gillnetters Ass'n v. Moos*, 92 Wn.2d 939, 948, 603 P.2d 819, 824 (1979).

[9] *E.g., Washington v. Wash. State Commercial Passenger Fishing Vessel Ass'n*, 443 U.S. 658, 679 (1979); *Conley v. Ballinger*, 216 U.S. 84, 90-91 (1910); *Blackfeather v. United States*, 190 U.S. 368, 377 (1903); *United States v. Washington*, 641 F.2d 1368 1372-73 (9th Cir. 1981), *cert. denied*, 454 U.S. (1982); *Puget Sound Gillnetters Ass'n v. U.S. District Court*, 573 F.2d 1123, 1126 (9th Cir. 1978) ("These rights were reserved, not by the individuals who happened to be alive in 1854 or 1855, but by tribes"), *vacated on other grounds*, 443 U.S. 658 (1979); *Whitefoot v. United States,* 293 F.2d 658, 663, 155 Ct. Cl. 127 (1961), *cert. denied,* 369 U.S. 818 (1962); *State v. Posenjak*, 127 Wn. App. 41, 48, 111 P.3d 1206, 1211 (2005).

[10] *Cree v. Waterbury*, 873 F. Supp. 404, 428-29 (E.D. Wash. 1994) (Yakama Treaty public highways right), *rev'd on other grounds*, 78 F.3d 1400 (9th Cir. 1996); *United States v. Washington*, 384 F. Supp. 312, 412 (W.D. Wash. 1974) ("Boldt decision"), *aff'd*, 520 F.2d 676 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976); *State v. Price*, 87 Wn. App. 424, 429-32, 942 P.2d 377, 380-81 (1997) (non-Indian spouse of Yakama tribal member could not exercise treaty right).

[11] *Settler v. Lameer*, 507 F.2d 231, 238 (9th Cir. 1974); *United States v. Washington*, 384 F. Supp. 312, 403 (W.D. Wash. 1974) (CL 36), *aff'd*, 520 F.2d 676, 686 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976).

[12] *U.S. v. Washington*, 384 F. Supp. at 403 (CL 37), 410.

has already prosecuted under tribal law.[13] The Tribes and the State have overlapping regulatory authority over fishing by treaty Indians.[14,15]

Tribes do not have authority to regulate non-members who take fish outside the Tribe's reservation.[16]

Non-Indians' rights under the treaties do not belong to individual persons; rather, non-Indians may take fish from state waters only to the extent state law allows it.[17]

• The Treaty Fishing Right Applies to "Usual and Accustomed" Places: Places Where Indians Traditionally Fished

The treaty "right of taking fish" applies only to "usual and accustomed" grounds and stations or places. A tribal member fishing at a place that is not a usual and accustomed fishing place of his or her tribe is not exercising a treaty right and is subject to state laws regulating fishing.[18]

The Washington Territorial Supreme Court held in 1887 that "usual and accustomed" grounds and stations or places are particular places where Indians traditionally fished before the treaties were executed.[19] Other courts have followed that interpretation.[20]

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[13] *State v. Moses*, 145 Wn.2d 370, 37 P.3d 1216 (2002) (hunting)

[14] *United States v. Washington*, 520 F.2d 676, 686-87 n.4 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976). "[T]ribal sovereignty, standing alone, does not preclude state jurisdiction over Indian conduct off-reservation." *Cree v. Waterbury*, 873 F. Supp. 404, 416 (E.D. Wash. 1994), *rev'd in part on other grounds*, 78 F.3d 1400 (9th Cir. 1996).

[15] *United States v. Washington*, No. 70-9213 Phase I, Subproceeding No. 96-3, *Stipulation and Order Concerning Co-Management and Mass Marking* (W.D. Wash. April 28, 1997).

[16] *See United States v. Washington*, 384 F. Supp. 312, 410 (W.D. Wash. 1974), *aff'd*, 520 F.2d 676 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976). It is possible that tribes may have authority to regulate off-reservation fishing by Indians who are members of other tribes. *See United States v. Lara*, 124 S. Ct. 1628, 1636 (2004); 25 U.S.C. § 1301(2). In western Washington, however, the cited order in *U.S. v. Washington* precludes enforcement of such regulations.

[17] *Puget Sound Gillnetters Ass'n v. United States District Ct.*, 573 F.2d 1123, 1132 (9th Cir. 1978), *vacated on other grounds*, 443 U.S. 658 (1979); *Puget Sound Gillnetters Ass'n v. Moos*, 92 Wn.2d 939, 947-48, 603 P.2d 819, 824 (1979); *Purse Seine Vessel Owners Ass'n v. State*, 92 Wn. App. 381, 393-94, 966 P.2d 928, 935 (1998); *review denied*, 137 Wn.2d 1030, 980 P.2d 1284 (1999); *Atwood v. Shanks*, 91 Wn. App. 404, 413-14, 958 P.2d 332, 338, *review denied*, 136 Wn.2d 1029, 972 P.2d 464 (1998); *see United States v. Oregon*, 718 F.2d 299, 304 n.6 (9th Cir. 1983).

[18] *United States v. Washington*, 384 F. Supp. 312, 408 (W.D. Wash. 1974), *aff'd*, 520 F.2d 676 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976); *Seufert v. Olney*, 193 F. 200, 203 (E.D. Wash. 1911).

[19] *United States v. Taylor*, 3 Wash. Terr. 88, 13 P. 333 (1887), *enforced*, 44 F. 2 (C.C.D. Wash. 1890).

"Usual and accustomed grounds" may include depths to which humans did not have access until modern technology became available, however.[21]

A party seeking to establish that a place is a tribe's "usual and accustomed place" must show the "tribe's (or its predecessors') regular and frequent treaty-time use of that area for fishing purposes."[22] Evidence that individual tribal members may have used a place at treaty time by virtue of marriage into other tribes does not establish that a place was a usual and accustomed place of the Tribe itself.[23] A place that was an "unfamiliar location," or "used infrequently or at long intervals and extraordinary occasions," or "where use was occasional or incidental," is not a usual and accustomed place.[24]

The testimony of an expert anthropologist, based on documentary evidence, can establish that a place was a tribe's treaty-time usual and accustomed fishing place. Tribal elder testimony may bolster such evidence, but may be insufficient by itself.[25] The testimony of a few tribal members that they fished at a place during the twentieth century is not enough to show that the place was a usual and accustomed fishing place of their tribe in 1855.[26]

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[20] *E.g.*, *Seufert Bros. Co. v. United States*, 249 U.S. 194 (1919) (Yakama); *United States v. Winans*, 198 U.S. 371 (1905) (Yakama); *United States v. Washington*, 730 F.2d 1314 (9th Cir. 1984) (Makah); *United States v. Washington*, 384 F. Supp. 312, 332, 353 (W.D. Wash. 1974) (14 tribes), *aff'd*, 520 F.2d 676 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976); *United States v. McGowan*, 2 F. Supp. 426 (W.D. Wash. 1931) (Quinault).

[21] *United States v. Washington*, 157 F.3d 630, 643 (9th Cir. 1998), *cert. denied*, 526 U.S. 1060 (1999).

[22] *United States v. Washington*, 626 F. Supp. 1405, 1531 (W.D. Wash. 1985).

[23] *United States v. Washington*, 873 F. Supp. 1422, 1447 (W.D. Wash. 1994) (Yakama Nation failed to prove usual and accustomed shellfishing places in western Washington).

[24] *United States v. Washington*, 384 F. Supp. 312, 332, 353 (FF 14), 356 (FF 23) (W.D. Wash. 1974), *aff'd*, 520 F.2d 676 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976).

[25] *United States v. Washington*, 459 F. Supp. 1020, 1059 (W.D. Wash. 1975); *State v. Courville*, 36 Wn. App. 615, 623, 676 P.2d 1011, 1016 (1983); *see State v. James*, 72 Wn.2d 746, 748, 435 P.2d 521, 522-23 (1967); *cf. Bonnichsen v. United States*, 367 F.3d 864, 881-82 (9th Cir. 2004) (describing limitations of oral history).

[26] *United States v. Washington*, 764 F.2d 670, 674 (9th Cir. 1985) (tribal elder testimony about fishing activity in early 1900s could not support finding about treaty time fishing places); *United States v. Washington*, 730 F.2d 1314, 1315, 1318 (9th Cir. 1984) (discounting elder testimony about fishing during the 1900s); *see State v. Petit*, 88 Wn.2d 267, 272-73, 558 P.2d 796, 798-99 (1977) (Utter, J., dissenting) (describing testimony that majority had held insufficient to show that a place was a usual and accustomed place).

In Western Washington, treaty tribes' usual and accustomed grounds and stations have been specifically determined in the "Boldt decision" and subsequent litigation.[27] One unresolved question is the seaward extent of the ocean usual and accustomed grounds of the Quileute, Hoh, and Quinault Tribes.[28]

By contrast, little litigation has occurred regarding the locations of "usual and accustomed places" in the Columbia Basin.[29] The federal government has set aside specific "in-lieu" treaty fishing sites along the Columbia River to substitute for traditional Indian fishing sites inundated by dams.[30] Washington and Oregon recognize the mainstem Columbia River from just above Bonneville Dam upstream to the Snake River mouth as an area where mid-Columbia treaty tribes are entitled to exercise treaty fishing rights.[31] The status of other places may be unclear, however.[32]

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[27] *United States v. Washington*, 384 F. Supp. 312, 359-81 (W.D. Wash. 1974) ("Boldt decision") (Hoh, Lummi, Makah, Muckleshoot, Nisqually, Puyallup, Quileute, Quinault, Sauk-Suiattle, Skokomish, Squaxin Island, Stillaguamish, Upper Skagit, Yakama), aff'd, 520 F.2d 676 (9th Cir. 1975), cert. denied, 423 U.S. 1086 (1976); United States v. Washington, 459 F. Supp. 1020, 1049, 1066-69 (W.D. Wash. (1975) (Lower Elwha, Nooksack, Suquamish, Swinomish, Makah, Stillaguamish); United States v. Washington, 626 F. Supp. 1405, 1441-43, 1470, 1486 (W.D. Wash. 1981-1984) (Nisqually, Puyallup, Squaxin Island, Jamestown S'Klallam, Port Gamble S'Klallam, Lower Elwha Klallam); United States v. Washington, 626 F. Supp. 1405, 1466-68 (W.D. Wash. 1982), aff'd, 730 F.2d 1314 (9th Cir. 1984) (Makah); United States v. Washington, 626 F. Supp. 1405, 1527-32 (W.D. Wash. 1985), aff'd, 841 F.2d 317 (9th Cir. 1988) (Tulalip); United States v. Suquamish Indian Tribe, 901 F.2d 772 (9th Cir. 1990) (Suquamish); United States v. Washington, 873 F. Supp. 1422, 1447-50 (W.D. Wash. 1994) (Yakama, Upper Skagit), aff'd, 157 F.3d 630 (9th Cir. 1998), cert. denied, 526 U.S. 1060 (1999); Muckleshoot Tribe v. Lummi Indian Tribe, 141 F.3d 1355 (9th Cir. 1998) (Swinomish, Lummi); Muckleshoot Indian Tribe v. Lummi Indian Nation, 234 F.3d 1099 (9th Cir. 2000) (Lummi); United States v. Muckleshoot Indian Tribe, 235 F.3d 429 (9th Cir. 2000) (Muckleshoot), cert. denied, 534 U.S. 950 (2001); United States v. Lummi Indian Tribe, 235 F.3d 443 (9th Cir. 2000) (Lummi); see also United States v. McGowan, 62 F.2d 955 (9th Cir.) (Quinault and Quileute Tribes do not have usual and accustomed fishing stations in Columbia River estuary), aff'd mem., 290 U.S. 592 (1933).

[28] *See Midwater Trawlers Co-operative v. Dep't of Commerce*, 282 F.3d 710, 716 (9th Cir. 2002).

[29] In *State v. James*, 72 Wn.2d 746, 435 P.2d 521 (1967), the court determined that the Columbia River between Bonneville Dam and the Bridge of the Gods is a usual and accustomed place of the Yakama Nation. The court in the Yakima Basin water adjudication has determined the usual and accustomed places of the Yakama Nation along the Yakima, Naches, and Tieton Rivers. *Washington Dep't of Ecology v. Acquavella*, No. 77-2-01484-5, Report of the Court Concerning the Water Rights for the Yakima Indian Nation 79-80 (Yakima Cy. Super. Ct. Nov. 13, 1995).

[30] *See* 25 C.F.R. Parts 247, 248, *Sohappy v. Hodel*, 911 F.2d 1312 (9th Cir. 1990).

[31] *See* WAC 220-22-010(6), (7), (8) (defining fishing areas); WAC 220-32-050(2)(a) (Indian commercial fishing areas); WAC 220-32-055 & OAR 635-041-0015 (Indian subsistence fishing areas); OAR 635-041-0005 (Indian fishing areas). This area is sometimes called "Zone 6." *See* OAR 635-042-0001.

- **The Treaties Secure Physical Access to "Usual and Accustomed" Places, but Not "Open and Unclaimed Lands," Over Private Property**

The right of taking fish at usual and accustomed places preserves to the Indians an easement in land to get to and use traditional fishing places for taking fish and the associated activities mentioned in the treaties. Settlers acquired the land subject to the Indians' preexisting treaty rights.[33] The easement may be conditioned to protect landowners.[34] The treaty-secured easement of access to usual and accustomed fishing grounds and stations is a property right for which just compensation must be paid if taken.[35]

- **The Treaties Preempt State Power to Regulate the Exercise of Treaty Fishing Rights Except Where "Necessary for Conservation"**

The State may regulate the exercise of off-reservation treaty fishing and hunting rights where reasonable and necessary for the conservation of fish or game.[36] "Conservation" means "perpetuation of the species."[37] "'[R]easonable' means that a specifically identified conservation measure is appropriate to its purpose; and 'necessary' means

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[32] In 1942, the United States Department of the Interior prepared a comprehensive *Report on Source, Nature and Extent of the Fishing, Hunting and Miscellaneous Related Rights of Certain Indian Tribes in Washington and Oregon, Together With Affidavits Showing Locations of a Number of Usual and Accustomed Fishing Grounds and Stations*. It is sometimes called the "Swindell Report," after Edward G. Swindell, the lead investigator. The "Swindell Report" has been used as an exhibit in *U.S. v. Washington* and other cases. *See Whitefoot v. United States*, 293 F.2d 658, 665 (Ct. Cl. 1961), *cert. denied*, 369 U.S. 818 (1962); *Confederated Tribes of the Umatilla Indian Reservation v. Alexander*, 440 F. Supp. 553, 555 (D. Or. 1977); *State v. Moses*, 79 Wn.2d 104, 124, 483 P.2d 832 (1971) (Finley, J., dissenting) (describing Swindell report as a "definitive study"), *cert. denied*, 406 U.S. 910 (1972). A copy is available from the Washington State Library.

[33] *United States v. Winans*, 198 U.S. 371 (1905); *United States v. Taylor*, 3 Wash. Terr. 88, 13 P. 333 (1887), *enforced*, 44 F. 2 (C.C.D. Wash. 1890); *United States v. Washington*, 157 F.3d 630, 646-47 (9th Cir. 1998) (shellfish on private tidelands), *cert. denied*, 526 U.S. 1060 (1999).

[34] *United States v. Winans*, 198 U.S. 371, 384 (1905); *United States v. Washington*, 157 F.3d 630, 654 (9th Cir. 1998), *cert. denied*, 526 U.S. 1060 (1999).

[35] *Muckleshoot Indian Tribe v. Hall*, 698 F. Supp. 1504, 1510, 1516 (W.D. Wash. 1988); *see Nw. Sea Farms v. U.S. Army Corps of Engineers*, 931 F Supp. 1515, 1521 (W.D. Wash. 1996).

[36] *Tulee v. Washington*, 315 U.S. 681, 684 (1942) (fishing); *Antoine v. Washington*, 420 U.S. 194, 207 (1977) (hunting—Colville); *State v. Miller*, 102 Wn.2d 678, 686-88, 689 P.2d 81, 86 (1984) (hunting).

[37] *United States v. Washington*, 384 F. Supp. 312, 333 (W.D. Wash. 1974), *aff'd*, 520 F.2d 676 (1975), *cert. denied*, 423 U.S. 1086 (1976); *see id.* at 342, 415.

that such purpose in addition to being reasonable must be essential to conservation."[38] To be "reasonable and necessary for conservation," a regulation "must, when considered in the context of the total regulatory plan, be designed to preserve or maintain the resource."[39] State regulations that place a disproportionate conservation burden on treaty Indian fishing are discriminatory and therefore preempted by the treaties. State regulations must also meet appropriate procedural standards.[40] The treaties preempt state regulation of treaty fishing and hunting that is not "necessary for conservation."[41] "As part of his 1974 injunction, Judge Boldt enjoined the State from imposing salmon and steelhead conservation closures on Tribes judged to be self-regulating. At this time, three tribes are officially recognized as self-regulating in Washington: Quinault, Quileute, and Yakama.[42]

Laws prohibiting sale of fish generally are not "reasonable and necessary for conservation" (unless the tribe in question has a similar prohibition). The treaty right of taking fish includes the right to sell the fish.[43]

General public safety laws that are not specific to hunting or fishing can be enforced against Indians exercising off-reservation treaty rights.[44] The state may also be able to

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[38] *U.S. v. Washington*, 384 F. Supp. at 342; *see United States v. Oregon*, 657 F.2d 1009, 1012, 1017 (9th Cir. 1982) (upholding order enjoining Yakama fisheries on spring chinook); *Dep't of Game v. Puyallup Tribe, Inc.*, 86 Wash.2d 664, 667, 685, 548 P.2d 1058, 1063, 1072 (1976), *aff'd*, 433 U.S. 165, 177 (1977) (fishing regulation was necessary for conservation).

[39] *U.S. v. Washington*, 384 F. Supp. at 402 (CL 30).

[40] *E.g.*, *Puyallup Tribe v. Washington Game Dep't (Puyallup III)*, 433 U.S. 165, 177 (1977) (regulations allocating 45% of harvestable steelhead run to tribal fishery met "conservation necessity" standards), *aff'g* 86 Wn.2d 664, 548 P.2d 1058 (1976); *Antoine v. Washington*, 420 U.S. 194, 207 (1977); *Wash. Game Dep't v. Puyallup Tribe* (*Puyallup II*), 414 U.S. 44, 48 (1973) (regulation banning Indian gear was discriminatory toward Indians); *Puyallup Tribe v. Wash. Dep't of Game* (*Puyallup I*), 391 U.S. 392, 399 (1968); *Makah Indian Tribe v. Schoettler*, 192 F.2d 224 (9th Cir. 1951); *United States v. Washington*, 384 F. Supp. 312, 342, 402-04, 416, 417 (W.D. Wash. 1974) (CL 31, 32, 35, 42, Inj. ¶¶ 12, 19), *aff'd*, 520 F.2d 676 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976); *Sohappy v. Smith*, 302 F. Supp. 899, 907-12 (D. Or. 1969); *cf. State v. Squally*, 78 Wn.2d 475, 474 P.2d 897 (1970).

[41] *United States v. Washington*, 520 F.2d 676, 684-86 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976); *Purse Seine Vessel Owners Ass'n v. State*, 92 Wn. App. 381, 392, 966 P.2d 928, 934 (1998), *review denied*, 137 Wn.2d 1030, 980 P.2d 1284 (1999).

[42] *United States v. Washington, 384 F.Supp at 414*.

[43] *U.S. v. Washington*, 384 F. Supp. at 343 n.29; *see id* at 418 (Inj. ¶ 21).

[44] *State v. Olney*, 117 Wn. App. 524, 72 P.3d 235 (2003) (RCW 77.15.460, which prohibits possession of a loaded firearm in a motor vehicle, is a general safety law, not a hunting regulation, and can be enforced against Yakama Indians exercising treaty hunting rights), *review denied*, 151

apply health and safety regulations for fishing and hunting to Indians exercising treaty rights where the regulations do not otherwise impede the exercise of the right.[45] In the case of treaty shellfishing in Washington, the parties worked out a consent decree addressing food safety regulation.[46]

Where state license fees are involved, the treaties preempt state law to a somewhat greater extent than they preempt state laws regulating the time, place, and manner of fishing: The treaty right of taking fish preempts state fishing license fees where such fees are "not indispensable to the effectiveness of a state conservation program."[47]

In Western Washington, licensing of vessels used in treaty fisheries is governed by a consent decree.[48] In general, Tribes license their members' vessels.

- *The Treaties Secure a Right to a "Fair Share" of Fish: United States v. Oregon and United States v. Washington*

By the late 1960s, the demand for salmon had outstripped the supply in the Pacific Northwest. Tribal fisheries were at a disadvantage because of their location. Non-Indian fisheries in marine areas and in the lower Columbia River intercepted salmon migrating to spawning grounds before the salmon reached tribal usual and accustomed

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Wn.2d 1004, 87 P.3d 1185 (2004); *see Mescalero Apache Tribe v. Jones*, 411 U.S. 145, 148-49 (1973) ("Absent express federal law to the contrary, Indians going beyond reservation boundaries have generally been held subject to nondiscriminatory state law otherwise applicable to all citizens of the State.").

[45] *Lac Courte Oreilles Band of Lake Superior Chippewa Indians v. Wisconsin*, 740 F. Supp. 1400, 1423 (W.D. Wis. 1990); *Lac Courte Oreilles Band of Lake Superior Chippewa Indians v. Wisconsin*, 668 F. Supp. 1233, 1238-39 (W.D. Wis. 1987); *State v. Matthews*, 248 Wis.2d 78, 81, 635 N.W.2d 601, 602-03 (Wis. Ct. App. 2001); *see State v. Big John*, 146 Wis. 741, 751-52, 432 N.W.2d 576 (1988); *but see State v. Lemieux*, 110 Wis. 2d 158, 327 N.W.2d 669 (1983) (loaded-firearm law was an impermissible regulation of Indian hunting).

[46] *United States v. Washington*, No. 70-9213 Phase I, Subproceeding No. 89-3, *Consent Decree Regarding Shellfish Sanitation Issues* (W.D. Wash. May 4, 1994). *See* WAC ch. 246-282. The State had contended in the shellfish case that "commercial disposition of shellfish by the plaintiff tribes and their members is subject to reasonable, nondiscriminatory regulation by the state, under the exercise of the state's police power in the interest of protecting human health, safety and welfare." *United States v. Washington*, No C70-9213, Subproceeding 89-3, Pretrial Order at 11 (W.D. Wash. May 4, 1994). The issue was not litigated because the parties agreed to the Shellfish Sanitation consent decree.

[47] *Tulee v. Washington*, 315 U.S. 681, 685 (1942), *rev'g* 7 Wn.2d 124, 109 P.2d 280 (1941); *cf. Cree v. Flores*, 157 F.3d 762 (9th Cir. 1998) (Yakama Treaty preempts state truck license fees).

[48] *United States v. Washington*, No. 9213-Phase I, Subproceeding No. 88-1, *Consent Decree* (W.D. Wash. Nov. 28, 1994). Implementing rules appear at WAC 308-93-700 through 308-93-770.

fishing places upstream.[49] By the time the salmon reached tribal fisheries, few remained, and state regulators often sought to restrict tribal fishing to conserve the runs. The situation led the United States to sue the State of Oregon on behalf of four Columbia River treaty tribes in 1968. The United States contended that the treaties required Oregon to allow a fair share of the runs to pass upstream to tribal fisheries. The court agreed, and declared that Oregon must regulate its fisheries so as to pass a "fair share" of fish to tribal fishing places.[50] Washington, which shares authority with Oregon over Columbia River fisheries, downstream of the Wallula Gap, intervened in the case in 1974 and became bound by the decision.

In 1970, the United States filed a similar lawsuit against the State of Washington concerning fisheries on salmon runs from most of the watersheds in western Washington. In 1974, the court issued the "Boldt decision," holding that, under the treaties, the Tribes and non-Indians are each entitled to a fair share of fish.[51] The court rejected the Tribes' interpretation that the treaties entitled them to as many fish as they needed for a livelihood. The United States Supreme Court upheld the "fair share" interpretation in 1979.[52]

In crafting an equitable remedy, Judge Boldt decided that equal shares of the harvestable salmon available in Washington and closely adjacent marine waters from each run that passed through tribal fishing grounds would be "fair." Though altering some of the details, the Supreme Court approved this as a fair division.[53]

Seven weeks after the "Boldt decision," the court in the Oregon case amended its 1969 judgment, concluding that equal shares of harvestable salmon destined for tribal fishing places were "fair" for Columbia River fisheries, as well.[54] The 1969 *Sohappy* decree assumed that the geographic area within which treaty and non-treaty fisheries fairly share the harvest—the area within which catches "count" for harvest allocation—is the mainstem Columbia River between its mouth and McNary Dam. The court's Order of

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[49] *See United States v. Washington*, 384 F. Supp. 312, 411 (W.D. Wash. 1974).

[50] *Sohappy v. Smith*, 302 F. Supp. 899, 911 (D. Or. 1969). *See generally* John C. Gartland, *Sohappy v. Smith: Eight Years of Litigation Over Indian Fishing Rights*, 56 OR L. REV. 680 (1977).

[51] *United States v. Washington*, 384 F. Supp. 312, 401 (W.D. Wash. 1974) ("Boldt decision"), *aff'd*, 520 F.2d 676 (9th Cir. 1975), *cert. denied*, 423 U.S. 1086 (1976).

[52] *Washington v. Wash. State Commercial Passenger Fishing Vessel Ass'n*, 443 U.S. 658, 684-85 (1979).

[53] 384 F. Supp. at 343-44, 416; *Fishing Vessel*, 443 U.S. at 685-89.

[54] *United States v. Oregon*, Order Amending Judgment of October 10, 1969 (May 10, 1974), *aff'd & remanded*, 529 F.2d 570, 573-74 (9th Cir. 1976).

August 20, 1975 extended the area downstream to include non-Indian catches in the ocean off Oregon and Washington as well.

Fifty percent of the harvestable fish remains the presumptive "fair share" absent equitable factors suggesting another division.[55] Hatchery fish are included in the allocation of "fair shares." The rationale is that hatchery fish replace fish lost to habitat degradation caused by dams and development.[56]

The treaties secure a right to take any species of fish found at usual and accustomed places, including species to which Indians did not have access at the time the treaties were executed.[57]

4.3.2 Endangered Species Act (ESA)

The listing of four steelhead distinct populations segments (DPSs) in Washington State under the Endangered Species Act has added additional complexity to steelhead management. The Endangered Species Act of 1973, as amended, 16 U.S.C 1531 *et seq.* (ESA) provides broad protection for fish, wildlife, and plant species that are listed as threatened or endangered, and the conservation of the ecosystems on which they depend. Responsibility for implementing the ESA is shared by the U.S. Fish and Wildlife Service (USFWS)(for terrestrial and freshwater species) and NMFS (for most marine mammals and anadromous fish). The ESA provides for the conservation of species which have been so depleted in numbers that they are in danger of or threatened with extinction throughout all or a significant portion of their range. "Species" is defined

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[55] *See Washington v. Wash. State Commercial Passenger Fishing Vessel Ass'n*, 443 U.S. 658, 685 (1979); *Puyallup Tribe v. Wash. Dep't of Game (Puyallup III)*, 433 U.S. 165, 177 (1977); *United States v. Washington*, 157 F.2d 630, 631 (9th Cir. 1998), *cert. denied*, 526 U.S. 1060 (1999) (shellfish). It is not correct to say that the Tribes have a treaty right to half the fish, or that the phrase "in common with" in the treaties means half. The legal right that the treaties secure is a right to a fair share of fish. The equitable remedy that the courts have ordered to implement that right is half the harvestable fish within a defined geographic area. The court may modify the remedy should circumstances change or the equities dictate. *Fishing Vessel*, 443 U.S. at 686-88; *see United States v. Washington*, 157 F.3d 630, 652-53 (9th Cir. 1998) (Tribes not entitled to 50% of shellfish growers' production); *United States v. Washington*, Civil No. 9213-Phase I, Subproceedings 83-6/90-1, *Order Re: Status Conference* (W.D. Wash. May 2, 1996) (whether geographic area of 50/50 sharing should be extended to Alaska involves issue of whether "there are changed circumstances that might require an adjustment or modification of Judge Boldt's decision").

[56] *United States v. Washington*, 759 F.2d 1353, 1358-60 (9th Cir. 1985) (*en banc*), *cert. denied*, 474 U.S. 994 (1985).

[57] *United States v. Washington*, 157 F.2d 630, 643-44 (9th Cir. 1998), *cert. denied*, 526 U.S. 1060 (1999) (shellfish).

the ESA as a species, a subspecies, or for vertebrates only, a distinct population segment (DPS). NMFS has determined that a Pacific salmon or steelhead stock will be considered a distinct population segment, and hence a “species” under the ESA, if it represents an evolutionarily significant unit (ESU) of the biological species. A species is considered endangered if it is in danger of extinction throughout all or a significant portion of its range. A threatened species is one that is likely to become endangered in the foreseeable future.

Section 4 of the ESA prohibits the consideration of economic impacts in making species listing decisions. NMFS is required to make a listing decision based solely on the best scientific and commercial data available. However, under section 4, NMFS must consider economic impacts when designating critical habitat necessary for the continued survival of the species. After a species is listed, a recovery plan is prepared which identifies conservation measures to help the species recover.

Section 4(d) of the ESA requires the Secretary to adopt those regulations he deems necessary for the conservation of the species. Fishing activities which are conducted in compliance with a resource management plans approved by NMFS are exempt from take prohibitions on listed species. Section 7 of the ESA outlines the procedures for Federal interagency cooperation to conserve listed species and designated critical habitat, and requires all Federal agencies to consult with NMFS (or USFWS) concerning the potential effects of their actions on any listed species. Section 7(a)(1) requires federal agencies to conserve endangered and threatened species. Section 7(a)(2) requires federal agencies to ensure that any action authorized, funded, or carried out by such agencies is not likely to jeopardize endangered or threatened species, or result in the destruction or adverse modification of designated critical habitat. The determination that NMFS must make on the resource management plan constitutes a federal action and so requires consultation under section 7 of the Act.

If a proposed action is “likely to adversely affect” a listed species or its critical habitat, then formal consultation under section 7(a)(2) must be undertaken. Formal consultation concludes with NMFS’ issuing a biological opinion. If the biological opinion concludes that the proposed action is likely to “jeopardize” the continued existence of the listed species or result in the destruction or adverse modification of designated critical habitat, then NMFS may develop reasonable and prudent alternatives in order to avoid these outcomes.

Current ESA-listing determinations for Washington steelhead are summarized below:

Threatened: Snake River, Upper Columbia River, Middle Columbia River, and Lower Columbia River
Petitioned: Puget Sound

WDFW must apply for, and receive authorization from NOAA Fisheries for the incidental and direct "take" of listed steelhead ESUs associated with fisheries, artificial propagation, and research programs. Authorization may take several forms, including section 4(d), 7, or 10 permits.

4.3.3 Washington State Statutes

The mandate of the Washington Department of Fish and Wildlife is defined in RCW 77.04.012:

> "The department shall conserve the wildlife and food fish, game fish, and shellfish resources in a manner that does not impair the resource. In a manner consistent with this goal, the department shall seek to maintain the economic well-being and stability of the fishing industry in the state. The department shall promote orderly fisheries and shall enhance and improve recreational and commercial fishing in this state."

Two key state statutes provide policy sideboards for the management of non-Indian steelhead fisheries. Steelhead are classified as a game fish in RCW 77.08.020 and RCW 77.12.760 states that "Steelhead trout shall be managed solely as a recreational fishery for non-Indian fishermen under the rule-setting authority of the fish and wildlife commission."

The Fish and Wildlife Commission is provided the authority in RCW 77.12.047 to establish seasons, open waters, allowable gear types, and other management controls:

> "(1) The commission may adopt, amend, or repeal rules as follows:
>
> (a) Specifying the times when the taking of wildlife, fish, or shellfish is lawful or unlawful.
>
> (b) Specifying the areas and waters in which the taking and possession of wildlife, fish, or shellfish is lawful or unlawful.
>
> (c) Specifying and defining the gear, appliances, or other equipment and methods that may be used to take wildlife, fish, or shellfish, and specifying the times, places, and manner in which the equipment may be used or possessed.
>
> (d) Regulating the importation, transportation, possession, disposal, landing, and sale of wildlife, fish, shellfish, or seaweed within the state, whether acquired within or without the state.
>
> (e) Regulating the prevention and suppression of diseases and pests affecting wildlife, fish, or shellfish.

(f) Regulating the size, sex, species, and quantities of wildlife, fish, or shellfish that may be taken, possessed, sold, or disposed of.
(g) Specifying the statistical and biological reports required from fishers, dealers, boathouses, or processors of wildlife, fish, or shellfish.
(h) Classifying species of marine and freshwater life as food fish or shellfish.
(i) Classifying the species of wildlife, fish, and shellfish that may be used for purposes other than human consumption.
(j) Regulating the taking, sale, possession, and distribution of wildlife, fish, shellfish, or deleterious exotic wildlife.
(k) Establishing game reserves and closed areas where hunting for wild animals or wild birds may be prohibited.
(l) Regulating the harvesting of fish, shellfish, and wildlife in the federal exclusive economic zone by vessels or individuals registered or licensed under the laws of this state.
(m) Authorizing issuance of permits to release, plant, or place fish or shellfish in state waters.
(n) Governing the possession of fish, shellfish, or wildlife so that the size, species, or sex can be determined visually in the field or while being transported.
(o) Other rules necessary to carry out this title and the purposes and duties of the department.

(2) Subsections (1)(a), (b), (c), (d), and (f) of this section do not apply to private tideland owners and lessees and the immediate family members of the owners or lessees of state tidelands, when they take or possess oysters, clams, cockles, borers, or mussels, excluding razor clams, produced on their own private tidelands or their leased state tidelands for personal use. "Immediate family member" for the purposes of this section means a spouse, brother, sister, grandparent, parent, child, or grandchild.

(3) Except for subsection (1)(g) of this section, this section does not apply to private sector cultured aquatic products as defined in RCW 15.85.020 Subsection (1)(g) of this section does apply to such products."

Several other relevant state statutes are summarized below.

RCW 77.12.010. Limitation on prohibiting fishing with bait or artificial lures. The commission shall not adopt rules that categorically prohibit fishing with bait or artificial lures in streams, rivers, beaver ponds, and lakes except that the commission may adopt rules and regulations restricting fishing methods upon a determination by the director that an individual body of water or part thereof clearly requires a fishing method prohibition to conserve or enhance the fisheries resource or to provide selected fishing alternatives.

RCW 77.12.043. Contracts and agreements for propagation of fish or shellfish. (1) The director may enter into contracts and agreements with a person to secure fish or shellfish or for the construction, operation, and maintenance of facilities for the propagation of fish or shellfish. (2) The director may enter into contracts and agreements to procure from private aquaculturists fish or shellfish with which to stock state waters.

RCW 77.12.045 Territorial authority of commission -- Adoption of federal regulations and rules of fisheries commissions and compacts. Consistent with federal law, the commission's authority extends to all areas and waters within the territorial boundaries of the state, to the offshore waters, and to the concurrent waters of the Columbia river. Consistent with federal law, the commission's authority extends to fishing in offshore waters by residents of this state. The commission may adopt rules consistent with the regulations adopted by the United States department of commerce for the offshore waters. The commission may adopt rules consistent with the recommendations or regulations of the Pacific marine fisheries commission, Columbia river compact, the Pacific salmon commission as provided in chapter 77.75 RCW, or the international Pacific halibut commission.

RCW 77.12.459. Release and recapture of salmon or steelhead prohibited. A person other than the United States, an Indian tribe recognized as such by the federal government, the state, a subdivision of the state, or a municipal corporation or an agency of such a unit of government shall not release salmon or steelhead trout into the public waters of the state and subsequently to recapture and commercially harvest such salmon or trout. This section shall not prevent any person from rearing salmon or steelhead trout in pens or in a confined area under circumstances where the salmon or steelhead trout are confined and never permitted to swim freely in open water.

Mitigation agreements exist that legally define operations for many hatchery programs in Washington. One example is the Lower Snake River Compensation Plan, a congressionally authorized mitigation program that is intended to compensate for natural production lost as a result of the construction of dams in the Snake River basin.

4.4 Trends in Fishery Catch and Effort

4.4.1 Catch of Steelhead

Encounters, catch, and total mortality must be carefully defined when reporting harvest statistics for steelhead. We will consistently use the definitions of the ASFEC (1995):

> Encounters. The number of fish that initially encountered the gear. A fish that is encountered may either drop-off prior to landing, be released after being brought to the fisher, or retained as catch.
>
> Catch. The number of fish retained by the fisher.
>
> Total Mortality. The number of fish retained by the fisher plus the fish that were encountered that subsequently died as a result of drop-off or the catch-and-release process.

The total catch of steelhead in Washington has fluctuated substantially (Fig. 4-1). Catches exceeded 250,000 fish in the 1992-1993 season before declining to a low of approximately 100,000 fish in the 1997-1998 season. Catches subsequently increased, reaching almost 250,000 fish in the 2001-2002 season. Catch by tribal fishers declined from approximately 108,000 in the 1992-1993 season to less than 37,000 in the 2003-2004 season.

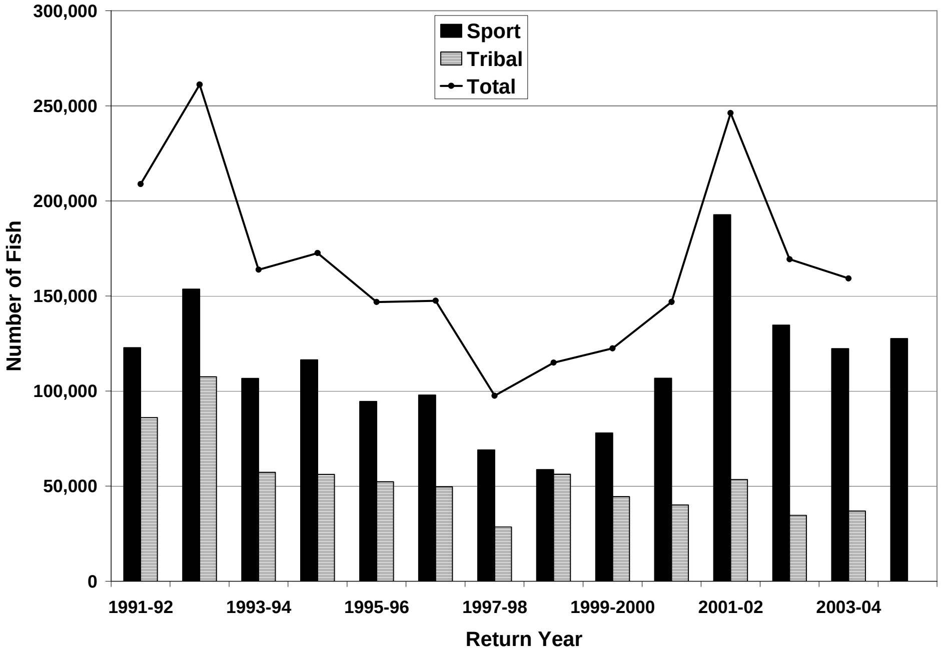

Figure 4-1. Total catch of steelhead in Washington by tribal and sport fishers.

Increases in the sport catch of steelhead in by sport fishers subsequent to the 1997-1998 season occurred primarily in the Columbia River basin (Fig. 4-2). Catches in the Columbia River basin increased from approximately 33,000 in the 1998-1999 season to over 138,000 in the 2001-2002 season. Catches in the other two areas (Washington Coast and Strait of Juan de Fuca-Puget Sound) also increased in the 2001-2002 season to approximately 27,000 fish.

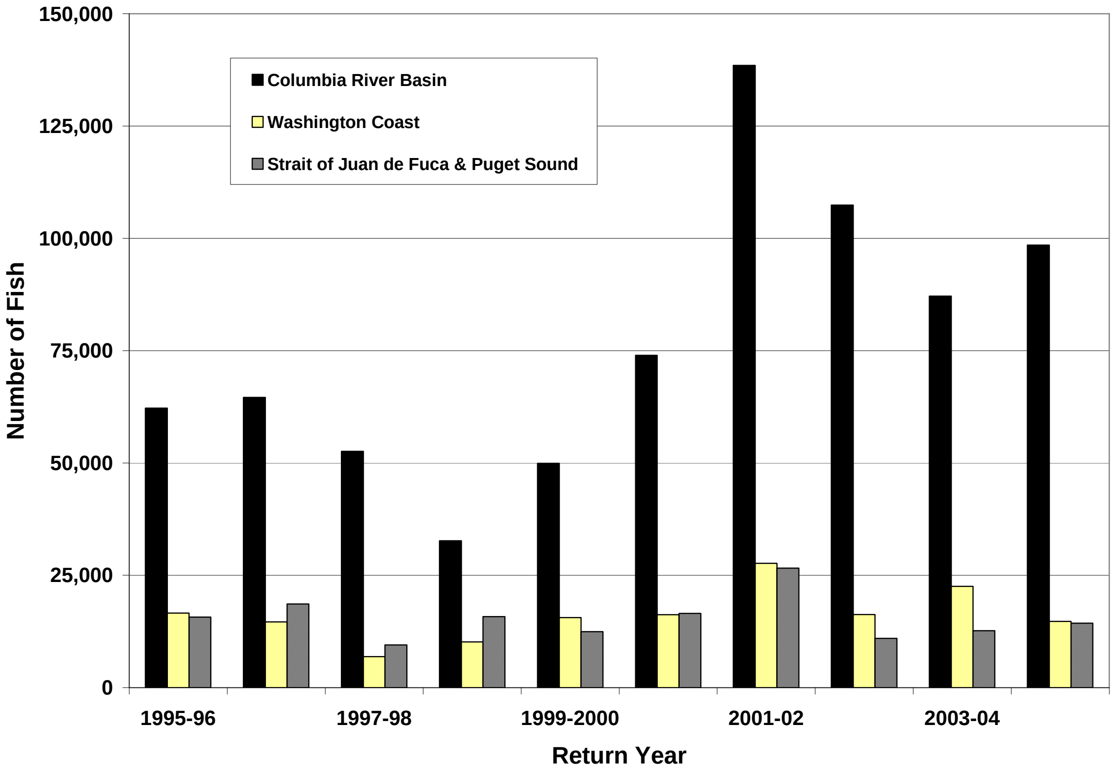

Figure 4-2. Catch of steelhead by sport fishers in the Columbia River basin, rivers along the Washington Coast, and rivers along the Strait of Juan de Fuca and Puget Sound.

A longer time series of catch of steelhead by sport fishers suggests a 7-8 year cycle has been repeated since the 1974-1975 season (Fig. 4-3). Low points in the cycle occurred in the 1975-1976 (68,806 steelhead), 1982-1983 (96,091 steelhead), 1990-1991 (85,509 steelhead), and 1998-1999 (58,675 steelhead) seasons. Variations in sport catch can reflect many factors, including the abundance of steelhead (see Chapter 7), the catchability of steelhead as affected by conditions such as stream flow, and fishing regulations. Since the 1986-1987 seasons, the catch of natural-origin steelhead has declined from approximately 40,000 fish to less than 5,000 fish (Fig. 4-3). Reductions in the catch of natural-origin steelhead have resulted from several factors, including increasingly restrictive regulations that required the release of natural-origin steelhead.

4.4.2 Angler Participation

The number of anglers and average number of days fishing for steelhead in Washington was estimated in four surveys conducted from 1965 through 2003 (WDG 1965; Mongillo and Hahn 1988; WDFW 1996; Michael 2004). The surveys indicate that both the number of Washington residents fishing for steelhead and the average number of days fished increased through the 1994-1995 fishing season (Table 4-2). The average number of days fished per angler increased from 10.8 in the 1964 survey to 20.7 in the 1995 survey; the estimate number of steelhead anglers increased from 133,000 to 212,002 during the same time period. The total fishing effort for the 1994-1995 season was 4.4 million angler-days. However, the estimated number of anglers participating, and the average number of days fished per angler, declined in the 2002-2003 steelhead season relative to the 1994-1995 season. The result was a 28% decline in participation in the steelhead sport fishery to 3.1 million angler-days.

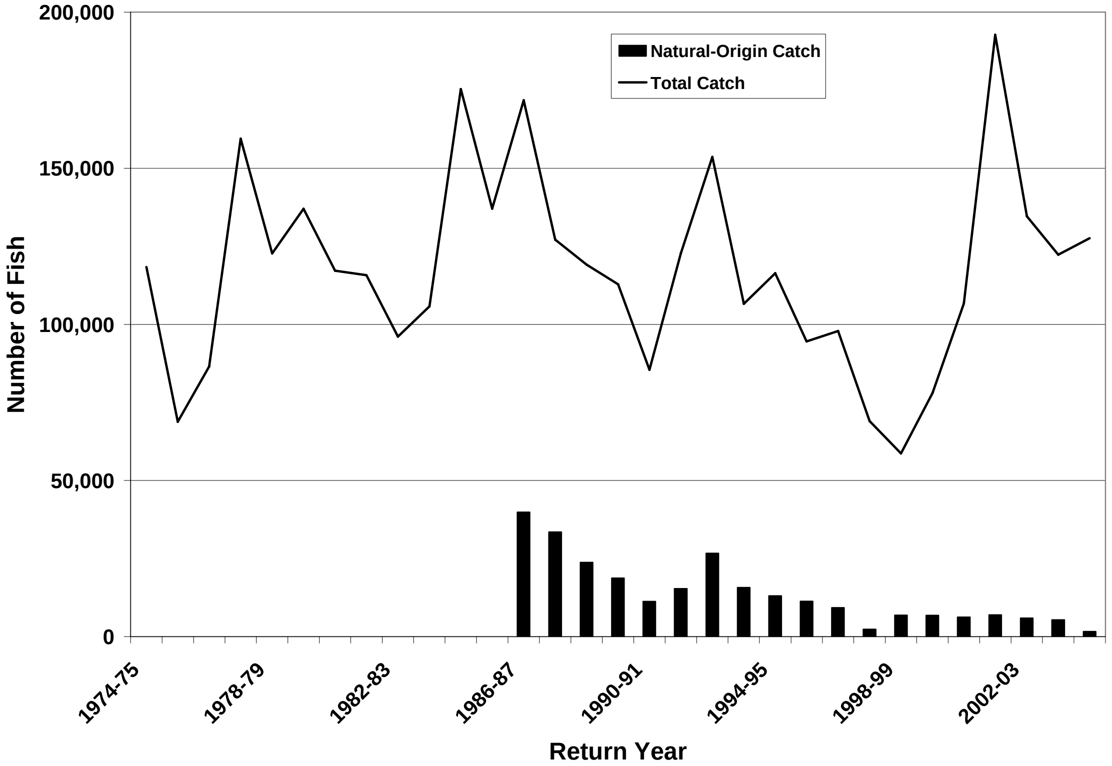

Figure 4-3. Catch of natural-origin steelhead and the total catch of steelhead in Washington by sport fishers.

Table 4-2. Average days fished for steelhead, number of anglers, and angler-days for residents of Washington who fished for steelhead for at least one day.

Fishing Year	Days per angler (95% CI)	Anglers	Angler-Days
January 1, 1964 through December 31, 1964	10.8 (NA)	133,000	1,436,100
January 1, 1986 through December 31, 1986	15.9 (NA)	178,325	2,895,900
May 1, 1994 through April 30,1995	20.7 (19.1, 22.3)	212,002	4,388,436
April 1, 2002 through March 31, 2003	18.3 (15.6, 21.0)	172,064	3,148,278

A second measure of trends in participation in the steelhead sport fishery is available from the number of catch record cards (CRCs) issued for steelhead. The CRC program was initiated for the 1948-1949 fishing season to estimate the sport catch of winter steelhead. Modifications in the program have occurred since that time, including extension of catch reporting for the summer season (1962 season), charging a fee for the card (1970 season), and combination of the CRC and fishing license for multiple species (1999-2000 season)(see Box 4-1 for additional information on the steelhead CRC). To improve the comparability of the CRC data for the years before and after the initiation of a CRC fee, only the CRCs for anglers who indicated that they fished for steelhead were used for years prior to the 1970 season. Even with this correction, the number of steelhead CRCs should be considered only an approximate indicator of angler participation in the steelhead fishery because of the many factors affecting CRC usage. The combination of multiple species on a single CRC or license precludes comparison of data collected subsequent to the 1998-1999 season and previous years.

The CRC data suggest that participation in the sport fishery for steelhead increased rapidly from the late-1940s until the mid-1970s (Fig. 4-4). Beginning with an average of approximately 45,000 steelhead CRC, the number issued increased to an average of 152,587 issued per year for the 1971-1975 time period. The number of steelhead CRC issued declined steadily in subsequent years, averaging only 86,898 for the 1995-1996 through 1998-1999 fishing seasons.

Box 4-1. Reporting of Sport and Tribal Catch of Steelhead

Catch record cards (CRCs) have been used in Washington since 1948 to estimate the sport catch of steelhead. Anglers are required to obtain a CRC prior to fishing for steelhead, to record the number and location of fish caught, and return the card at the end of the season. Substantial changes have occurred in the CRC program since its inception. Major events in the development of the CRC program are summarized below:

1948 – Free CRC required for anglers fishing for steelhead from December 1948 through April 1949
1962 – Catch reporting requirement extended to include entire year.
1970 – Fee charged for license and CRC (juveniles, elders, and some other special cases excluded).
1974 - Bias correction applied to account for non-response bias (anglers who do not turn in a CRC are less likely to catch as many steelhead as anglers who turn in the CRC).
1975- CRC reporting period changed from calendar year to fishing season. 1975 CRC reported catch for January 1, 1975 through April 30, 1976. 1976 CRC and subsequent years reported catch for the period of May 1 through April 30 of the subsequent year.
1984 - Fee charged for license and CRC for anglers of any age.
1986 - Catch of marked (clipped adipose or ventral fin) and unmarked steelhead recorded.
1999- Steelhead license eliminated.
2000- Multi-specie CRC (e.g., steelhead, salmon, halibut) initiated.
2001- Washington Interactive Licensing Database (WILD) implemented to issue fishing licenses and CRCs and electronically capture angler information.

Each steelhead caught is assigned to either the summer run or winter run depending upon the date of catch. Steelhead caught from May through October are defined as summer run; steelhead caught from November through April are defined as winter run with exception of steelhead caught above Bonneville Dam. All steelhead caught above Bonneville Dam are assumed to be summer steelhead.

Catches of steelhead in tribal fisheries are recorded on fish tickets that are typically completed by fish buyers at the time the catch is sold or by tribal fishery management staff. The fish ticket includes information on the date of the landing, the fishing area where the fish were caught, the type of gear used to catch the fish, the tribal affiliation of the fisher, the number of fish caught, and the total weight of the fish caught.

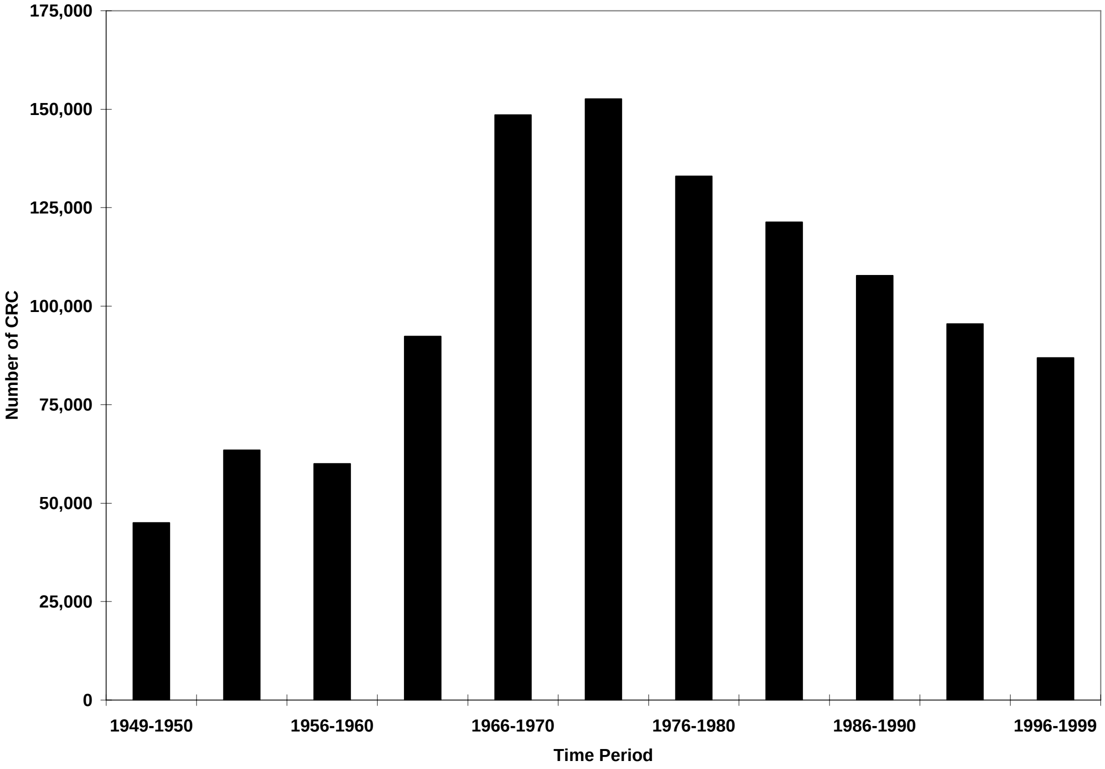

Figure 4-4. Average number of steelhead CRC for 5-year periods from the initiation of the program for the 1948-1949 fishing season through the 1998-1999 fishing season.

4.5 Recreational Angler Surveys

The stewardship responsibility of WDWF requires that recognition and balancing of the interests and values of a wide variety of Washington State residents. One group of residents that WDFW has surveyed repeatedly is comprised of fishers who have obtained a CRC or freshwater fishing license. WDFW conducted five surveys of recreational anglers who obtained a CRC or freshwater fishing license in Washington from 1986 through 2002 (Table 4-3). Results from those surveys are summarized below; additional information may be found in the reports by Mongillo and Hahn (1988), WDFW (1996), and Michael (2004).

Table 4-3. Surveys of Washington anglers conducted from 1987 through 2002.

Survey Name	Survey Type	Sample Frame	Sample Size	Source
1987	Mail	Residents of Washington issued a freshwater fishing license for the 1986 season.	3,438	Mongillo and Hahn (1988)
1995 General	Telephone	Anglers issued a freshwater fishing license for the May 1994 through April 1995 season.	1,522	WDFW (1996)
1995 Steelhead	Telephone	Anglers issued a steelhead catch record card for the May 1994 through April 1995 season.	1,042	WDFW unpublished data.
2001	Telephone	Anglers issued a fishing license for the May 2000 through April 2001 season.	2,143	WDFW unpublished data.
2003	Telephone	Anglers issued a combination (valid in freshwater and saltwater areas) or freshwater fishing licenses for the April 2002 through March 2003 season.	1,541	Michael (2004)

Catch and Release Fisheries

Angler preferences regarding catch and release fisheries were evaluated in both the 1995 Steelhead and 2001 surveys. In the 1995 Steelhead survey, anglers were asked the following question:

> "Imagine a river that does not have enough wild steelhead to meet spawning requirements, but does have enough hatchery steelhead to meet hatchery spawning requirements.
>
> Which of the following three regulations would you favor for this river?
>
> 1) Close all steelhead fishing to allow maximum protection of the wild steelhead (close);
> 2) Allow catch-and-keep fishing for hatchery fish but require all wild, or unmarked, fish to be released (hatchery retention with wild steelhead release); or
> 3) Catch and release for both wild and hatchery steelhead (catch and release hatchery and wild)."

Of the anglers interviewed, 75.2% supported hatchery retention with wild steelhead release, 15.8% supported catch and release of hatchery and wild, 8.4% supported a closure, and 0.6% had no opinion.

The question regarding catch and release was modified in the 2001 survey to include three variations in the status of the natural-origin steelhead.

> "Question 34. First, consider a river that has more wild steelhead than are needed to meet spawning requirements and also has more hatchery steelhead than are needed to meet hatchery needs
>
> Question 35. Now consider a river with a wild steelhead run size that is close to but below spawning requirements, but does have enough hatchery steelhead to meet hatchery needs. Which sport fishing regulations would you prefer for this river?
>
> Question 36. Now consider a river with a wild steelhead run size that is far below spawning requirements, but again, does have enough hatchery steelhead to meet hatchery needs. Which sport fishing regulations would you prefer for this river?"

The anglers interviewed were then asked to identify the preferred fishing regulations from among the following choices:

1) Allow harvest of both wild and hatchery steelhead (hatchery and wild retention);
2) Catch-and-release all wild and all hatchery steelhead (catch-and-release hatchery and wild);
3) Hatchery fish may be kept, but all wild steelhead must be released (hatchery retention, wild-steelhead-release); or
4) Close all fishing for steelhead (close).

In general, the anglers interviewed favored more restrictive regulations as the abundance of the wild population declined (Table 4-4). Anglers supporting a closure increased from 1.9% to 29.1% as the status of the wild population declined from above goal to far below goal, while those supporting retention of both the hatchery and wild population declined from 33.9% to 5.4%. Perhaps more interesting is that 60% of the anglers surveyed supported the release of wild fish (sum of regulation options 2 and 3) even when the wild population was more abundant than the escapement goal.

Table 4-4. Results from 2001 angler survey regarding preferred regulations when the wild population is either above, slightly below, or far below the escapement goal.

Preferred Regulation	**Wild Population Status**		
	Above Goal	**Slightly Below Goal**	**Far Below Goal**
1) Hatchery and Wild Retention	33.9%	9.5%	5.4%
2) Hatchery Retention, Wild-Steelhead-Release	49.3%	59.0%	41.4%
3) Catch-and-Release Hatchery and Wild	11.5%	17.6%	20.9%
4) Close all Fishing	1.9%	10.3%	29.1%
5) No Opinion	3.4%	3.5%	3.2%

Gear Preferences

Recreational anglers have been asked about the type of gear they preferred to use when fishing for summer and winter steelhead. In the 1995 General and 2003 surveys, the anglers were asked to identify the primary choice of gear among the following options: 1) bait; 2) lure with bait; 3) lure; or 4) fly. In both years, approximately 9% of the anglers interviewed identified that fly fishing was their primary choice of gear (Fig. 4-5). However, the number of anglers selecting lures declined from 41% in the 1995 General survey to 28% in 2003. Increases occurred in percentage of anglers identifying bait and lure with bait as the primary gear type.

The other surveys conducted by WDFW included only three gear categories (bait with or without lure, lure, and fly), but they do provide a longer time period for evaluation of trends in the selection of fishing gear (Fig. 4-6). Results from the surveys indicate that the use of lures has been trending downward since the 1987 survey, while the use of flies as the primary gear choice has stayed constant at about 9 percent.

Fishing gear preferences for summer steelhead and winter steelhead were similar in the 2003 survey (Fig. 4-7). Usage of lures and flies was slightly higher for the anglers surveyed who fished for summer steelhead than for anglers who fished for winter steelhead.

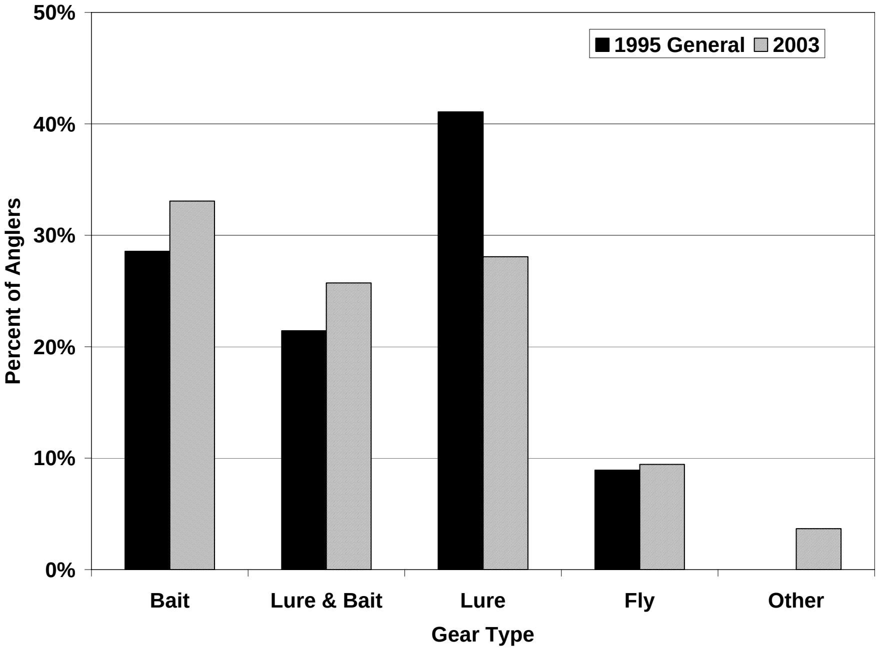

Figure 4-5. Preferred gear for steelhead anglers interviewed in the 1995 General and 2003 surveys.

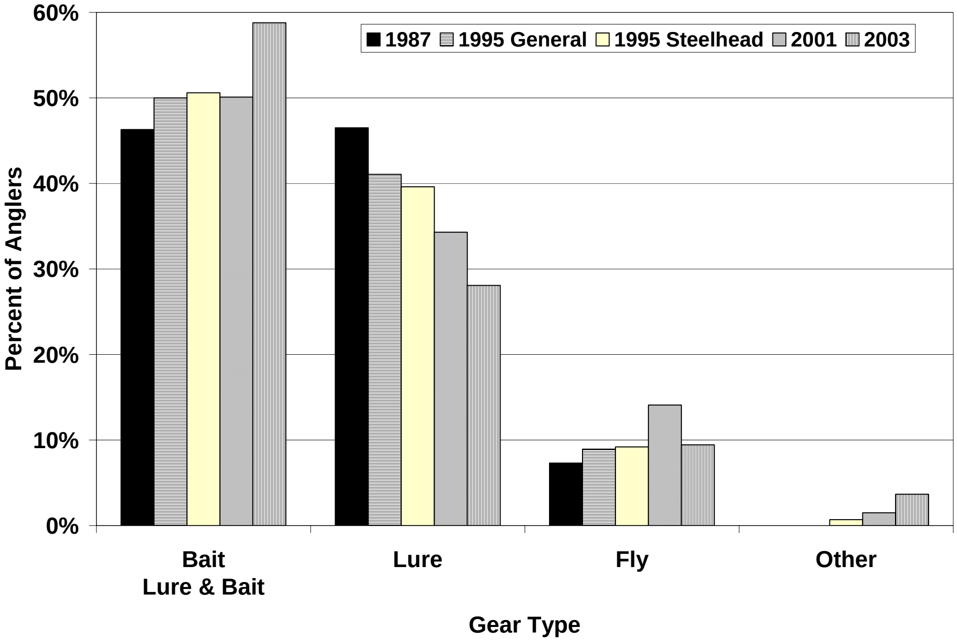

Figure 4-6. Preferred gear of steelhead anglers in the 1987, 1995 General, 1995 Steelhead, 2001, and 2003 surveys.

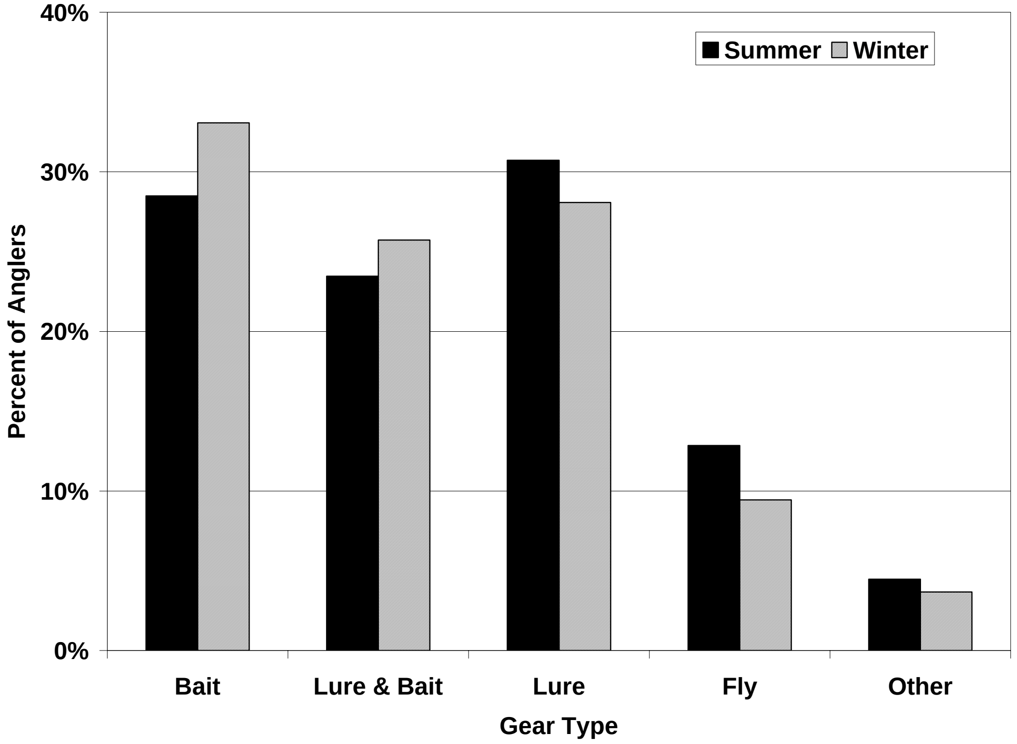

Figure 4-7. Preferred gear of anglers fishing for summer steelhead or winter steelhead in the 2003 survey.

Voluntary Catch-and Release

The 1987, 1995 General, and the 2003 surveys asked anglers a question similar to the following: "What percent of the steelhead that you catch, and are legal to keep, do you voluntarily release?"

The surveys indicate that anglers are becoming more likely to release steelhead that legally can be retained (Fig. 4-8). In the 1987 survey, anglers surveyed indicated that an average of 14% of the steelhead landed were released; this increased to 40% in the 1995 General survey, and 42% in the 2003 survey. The 2003 survey provided additional information on differences in release rates for summer and winter steelhead. The anglers interviewed indicated that they released an average of 40% of the winter steelhead and 44% of the summer steelhead landed that could legally be retained. However, a substantial percentage of anglers interviewed in the 2003 survey did not release any steelhead that could legally be retained (20% of summer steelhead anglers; 14% of winter steelhead anglers).

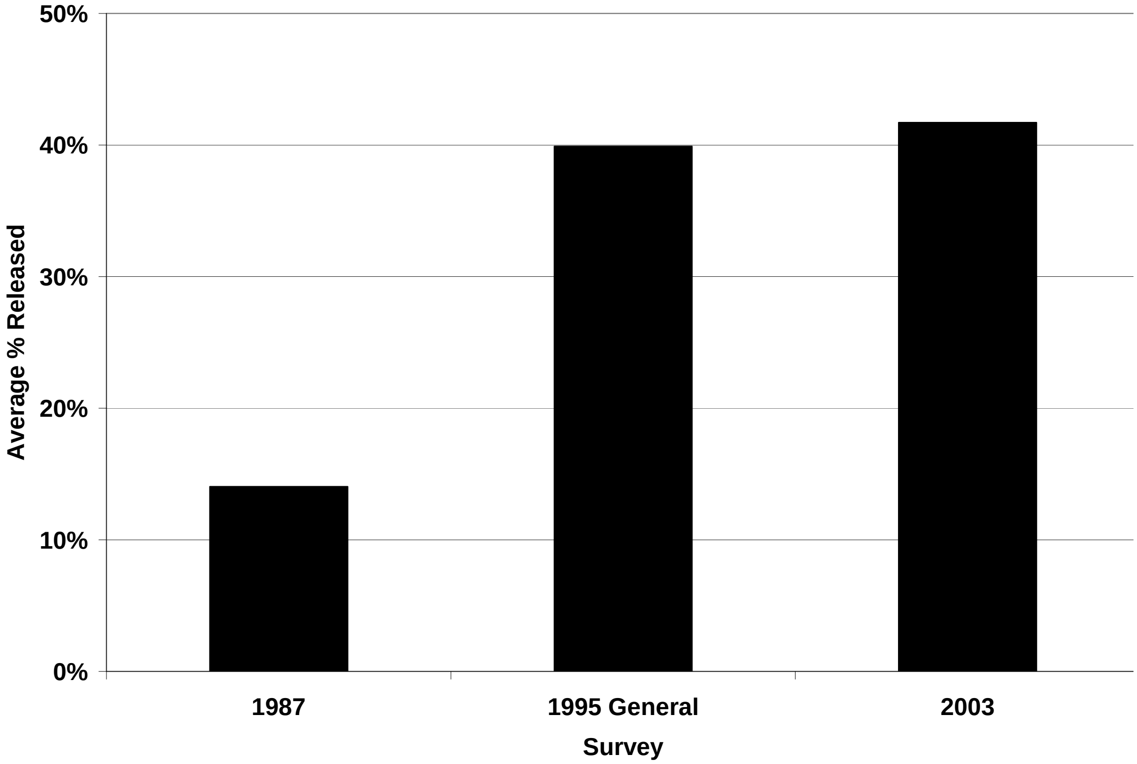

Figure 4-8. Average percent of steelhead released that could legally be retained for anglers interviewed in the 1987, 1995 General, and 2003 surveys.

4.6 Management Trade-offs

Fisheries can potentially pose risks at the population, species, and ecosystem level (see reviews by Law 2000; Tittensor et al. in press). Fishery harvest rates that are too high can reduce species abundance to levels below those consistent with maximizing catch, recreational opportunities, or economic benefits (i.e., California sardine, Peruvian anchoveta, and North Sea herring fisheries) and, particularly in conjunction with other factors such as habitat degradation, can increase the risk of the extirpation of a population. While the potential effects of fisheries on abundance have traditionally been the focus of fishery management, spatial structure and diversity have received increasing attention in recent assessments. Changes in spatial structure and diversity, while sometimes subtle, can be equally important in reducing the potential productivity and viability of populations (Conover and Munch 2002; Berkeley et al. 2004; Olsen et al. 2004). More broadly, fisheries have the potential to substantially alter the structure and functional relationships of ecosystems (Pauly et al. 2001; Ward and Meyers 2005). The magnitude of the risks posed by a steelhead fishery will depend on how, when, and where the fishery is implemented, the biological characteristics of the steelhead in the fishery, and the ecosystem context in which the fishery occurs.

Walters and Martell (2004) suggest that the central problem of fisheries decision-making is evaluating the trade-offs between these risks (and others) and the cultural and economic benefits of fisheries over both the short- and long-term. Their insightful book, *Fisheries Ecology and Management*, provides several examples that we have adapted and expanded upon for Washington steelhead:

1) Short-term vs. Long-term Benefits. A higher level of harvest in the shortterm can mean a reduced level of harvest in the future. Conversely, the reduction or elimination of fisheries can result in the loss of communities or cultural values.
2) Spatial Structure and Diversity vs. Harvest Level. A higher level of harvest in a fishery comprised of multiple populations (or subpopulations) can result in a loss of spatial structure or diversity at the population (or subpopulation) level.
3) Ecological Function vs. Economic Value. The harvest of economically valuable species can result in a reduction in the abundance of other species that depend on the harvested species for food or as a source of marine derived nutrients.
4) Selective vs. Nonselective Fisheries. Fishing gear or regulations that facilitate reductions in the harvest of depressed species or populations may be expensive to implement, preclude the participation of some fishers, or result in the loss of traditional cultural practices.
5) Artificial vs. Natural Production. Artificial production programs can provide additional fishing opportunities but may reduce the diversity, spatial structure, productivity, or abundance of natural populations.
6) Funding of Stock Assessment vs. Artificial Production. Investment in artificial production programs may increase fish abundance, but a reduction in stock assessment may result in a loss in fishing opportunities or place populations at risk of overfishing.

Trade-offs between performance measures can be represented graphically by plotting the pairs of performance measures values that could be achieved under various management approaches (Fig. 4-9). The shape of the relationship between the performance measures is informative. A concave relationship indicates that a small increase in performance measure X will result in a disproportionate reduction in performance measure Y. Concave relationships are difficult from both a policy and a technical perspective. From a policy perspective, identifying a satisfactory solution may be difficult because a relatively small increase in one performance measure can only be obtained by a substantial loss in the other performance measure. Results from the analysis are likely to be sensitive to the choice of models and parameter values and, because the policy trade-off is a difficult one, technical analyses are likely to be closely scrutinized. Although tradeoffs may also be difficult if a convex relationship exists, finding an acceptable compromise will generally be easier because increasing the value of one performance measure results in a relatively small decrease in the other performance measure.

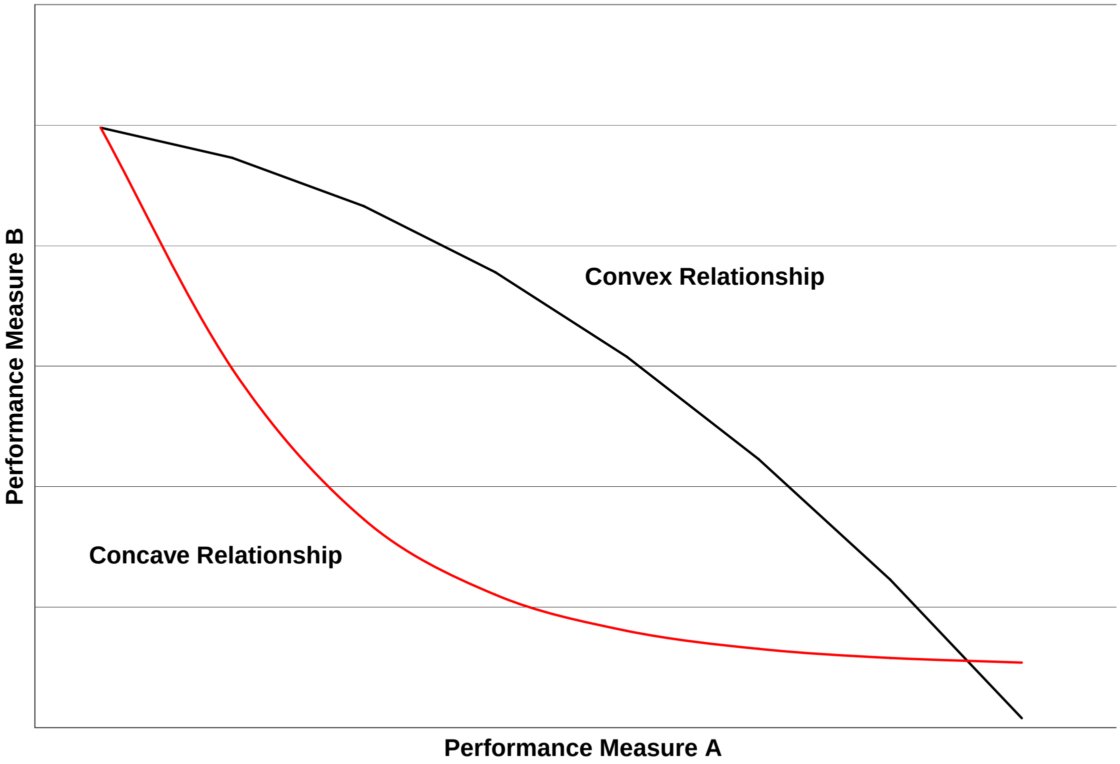

Figure 4-9. Form of concave and convex relationships illustrating trade-offs between performance measures A and B.

4.7 Watershed Management Strategies

A strategy describes the general approach that will guide harvest, hatchery, and habitat management actions implemented in the pursuit of a management goal. Strategies for habitat, harvest, and hatchery production, often referred to as the all-h sectors, have often been developed and evaluated in isolation. Optimal harvest strategies, for example, have been explored under a variety of conditions (Clark 1985), but rarely have interactions with habitat and artificial production strategies been considered. This development of sector-specific strategies has continued to occur despite the increasing recognition that the status of west coast salmonids depends on the aggregate effect of the habitat, harvest, and artificial production sectors.

In this section we will begin by briefly describing several common harvest and hatchery management strategies. We will then focus on two strategies often used in the management of salmonid populations, discuss their interaction with the quality and quantity of freshwater habitat, and illustrate trade-offs that are frequently encountered during implementation.

Three general harvest management strategies for anadromous salmonid populations have been the subject of extensive theoretical and practical evaluation: 1) constant catch; 2) constant harvest rate; or 3) constant escapement. Reviews of the extensive literature on these strategies are provided in Hilborn and Walters (1992) and Walters and Martell (2004).

A constant catch strategy is perhaps the easiest to implement and provides the greatest stability to fishers. Unfortunately it also places populations at the greatest risk of substantial and potentially irreversible declines in abundance. Reductions in abundance associated with environmental factors are accentuated by a constant catch strategy, potentially driving the population to economic extinction or extirpation.

Constant harvest rate strategies may be optimal when stakeholders are averse to large variations in catch (Deriso 1985) or for some mixed-stock fisheries (Hilborn 1985). This strategy is also likely to provide greater stability in terms of season length or catch to fishers than a constant escapement strategy. When longterm changes in the stock-recruit function occur, as has been observed for steelhead populations in several areas of Washington, analyses by Walters and Parma (1996) suggest that the optimal strategy is to: 1) maintain the same harvest rate if only the carrying capacity is changing; or 2) vary the harvest rate to track changes in the intrinsic productivity of the population.

Rigorous analysis of constant escapement strategies was initiated by Ricker (1958). Subsequent analyses have generally confirmed his conclusion that a constant escapement policy maximizes the average catch if: 1) the population is a single homogenous unit; 2) the population size at the start of fishing is known without error; and 3) the stock-recruit relation is stationary with independent annual variation in survival. In the presence of a longterm shift in the stock-recruit relation (e.g., decadal scale changes associated with the marine environment), the optimal strategy is to track these shifts by keeping the target escapement level near the most productive level (Walters and Martell 2004).

Two strategies for artificial production programs were discussed at length in the previous chapter. Briefly, the intent of an integrated strategy is that fish of natural- and hatchery-origin become fully reproductively integrated as a single population. This will always require that natural-origin adults are incorporated in the broodstock for the hatchery program, and hatchery-origin adults may spawn in natural areas. The intent of an isolated program (called segregated in HSRG 2004) is for the hatchery population to represent a distinct population that is reproductively isolated from naturally-spawning populations.

The artificial production and harvest management strategies for steelhead populations in Washington can be broadly grouped into one of six categories (Table 4-5). It should be noted that harvest management strategies implemented for Washington steelhead populations are typically more complex than a constant escapement or constant harvest rate. For example, harvest rates for many Upper Columbia steelhead populations vary from 0% to 8% depending upon population abundance. Similarly, although the harvest management strategy for many Puget Sound populations is similar to a fixed escapement, in practice some harvest may occur even when the population abundance is slightly less than the escapement goal. Despite these simplifications, it is apparent that the majority of Washington steelhead populations are currently managed in one of three categories: 1) isolated artificial production and constant escapement; 2) isolated artificial production and constant harvest rate; and 3) integrated artificial production and constant harvest rate.

Table 4-5. Examples of artificial production and harvest management strategies for steelhead populations in Washington.

Artificial Production Strategy	Harvest Management Strategy	
	Constant Escapement	Constant Harvest Rate
No Artificial Production	Nisqually Winter	
Integrated		Upper Columbia populations such as Wenatchee, Methow, Okanogan
Isolated	Puget Sound populations such as Skagit Winter, Snohomish Winter	Lower Columbia populations such as Kalama Winter, Elochoman Winter.

The goal of the steelhead fishery comanagers is to protect, restore and enhance the diversity and long-term productivity of Washington’s steelhead and their habitats in order to sustain ceremonial, subsistence, commercial and recreational fisheries and provide for associated cultural, economic and ecological benefits for the residents of Washington State. Our objective in the following section is to evaluate the general form of the trade-offs inherent in alternative strategies for achieving this goal. The evaluation relies primarily on a model that incorporates population dynamics for adults spawning in the hatchery and natural spawning areas (specify a and b parameters of a Beverton-Holt stock-recruit function), population fitness, and rules that prescribe the artificial production and harvest management actions that will be taken under alternative resource conditions. We view the development of this model as an initial step toward the development of tools that can be used on a watershed-specific basis to inform policy decisions.

4.7.1 Integrated Hatchery Program, Constant Harvest Rate

An integrated hatchery program linked with a harvest rate management strategy is currently used in the management of steelhead populations in the Upper Columbia River (NMFS 2002; WDFW 2002). In general, this approach includes three primary components: 1) an integrated artificial production program implemented to reduce the risk of extinction of a natural population and/or increase harvest opportunities; 2) external marking of at least a portion of the hatchery-origin juveniles to facilitate harvest in a selective fishery; and 3) a maximum allowable harvest rate on returning adults. In the Upper Columbia plan, a stepped harvest rate schedule is linked to the abundance of natural-origin steelhead.

A watershed management strategy that incorporates these strategies for artificial production and harvest management is likely to encounter at least three fundamental trade-offs: 1) harvest level versus fitness of natural spawners; 2) harvest level versus number of natural spawners; and 3) harvest level versus spatial structure of population. Each of these trade-offs will also be affected by the quality and heterogeneity of the habitat.

Harvest Level vs. Fitness in Natural Environment; Vary Habitat Productivity

Case 1 simulated an integrated artificial production program linked with a constant harvest rate strategy. The artificial production program was set at twelve levels ranging from 0 to 1.59 million smolts. Adults of natural-origin were harvested at a rate of 20%; adults of hatchery-origin were harvested at a rate of 60%. Of the adults of hatchery-origin that were not harvested, 70% returned to the hatchery and 30% to natural spawning areas. Thirty percent of the broodstock used in the hatchery program was of natural-origin.

The proportionate natural influence (PNI) is a measure of the time the population spawns in the natural environment. Under the assumptions discussed in section 3.3.3, a PNI of more than 50% leads to a population with an equilibrium state with characteristics more like those of a pure natural population than a pure hatchery population. In Case 1, the average PNI over 25 generations decreased as the level of the artificial production program (and harvest mortality) increased (Fig. 4-10). This reduction in the PNI resulted from two factors. As the size of the artificial production program increased: 1) a greater proportion of the natural-origin adults were used for hatchery broodstock relative to natural spawning; and 2)an increasing number of hatchery-origin adults were present in natural spawning areas.

A convex relationship existed between the average PNI and the level of harvest mortality, and the extent of nonlinearity increased as habitat quality decreased. The nonlinearity of this relationship has several important consequences. First, at a given level of habitat productivity, increases in the size of the artificial production program (and fishery harvest) will come at a disproportionate cost in a reduction in the PNI. Second, the increasing nonlinearity as habitat quality declines suggests that achieving both PNI and harvest objectives will become increasingly difficult as habitat quality declines.

The relative mean fitness of the population is also predicted to decline as the size of the artificial production program and fishery harvest increase (Fig. 4-11). With the parameters used in this scenario, the mean fitness of the population was reduced by approximately 9% under relatively good habitat conditions (a=7.0, b=6,000), and by approximately 21% under poor habitat conditions (a=1.75; b=1,500). As with the PNI, the form of the relationship became increasingly convex as habitat quality declined.

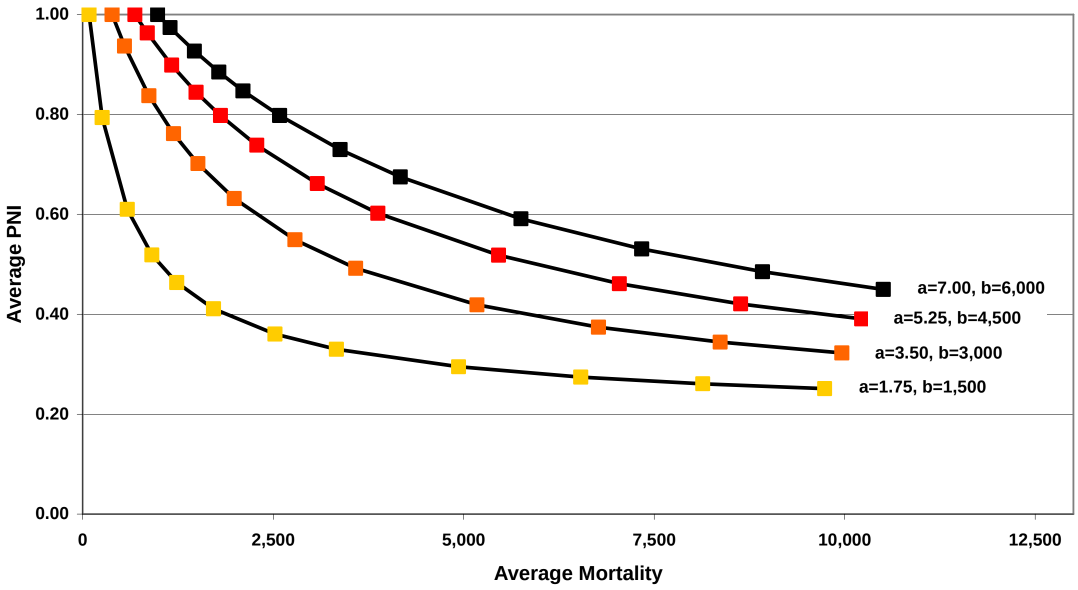

Figure 4-10. Relationship between fishery harvest mortality, PNI, and aquatic habitat productivity in Case 1.

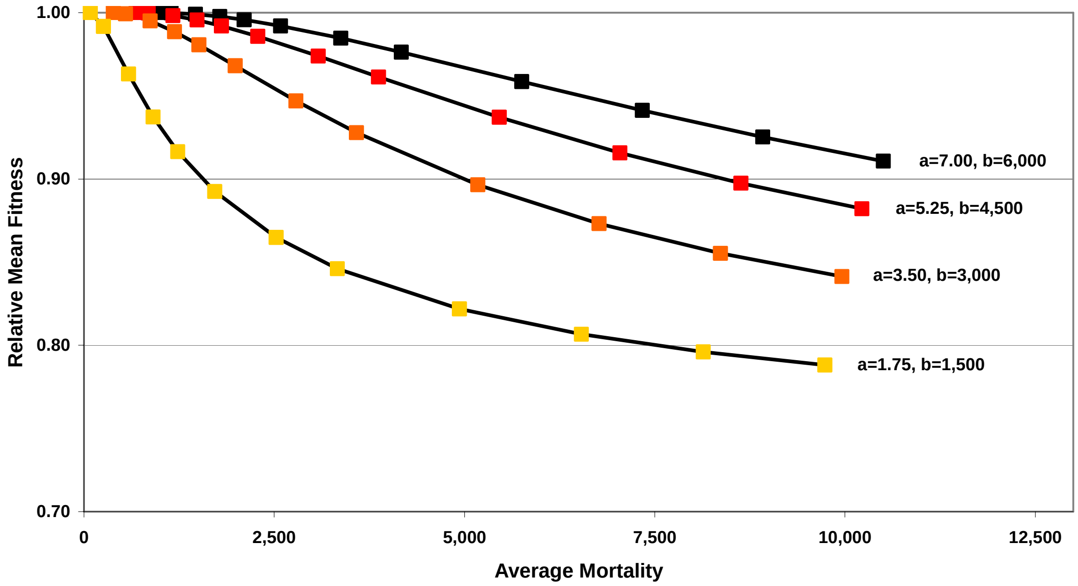

Figure 4-11. Relationship between fishery harvest mortality, relative mean fitness of the population, and habitat productivity in Case 1.

Harvest Level vs. Number of Spawners; Vary Habitat Productivity

In Case 1, the average fishing mortality and the number of natural spawners (natural- and hatchery-origin) increased as the size of the artificial production program increased (Fig. 4-12). The relationship was nearly linear since adults were fished at a constant harvest rate and a constant proportion of hatchery-origin adults returned to natural spawning areas. An upward-shift in the relationship occurred as habitat quality improved and an increasing number of natural-origin fish contributed to the harvest.

A slightly convex relationship existed in Case 1 between the number of natural-origin spawners and fishing mortality (Fig. 4-13). Under poor habitat conditions, the number of natural-origin spawners increased slightly when relatively small levels of artificial production programs were introduced in the simulations. This increase occurred because the combination of the stock-recruit parameters and fishery harvest rate modeled (20%) resulted in fewer natural-origin spawners than the equilibrium value. Initially, adding hatchery-origin spawners to the natural spawning areas increased the subsequent natural production. However, when the equilibrium value of spawners was achieved, additional increases in natural spawners did not result in an increase in production. Furthermore, as the size of the production increased further, the number of natural-origin spawners began to decline because of the reduction in the mean fitness of the population and the increased proportion of natural-origin used for the hatchery broodstock program.

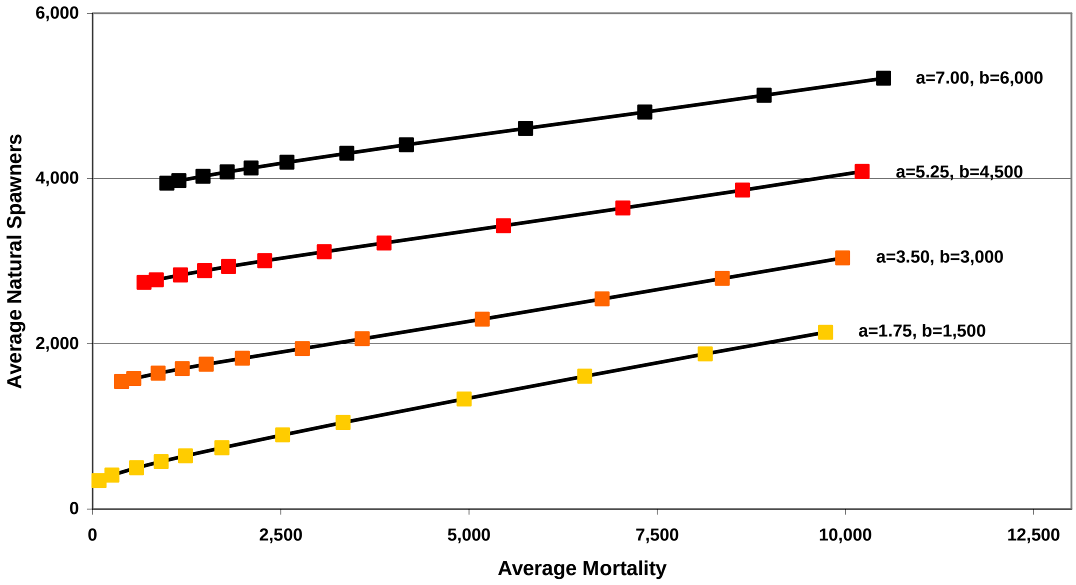

Figure 4-12. Relationship between fishery harvest mortality, natural spawners, and habitat quality in Case 1.

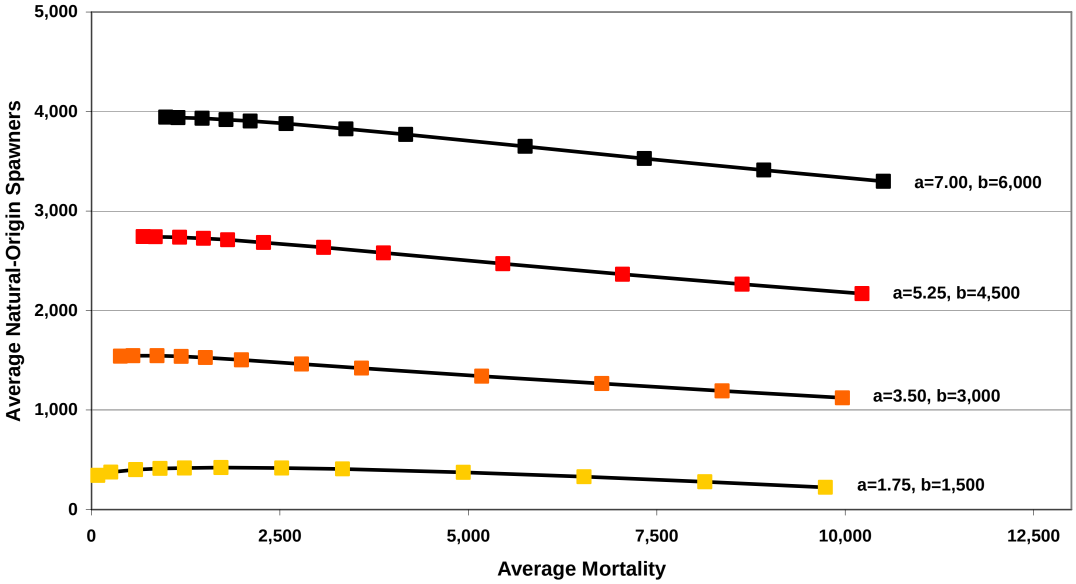

Figure 4-13. Relationship between fishery harvest mortality, natural-origin spawners, and habitat quality in Case 1.

Harvest Level vs. Number of Spawners; Vary Harvest Rate

The effect of the harvest rate was examined in Case 2 by varying harvest rates on natural-origin adults from 0.1 to 0.6. Harvest rates on adults produced from the artificial production program were set at 0.6 as in Case 1. Parameters for the stock-recruit function in the natural-environment were fixed at a=3.5 and b=3,000. All other parameters in the simulation were identical to Case 1.

Increasing the harvest rate on natural-origin adults reduces the number of natural-origin spawners for an integrated production program of a given size (Fig. 4-14). In addition, the nonlinearity of the relationship between natural-origin spawners and fishery mortality increased as the harvest rate increased. This response was similar to that which occurred when habitat quality was reduced in Case 1. In both cases, increases in the number of natural-origin spawners associated with the introduction of an artificial production program were greatest when the combination of the stock-recruit parameters and the harvest rate on natural-origin adults results in fewer natural-origin spawners than capacity.

The potential benefits of a lower harvest rate on natural-origin adults relative to hatchery-origin adults can also be evaluated in Fig. 4-14. A vertical line connecting points with equal levels of artificial production would indicate that there was no reduction in fishery harvest associated with an increasing number of natural-origin spawners. Although this does not occur under the conditions in this simulation, substantial increases in the number of natural-origin spawners could be achieved with relatively modest reductions in fishery harvest. For example, with an artificial production program of 266,000 smolts (dashed line in Fig. 4-14), reducing the harvest rate on natural-origin adults from 60% (non-selective harvest) to 10% resulted in a 23% reduction in fishery harvest but a 327% increase in the average number of natural-origin spawners.

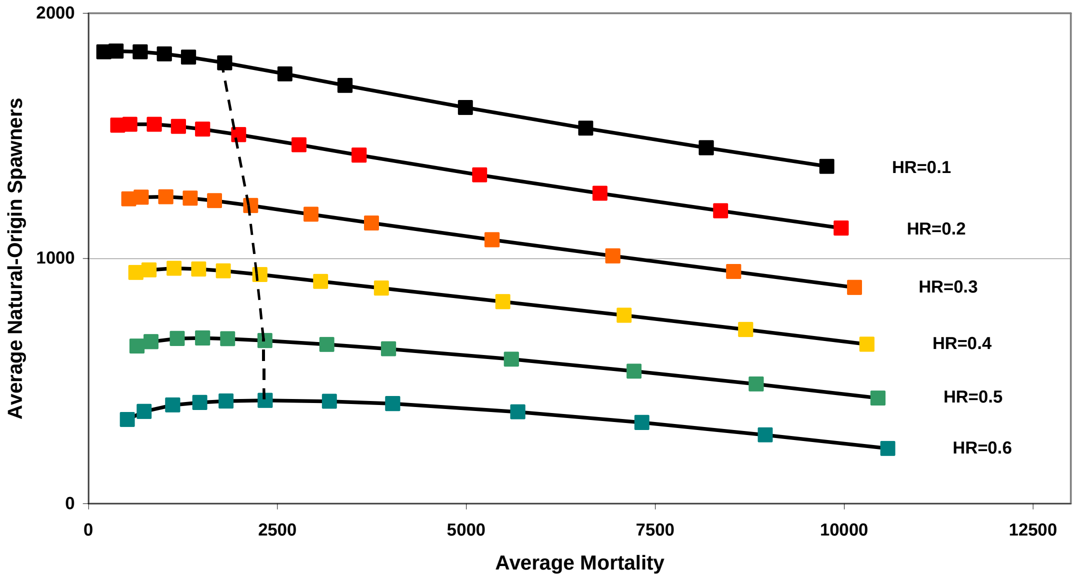

Figure 4-14. Relationship between fishery harvest mortality, natural-origin spawners, and harvest rate on natural-origin adults in Case 2. Dashed line indicates simulation results for artificial production program of 266,000 smolts at varying harvest rates on natural-origin adults.

Performance of Strategy if Hatchery Origin Spawners Controlled

The evaluation of the trade-offs for this strategy presented previously have all assumed that a fixed proportion of the hatchery-origin adults returned to natural spawning areas. If a weir or other structure allows sorting of spawners returning to the river, the performance of the strategy may be enhanced by controlling the proportion of natural- and hatchery-origin spawners in natural spawning areas. The benefits of controlling the number of hatchery-origin spawners can be evaluated relative to the funding and biological costs (e.g., potential delay of migration, handling mortality) that may occur if sorting of spawners is required. Under some conditions (small artificial production programs, low proportion of hatchery fish returning to natural spawning areas, productive natural habitat, low harvest rate on natural-origin adults), the additional costs of sorting may not be warranted.

An example is provided in Fig. 4-15 where simulation parameters are identical to Case 1 except the proportion of hatchery-origin adults returning to natural spawning areas is set at three levels (0.10, 0.30, 0.50). The performance of this strategy at the three rates is contrasted with a strategy in which a target PNI of 50% is established. Note that with an artificial production program of up to 186,000 smolts, the modeled PNI exceeds the target PNI because an insufficient number of hatchery-origin adults exists to meet hatchery broodstock requirements and assure that 30% of the natural spawners are of hatchery-origin. Assuring control of the PNI becomes increasingly important as the size of the program and the proportion of hatchery-origin adults returning to natural spawning areas increase.

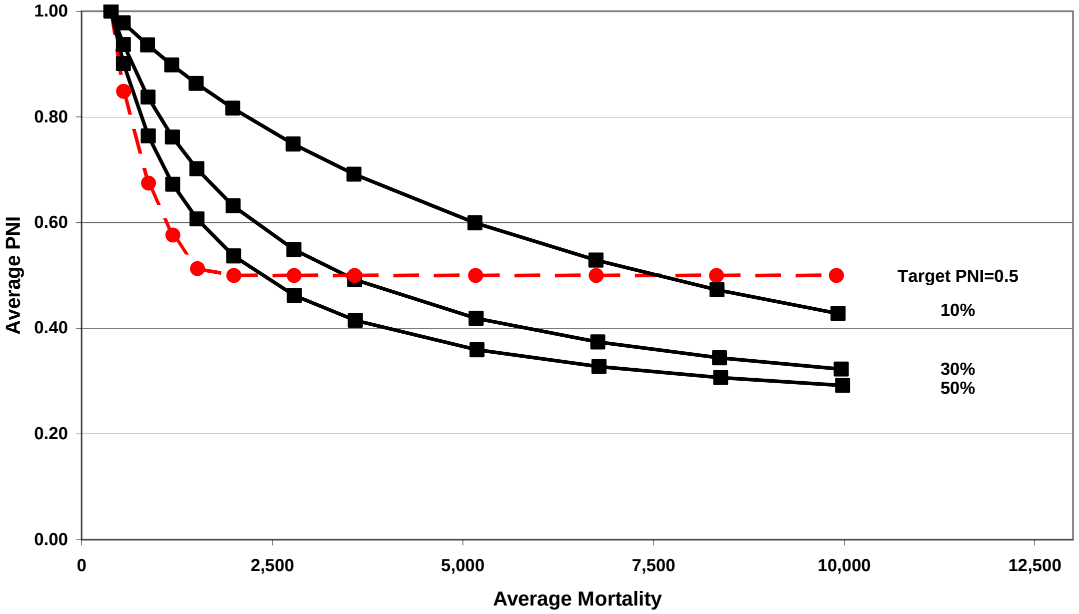

Figure 4-15. Relationship between fishery harvest mortality and PNI for varying rates of hatchery-origin adults to natural-spawning areas and when sorting to achieve a target PNI.

4.7.2 Isolated Hatchery Program, Constant Escapement Management

A strategy that links an isolated hatchery program and constant escapement management has been applied in many tributaries to the Lower Columbia River, the Washington coast, the Strait of Juan de Fuca, and Puget Sound. The key characteristics of this approach are: 1) an isolated artificial production program exists to increase harvest opportunities; 2) the juveniles released from the artificial production program are externally marked to provide for harvest in a selective fishery; 3) the allowable catch of natural-origin steelhead is constrained by the abundance of the natural run relative to the escapement goal. The methodology used to develop many of the escapement goals is described in Gibbons et al. (1985).

A watershed management strategy that incorporates these strategies for artificial production and harvest management is likely to encounter at least two fundamental trade-offs: 1) harvest level versus loss of diversity; and 2) harvest level versus fitness of natural spawners. Just as for the integrated artificial production and constant harvest rate strategy, the form of these relationships will be affected by the quality and heterogeneity of the habitat.

Harvest Level vs. Gene Flow; Vary Spawn Timing and Habitat Productivity

Case 3 simulated an isolated hatchery program linked with a constant escapement harvest management strategy. In the simulations, the fishery harvest was constrained so that the number of natural-origin adults spawning was equal to the level associated with the maximum sustainable harvest. Adults of hatchery-origin were harvested at a rate of 60%, and 70% of the remaining adults returned to natural spawning areas. Gene flow between the hatchery and natural-origin adults in natural spawning areas was modeled using the relationship presented in section 3.3.2 with spawn-timing overlap ranging from 0.01 to 0.20 for o_h and o_n. The artificial production program was set at the same twelve levels used in cases 1 and 2 (0 to 1.59 million smolts).

Gene flow from the adults produced from an isolated hatchery program to a natural population can affect population diversity and fitness. As discussed in Section 3.3.2, relatively low levels of gene flow can over multiple generations significantly reduce population diversity. For this reason, one conclusion of a 1995 workshop on hatchery programs operated with nonlocal broodstock was that there was “no genetic justification for allowing gene flow from non-native fish at levels as high as 5%” (NMFS 1997).

Increases in the fishery harvest level were associated with a substantial increase in gene flow under poor habitat conditions and the other conditions simulated in Case 1 (Fig. 4-16). Although increasing the extent of the spawn timing overlap of the hatchery and natural-origin adults increased gene flow, the initial slope of the harvest-gene flow relationship is relatively high regardless of the degree of the overlap in spawn timing. Consequently, maintaining population diversity under poor habitat conditions is likely to be difficult with an isolated artificial production strategy and the conditions simulated even when the escapement of the natural stock is maintained at a level consistent with the maximum sustainable yield.

The trade-offs between the fishery harvest level and gene flow are less difficult under relatively good habitat conditions (Fig. 4-17). Under these conditions, the initial slope of the relationship is not as steep. However, even under good habitat conditions, gene flow was relatively insensitive to the overlap in spawn timing of the hatchery and natural-origin spawners. For example, at a artificial production level of 186,000 smolts, a twenty fold increase in the spawn-timing overlap (from o_h=o_n= 0.01 to o_h=o_n= 0.20) resulted in only a doubling of gene flow from 2.5% to 5%.

Harvest Level vs. Fitness; Vary Spawn Timing and Habitat Productivity

A concave relationship generally existed between the fishery harvest level and mean population fitness (Figs. 4-18 and 4-19). A greater degree of concavity was evident as habitat productivity declined and the extent of overlap in the spawn timing of hatchery and natural-origin adults increased. Particularly under poor habitat conditions, mean population fitness was also relatively insensitive to the degree of spawn timing overlap in hatchery and natural-origin spawners. Mean population fitness increased from 76% to 83% with a 20-fold increase in spawn timing overlap (from o_h=o_n= 0.01 to o_h=o_n= 0.20) at an artificial production level of 186,000 smolts.

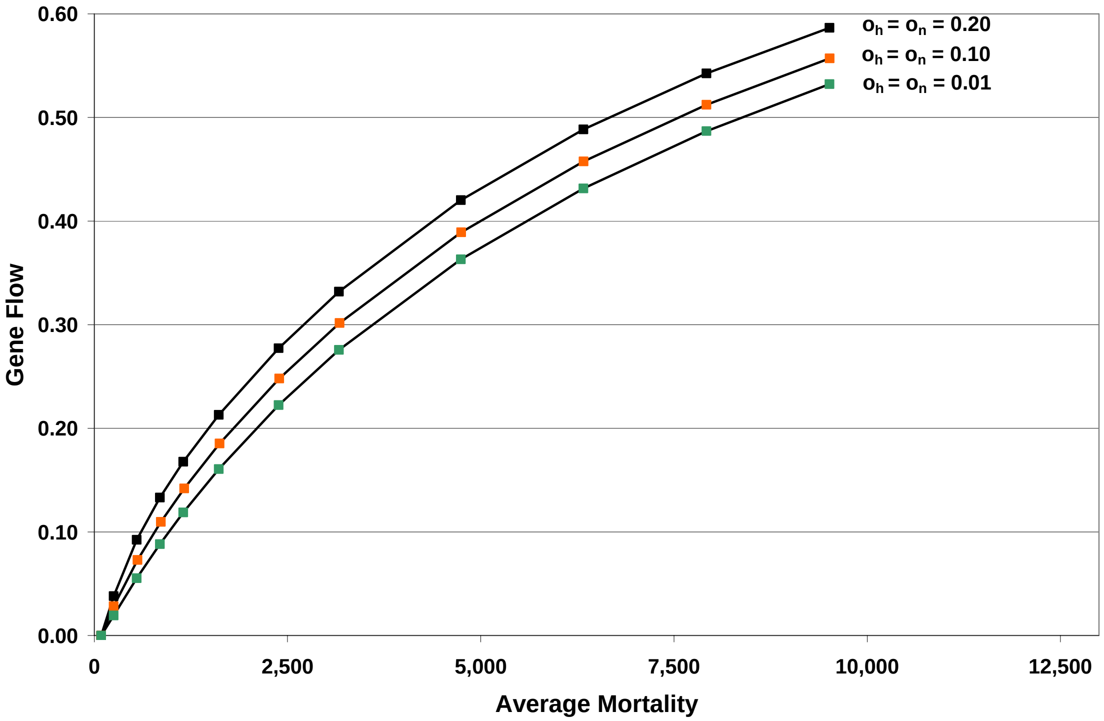

Figure 4-16. Relationship between gene flow and fishery harvest mortality for varying levels of spawn timing overlap and poor habitat productivity (a=1.75; b=1,500).

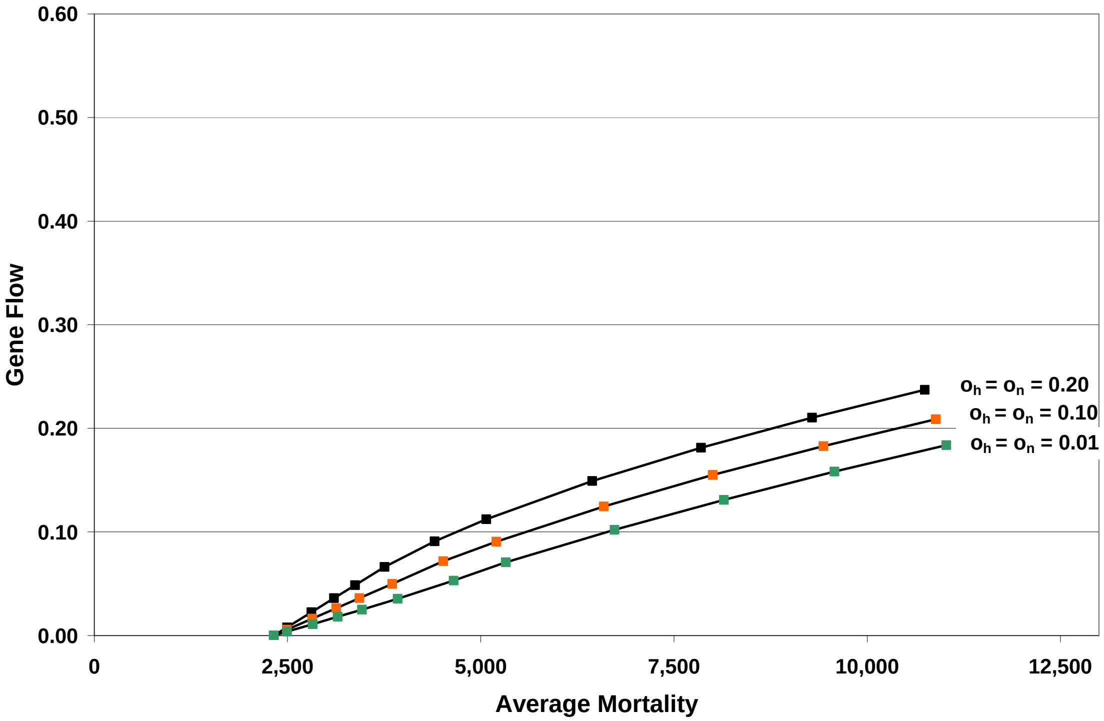

Figure 4-17. Relationship between gene flow and fishery harvest mortality for varying levels of spawn timing overlap and good habitat productivity (a=7.00; b=6,000).

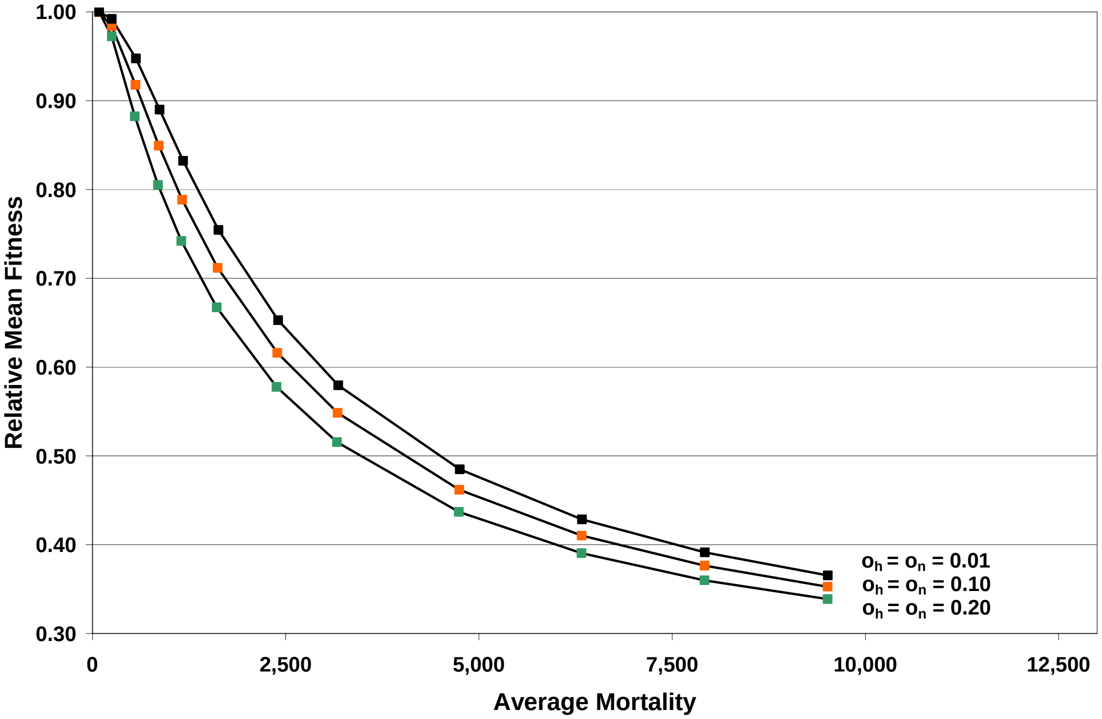

Figure 4-18. Relationship between fitness and fishery harvest mortality for varying levels of spawn timing overlap and poor habitat productivity (a=1.75; b=1,500).

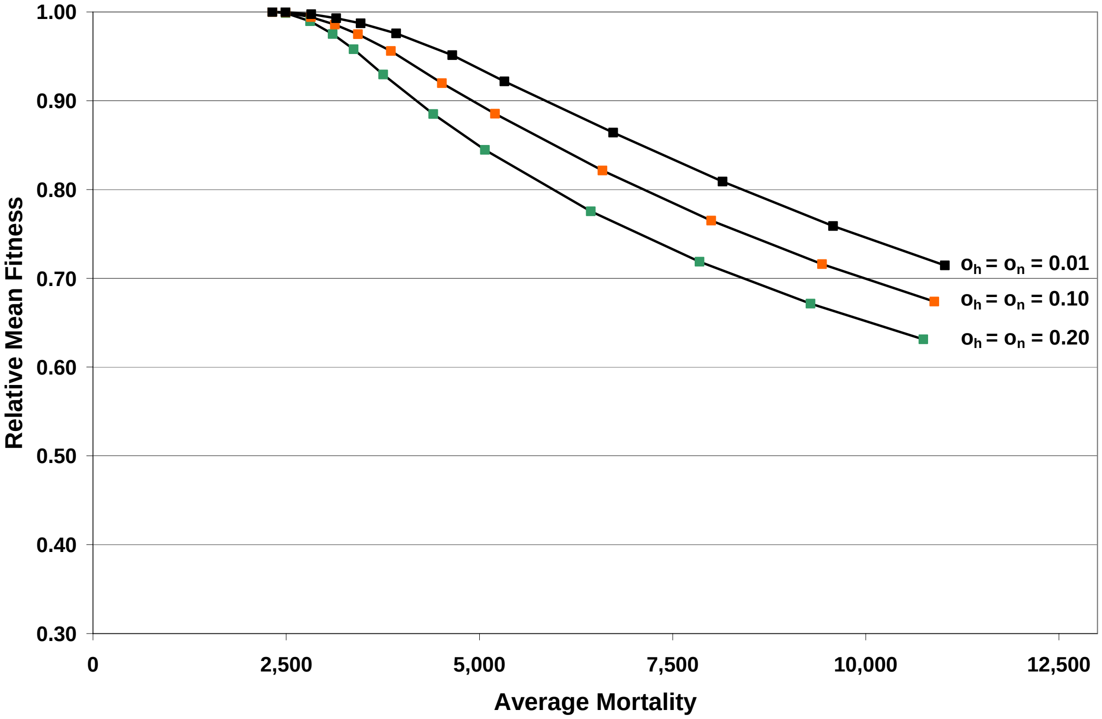

Figure 4-19. Relationship between fitness and fishery harvest mortality for varying levels of spawn timing overlap and good habitat productivity (a=7.00; b=6,000).

4.8 Harvest Regulation Tactics

Regulation tactics are the methods used in the fishery to implement the harvest strategy. They may be broadly categorized as either input controlled or output controlled (Walters and Martell 2004). An input controlled approach attempts to limit exploitation rates through time and area closures, effort limitations, bag limits, or direct assessment of exploitation rates. Conversely, in an output controlled fishery, the total allowable catch (or mortality) is established prior to the season, catch is monitored as the fishery proceeds, and the fishery is closed when the catch (or output) meets the control point. In general, the information required to implement output control are more extensive and costly to collect. Estimates of abundance, in particular, must be accurate to successfully implement an output control approach.

The choice of tactics is likely to depend on the fishery harvest strategy and fishery specific variables such as the intensity of the fishery, uncertainty in estimates of steelhead abundance, vulnerability, and fishing effort, and variability in recruitment rates. Hilborn and Walters (1992) provided a qualitative evaluation of the merits of various combinations of strategies and tactics (Table 4-6). When uncertainty exists only in the estimate of abundance, they suggest that the best tactic for a constant escapement strategy is limits on the season; the best tactic for a constant exploitation strategy is limitation of fishing effort.

Table 4-6. Relative merits of tactics and strategies when uncertainty exists only in abundance.

Strategy	**Tactic**		
	Catch Quota	**Time Limitation**	**Effort Limitation**
Constant Escapement	Worst	Best	Medium
Constant Harvest Rate	Worst	Medium	Best
Constant Catch	Best	Worst	Medium

A more productive approach would be to analyze the complete cycle of data gathering, analysis, and fishery implementation using closed-loop analyses (Punt and Smith 1999; Sainsbury et al. 2000). Walters and Martell (2004) suggest that this approach has been "extraordinarily helpful in detecting problems in stock-assessment methods, evaluating alternative investments in data gathering, and solving problems that can arise when assessment procedures are "linked" to practical management."

4.8 Additional Technical Questions

Several technical questions arose during the preparation of this chapter that will require additional evaluation. These technical questions will be broadly discussed in the final version of this report and more specifically addressed in subsequent fishery management plans.

1) How has the run timing of natural populations of steelhead been affected by fisheries targeting early-timed winter steelhead of hatchery-origin.
2) What is the mortality of steelhead in catch–and-release fisheries?
3) What spawning levels are associated with population viability, maximum sustainable harvest, maximum production, or some other reference point?

4.9 Discussion

Perhaps the most complicated and controversial species for WDFW to manage is the state fish – the steelhead. Steelhead, and in particular natural-origin steelhead, stir deep emotions among both recreational anglers and Native American fishermen.

Substantial evolution in steelhead management steelhead has occurred during the last 50 years in response to improved understanding of the biological requirements of *O. mykiss* and the potential effects of anthropogenic actions. These evolutionary steps include:

> Fisheries on Juvenile Steelhead (1940s and 1950s). Information on the timing of smolt migration and mortality of juvenile steelhead in freshwater trout fisheries (Meigs and Pautzke 1941) led to a delay in the opening of freshwater recreational fisheries (Larson and Ward 1954).
>
> Effects of Domesticated Hatchery-Origin Steelhead (1970s and 1980s). Concerns about the potential effects of domesticated hatchery-origin steelhead on the fitness of naturally spawning populations (Royal 1973) led to research on the fitness of hatchery-origin steelhead that spawned naturally (Crawford et al. 1977). Findings from the research led to improved tools to evaluate the potential effects of the release of hatchery steelhead smolts (Hulett and Leider 1993) and to modification of release levels.
>
> Fishery Harvest Rates on Natural-Origin Steelhead (1980s). Concerns about increases in harvest rates on natural-origin steelhead led to the marking of hatchery production, mark-selective fisheries, and the identification of escapement goals (Gibbons et al. 1985).

Interactions with Hatchery-Origin Rainbow Trout (1980s and 1990s). Research on the potential ecological and genetic interactions of hatchery-origin juvenile rainbow trout and juvenile steelhead (Campton 1985) led to policies restricting the release of hatchery-origin rainbow trout in anadromous waters (WDG 1984).

Each change in management, and often the supporting monitoring and research, was greeted with skepticism, but in hindsight each was a step forward in steelhead management.

New monitoring and research have provided additional insights on the biology of *O. mykiss*, yet heightened concerns exist over the status of some populations. Increased recognition of the importance of the diversity and spatial structure of steelhead, the potential effects of hatchery-origin steelhead on the diversity and fitness of natural populations, and the genetic and ecological interactions of trout and steelhead are new frontiers that will shape the continued evolution of management. Incorporation of these elements will require a new generation of analytical tools that facilitate the evaluation of management trade-offs, trade-offs that must be evaluated in the broader context of the interacting effects of habitat productivity, fishery harvest, and hatcheries.

The complex jurisdictional responsibilities, extensive habitat changes, increasing human population of the state, and the multiple desires of user groups challenge the department to meet its mandate to preserve, protect and perpetuate the resource and maximize public recreational opportunities and meet tribal obligations. The development and implementation of improved, integrated strategies for habitat, fishery harvest, and hatchery management will likely require a heightened level of interaction with local governments and collaboration with stakeholders. Extensive discussion with stakeholders will be needed to evaluate steelhead management trade-offs, generate and discuss new strategies, and solicit review and comment on alternative strategies. In addition to the existing Fish and Wildlife Commission process, the Steelhead and Cutthroat Policy Advisory Group, and regulatory processes such as the State Environmental Protection Act, these discussions might be enhanced through informal workshops and focus groups.

4.10 Findings and Recommendations

Finding 4-1. Steelhead fisheries are an important part of the cultural heritage of Washington and provide substantial economic benefits. Steelhead and anadromous salmonids are of nutritional, cultural, and economic importance to Native American tribes. Known for their explosive power and their preference for fast-flowing rivers, these fish have long held a special place in the lore of Northwest anglers. Recreational fishers spent an average of $105 million dollars per year fishing for steelhead during the last decade with an associated economic output of over $200 million dollars per year.

Finding 4-2. Management of steelhead fisheries is based on a complex web of federal and state court orders, federal regulations associated with the Endangered Species Act, and state statutes. Many steelhead fisheries in Washington are managed cooperatively with Native American tribes in a unique government-to-government relationship defined by treaties, court decisions, and legislation. The *U.S. v. Washington* and *U.S. v. Oregon* decisions determined that the Treaty Tribes and non-Indians are each entitled to a fair share of fish, defined as equal shares of harvestable salmon or steelhead.

Finding 4-3. The recreational catch of steelhead has fluctuated cyclically during the last 30 years, ranging from approximately 193,000 in the 2001-2002 season to a low of less than 59,000 in the 1998-1999 season. Variations in the recreational catch can reflect many factors, including the abundance of steelhead, the catchability of steelhead as affected by conditions such as stream flow, and fishing regulations. Four peaks in the catch of steelhead are evident during the 30 years, separated by approximately by 7 to 9 year periods of declining catch.

Finding 4-4. The percentage of the recreational catch of steelhead originating from natural production has declined from 26% in the 1987-1988 season to approximately 1% in the 2004-2005 season. The cautious management approach implemented by WDFW in the mid-1980s, including mark-selective fisheries, has effectively reduced the catch of natural-origin steelhead while providing opportunities to harvest steelhead of hatchery-origin.

Finding 4-5. Angler interest in catch-and-release fisheries has increased relative to 1987. Phone surveys indicate that anglers are becoming more likely to release steelhead that can be legally retained. In the 1987 survey, anglers indicated that an average of 14% of the steelhead landed were released; this increased to 40% in 1995 and 42% in 2003.

Finding 4-6. Achieving management goals for steelhead will be promoted by an integrated strategy for habitat protection and restoration, hatchery practices, and harvest management. A strategy describes the general approach that will guide management actions in the pursuit of a desired future state. Strategies for habitat, harvest, and hatchery production, often referred to as the all-H sectors, have often been developed and evaluated in isolation. Misalignment of strategies can result in unexpected population and ecosystem responses and can make it difficult to achieve goals.

Finding 4-7. Management of steelhead requires evaluation of the trade-offs between conflicting objectives and an effective process for determining where to operate along these trade-offs. Embedded in this paraphrasing of Walters and Martell (2004) are three important implications: 1) achieving all management objectives is rarely possible; 2) explicit evaluation of trade-offs promotes discussion and the development of improved strategies; 3) selection of strategies is not simply a technical analysis, but requires extensive communication and discussion with stakeholders. Trade-offs likely to be encountered in the management of steelhead include habitat quality versus spawner abundance, harvest level versus the fitness of the natural population, and population diversity versus versus harvest level.

> *Recommendation 4-1.* Develop and implement improved methods and forums to inform constituents about steelhead management trade-offs, generate and discuss new strategies, and solicit review and comment on alternative strategies. In addition to the existing Fish and Wildlife Commission process and the Steelhead and Cutthroat Policy Advisory Group, these methods could include informal workshops and focus groups.
>
> *Recommendation 4-2*. Building on the concepts developed in this paper, develop and apply on a population specific basis analytical tools to evaluate trade-offs between competing management objectives.
>
> *Recommendation 4-3*. In conjunction with the fishery comanagers, continue to annually assess the predicted abundance of steelhead populations, identify allowable fishing rates, and monitor the impacts of fisheries.

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Appendix 4-1. Treaty Status of Indian Tribes in Washington and Adjacent Areas.

Native American tribes in Washington can be grouped into three broad categories relative to fishery management: 1) Treaty tribes (i.e., entitled to exercise treaty rights); 2) federally recognized non-treaty tribes; 3) and non-treaty tribes that are not federally recognized. The following tables are from Woods (2006).

Treaty Tribes (i.e, entitled to exercise treaty rights)

Tribe	*Treaty*	*Authority for Tribe's Treaty Status*
Hoh	Olympia	*United States v. Washington,* 384 F. Supp. 312, 359 (W.D. Wash. 1974)
Jamestown S'Klallam	Point No Point	*United States v. Washington*, 626 F. 1405, 1486 (W.D. Wash. 1984)
Lower Elwha Klallam	Point No Point	*United States v. Washington*, 459 F. Supp. 1020, 1039-40 (W.D. Wash. 1975)
Lummi	Point Elliott	384 F. Supp. at 360
Makah	Neah Bay	384 F. Supp. at 363
Muckleshoot	Medicine Creek, Point Elliott	384 F. Supp. at 365
Nez Perce (ID)	Nez Perce	*Sohappy v. Smith*, 302 F. Supp. 899, 904 (D. Or. 1969)
Nisqually	Medicine Creek	384 F. Supp. at 367
Nooksack	Point Elliott	459 F. Supp. at 1040-41
Port Gamble S'Klallam	Point No Point	459 F. Supp. at 1039
Puyallup	Medicine Creek	384 F. Supp. at 370
Quileute	Olympia	384 F. Supp. at 372
Quinault	Olympia	384 F. Supp. at 374
Sauk-Suiattle	Point Elliott	384 F. Supp. at 375-76
Salish-Kootenai (MT) (no treaty rights confirmed in Washington at this time)	Hell Gate	*Moe v. Confederated Salish & Kootenai Tribes*, 425 U.S. 463, 466 (1976)
Shoshone-Bannock (ID) (no treaty rights confirmed in Washington at this time)	Fort Bridger	*State v. Tinno*, 497 P.2d 1386, 94 Idaho 759 (1972)
Skokomish	Point No Point	384 F. Supp. at 376
Squaxin Island	Medicine Creek	384 F. Supp. at 377
Stillaguamish	Point Elliott	384 F. Supp. at 378
Suquamish	Point Elliott	459 F. Supp. at 1040
Swinomish	Point Elliott	459 F. Supp. at 1039
Tulalip	Point Elliott	459 F. Supp. at 1039
Umatilla (OR)	Walla Walla	302 F. Supp. at 904
Upper Skagit	Point Elliott	384 F. Supp. at 379
Warm Springs (OR)	Middle Oregon	302 F. Supp. at 904
Yakama	Yakama	384 F. Supp. at 380

Non-treaty Tribes (Federally Recognized)

Tribe	*Authority for Tribe's Non-Treaty Status*
Chehalis	*Confederated Tribes of Chehalis Indian Reservation v. Washington*, 96 F.3d 334, 340-41 (9th Cir. 1996)
Coeur d'Alene (ID)	*Idaho v. United States*, 533 U.S. 262 (2001)
Colville (have off-reservation rights in former north half of Colville Reservation per *Antoine v. Washington*, 420 U.S. 194 (1975) and in part of Lake Roosevelt per 16 U.S.C. § 835d)	*United States v. Oregon*, 29 F.3d 481 (9th Cir. 1994)
Cowlitz	*See Wahkiakum Band of Chinook Indians v. Bateman*, 655 F.2d 176, 178-80 (9th Cir. 1981); *Confederated Tribes of Chehalis Indian Reservation v. Washington*, 96 F.3d 334, 340-41 (9th Cir. 1996)
Kalispel	*United States v. Pend Oreille Pub. Util. Dist.*, 926 F.2d 1502, 1508 n.6 (9th Cir. 1991)
Samish	*United States v. Washington*, 641 F.2d 1368 (9th Cir. 1981)
Shoalwater Bay	*Confederated Tribes of Chehalis Indian Reservation v. Washington*, 96 F.3d 334, 340-41 (9th Cir. 1996)
Snoqualmie	*United States v. Washington*, 641 F.2d 1368 (9th Cir. 1981)
Spokane (have off-reservation rights in part of Lake Roosevelt per 16 U.S.C. § 835d)	*Spokane Tribe of Indians v. United States*, 163 Ct. Cl. 58 (1963)

Non-Treaty Tribes (Not Federally Recognized)

Tribe	*Authority for Tribe's Non-Treaty Status*
Chinook (federal recognition denied 67 Fed. Reg. 46204 (July 12, 2002))	*Wahkiakum Band of Chinook Indians v. Bateman*, 655 F.2d 176, 178-80 (9th Cir. 1981); *see Confederated Tribes of Chehalis Indian Reservation v. Washington*, 96 F.3d 334, 340-41 (9th Cir. 1996)
Duwamish (federal recognition denied 66 Fed. Reg. 49966 (Oct. 1, 2001); H.R. 852 pending in 109th Congress)	*United States v. Washington*, 641 F.2d 1368 (9th Cir. 1981)
Snohomish (federal recognition denied 68 Fed. Reg. 68942 (Dec. 10, 2003))	*United States v. Washington*, 641 F.2d 1368 (9th Cir. 1981)
Snoqualmoo	*State v. Posenjak*, 127 Wn. App. 141, 111 P.3d 1206 (2005)
Steilacoom (petition for federal recognition pending. 65 Fed. Reg. 5880 (Feb. 7, 2000))	*United States v. Washington*, 641 F.2d 1368 (9th Cir. 1981)
Wanapum	*See* RCW 77.12.453

Chapter 5

Population Structure

Key Questions:

a) *What were the historical populations of steelhead in Washington?*
b) *How have anthropogenic factors such as hatchery programs and habitat modifications affected population structure?*
c) *What is the source of broodstock for hatchery programs in each region?*

5.1 Introduction

This chapter presents a listing of extant and extinct naturally spawning populations of steelhead in Washington, identifies anthropogenic influences on population structure, and summarizes the methods used to identify populations. Current and recent sources of broodstock for hatchery programs are also provided.

5.1.1 Natural Populations

Identification of population structure is a critically important step in the assessment and management of salmonids. Population-specific data often are the basic unit of analysis for assessments of productivity, sustainable fishery exploitation rates, and extinction risk. Failure to correctly identify the underlying population structure of a species aggregation can result in the loss of habitat essential to preserve genetic diversity, the application of fishing exploitation rates that are unsustainable (Hilborn 1985), or the selection of inappropriate broodstock for an artificial production program (Waples 1991; RASP 1992).

When the Washington Department of Fisheries, the Washington Department of Wildlife and the western Washington treaty tribes created the framework for the 1992 Salmon and Steelhead Stock Inventory[1], guidelines for stock identification were developed based on the definition of a stock proposed by Ricker (1972):

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[1] Originally labeled as SASSI in 1992, the acronym was modified to SaSI (Salmonid Stock Inventory) in 1999 to reflect the addition of Dolly Varden and bull trout. SaSI is a standardized, uniform approach to identifying and monitoring the status of Washington's salmonid fish stocks. The inventory is a compilation of data on all wild stocks and a scientific determination of each stock's status as: *healthy, depressed, critical, unknown, or extinct*. SaSI data and status rating is accessible through the web application SalmonScape (see Box 3-1).

> "…the term stock is used here to describe the fish spawning in a particular lake or stream (or portion of it) at a particular season, which fish to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season. What constitutes a "substantial degree" is open to discussion and investigation, but I do not mean to exclude *all* exchange of genetic material between stocks, nor is this necessary in order to maintain distinctive stock characteristics that increase an individual's expectation of producing progeny in each local habitat.
>
> In some rivers a number of stocks can be grouped together on the basis of similarity of migration times. The word *run* will be used for such groupings. Thus we may speak of a fall run of chinook or steelhead for example. Each run may comprise a considerable number of stocks."

McElhany et al. (2000) also built on Ricker's concept to define populations for the purpose of recovery planning. The phrase a "substantial degree" of interbreeding was refined and more clearly defined as "two groups are considered independent populations if they are isolated to such an extent that exchanges of individuals among the populations do not substantially affect the population dynamics or extinction risk of the independent populations over a 100-year time frame."

In practice, WDFW has found that empirical data are either not available or sufficiently precise to distinguish a stock in the sense of WDF et al. (1993) from a population as defined by McElhany et al. (2000). For consistency with ongoing recovery planning, the term population is used throughout the remainder of this document.

The ESA refers to subspecies and "distinct population segments" (DPSs) as the listable units of biological organization. However, the ESA provides no guidance for identifying these units. Waples (1991) proposed the use of an Evolutionarily Significant Unit (ESU) to identify subspecies and distinct population segments of Pacific salmon and steelhead. An ESU is a population or group of populations within a species that: 1) is substantially reproductively isolated from other populations (or groups of populations) of the same species and; 2) represents an important contribution to the evolutionary legacy of the species as a whole (Waples 1991). NOAA Fisheries formally adopted ESUs as the population units for listing/delisting (NMFS 1991)(Fig. 5-1).

Steelhead ESUs were identified by the NOAA Fisheries steelhead BRT as part of their coastwide reviews of steelhead status (Busby et al. 1996; Good et al. 2005). Individual ESUs were identified based on genetic and ecological evidence for reproductive isolation, including the presence of natural barriers that could serve to isolate populations. Genetic and ecological distinctiveness were assessed based on information about migration and spawn timing, life history patterns, zoogeography and hydrology.

NOAA Fisheries subsequently decided to use distinct population segments, rather than ESUs, for listing determinations because the ESA jurisdictional responsibility for *O. mykiss* is shared with the U.S. Fish and Wildlife Service (71 FR 834).

This report uses the concept of ESUs to provide a geographic structure above the populations level. We decided to use ESUs because of their biological, rather than administrative, basis but retained sub-regional biological and management groupings as appropriate. We relied on Busby et al. (1996) for descriptions of the geographic extents and factors that influenced the definition of individual ESUs. Recognizing that the ESUs are too coarse for stock assessment, harvest and habitat management, nearly all data have been acquired and organized at the stream or watershed level and grouped into sub-regions (e.g., Hood Canal, Grays Harbor, Willapa Bay).

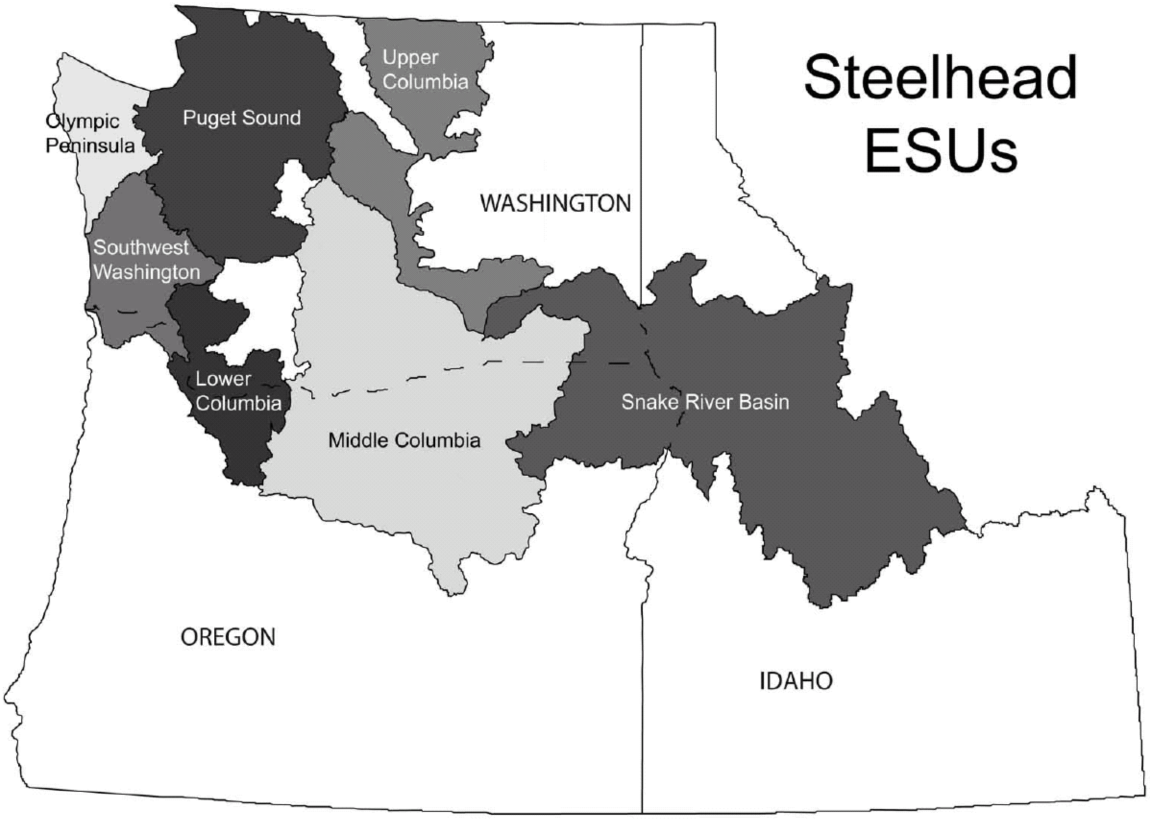
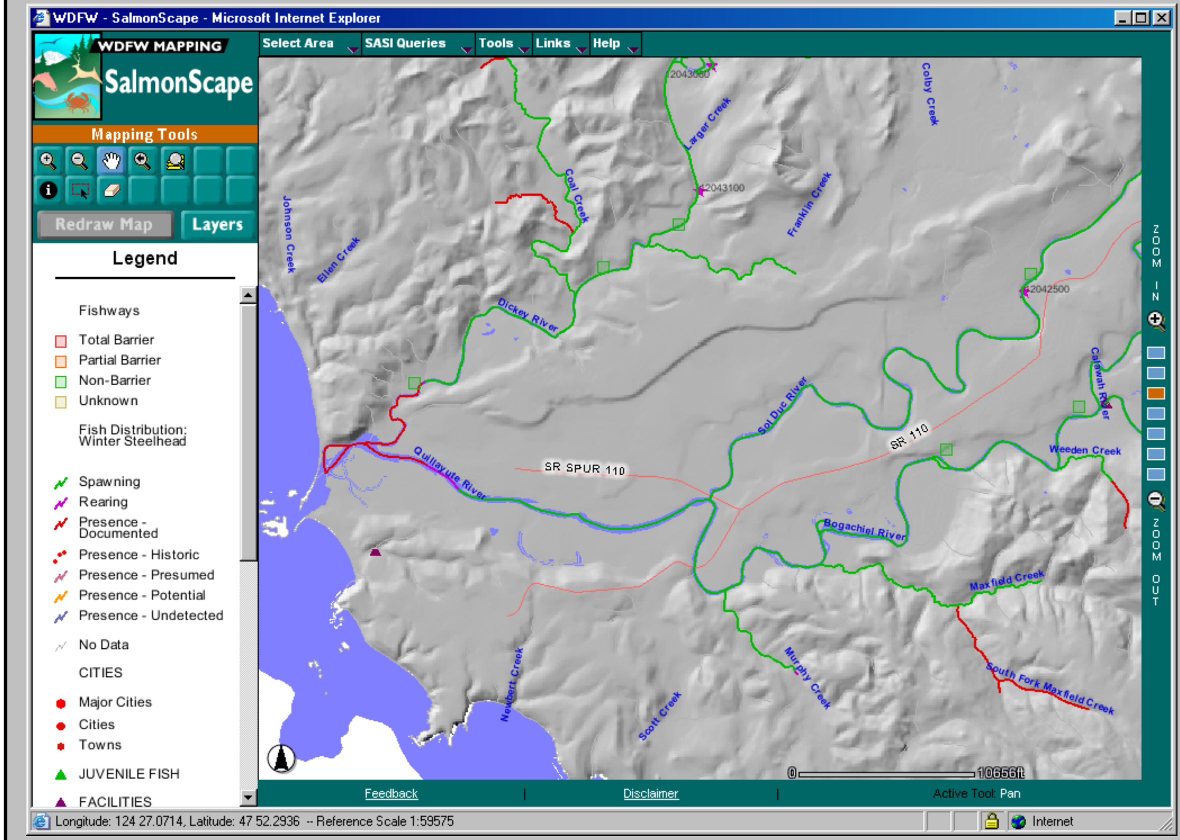


Figure 5-1. Steelhead ESUs all or partially located in Washington State.

Box 5-1. SalmonScape Web Application

A variety of fish and habitat-related information can be viewed on the Web using the WDFW SalmonScape application. SalmonScape supports interactive selection and display of spatial datasets such as steelhead populations, SaSI stock status, fish distribution and use, migration barriers, EDT preservation and restoration priorities (WRIAs 22-28 only), juvenile fish trap sites, and stream habitat attributes. These data can be displayed against many background layers, including administrative boundaries, roads, streams, major public land ownership, township/section lines, shaded relief imagery and orthophotos.

The SalmonScape URL is http://wdfw.wa.gov/mapping/salmonscape/index.html. A screenshot of a typical page featuring winter steelhead distribution and use in the lower Quillayute River appears below.



5.1.2 Hatchery Broodstock

The historical origin and characteristics of the broodstock for artificial production programs are important for at least two reasons. First, gene flow from hatchery-origin steelhead to a natural population, or introgression, may make it difficult to identify historical populations from current genetic or other biological data. Understanding the characteristics of the hatchery-origin steelhead can help explain and clarify confusing or contradictory results. Second, the assessment of an artificial production program is dependent in part on understanding the historical origin and characteristics of the source of broodstock.

5.2 Methods

5.2.1 Historical Populations

Following listing of all Columbia River steelhead under ESA, Technical Recovery Teams (TRTs) under NOAA Fisheries leadership have been convened for the Willamette/Lower Columbia River and the Interior Columbia River basins. One of the initial tasks of each TRT was to identify historical steelhead populations in the Columbia and Snake rivers. The Willamette/Lower Columbia TRT (WLCTRT) focuses on the Upper Willamette (above Willamette Falls) ESU and the Lower Columbia River ESU (Myers et al. 2004). The Interior Columbia Basin TRT (ICTRT) focuses on the Middle Columbia, Snake River and Upper Columbia ESUs (ICTRT 2003).

The approaches taken by the two TRTs to identify historical populations are somewhat different. The WLCTRT has attempted to identify watersheds whose size and habitat characteristics historically were large enough to support viable demographically independent populations (Myers et al. 2004). The information used to do so includes documented historical use, differences in run and/or spawn timing, geographic isolation and basin-specific information about features such as impassable barriers. Geographic isolation was determined using “geographic templates”. The WLCTRT attempted to identify minimum basin areas (geographic templates) needed to support a demographically independent population. Minimum basin area determination was based on examination of the number of extant populations known or thought to be distinct within stream basins of different sizes. The ICTRT identified historically occupied areas, generally located above dams, which once supported anadromous *O. mykiss* and which now have lost the species or support only resident *O. mykiss*.

No systematic effort has been previously made by WDFW to identify historical populations of steelhead in Puget Sound or the Washington coast. SaSI includes all current populations but not extinct stocks unless the extinction has occurred recently and is well documented by state, tribal or other biologists. We reviewed historical records and published studies to identify any additional historical populations that may have been extirpated in the ESUs for which TRTs have not been convened (Puget Sound, Olympic Peninsula, and Southwest Washington).

5.2.2 Extant Native Populations

Genetic analyses from external sources (ICTRT 2003; Myers et al. 2004) and WDFW were used to help identify steelhead populations. WDFW analyses were generally based on 156 collections of juveniles or adults collected from 1993 through 1996 (see Phelps et al. 1994; 1997). These investigators conducted horizontal starch-gel electrophoresis to analyze variation at 56 enzyme-coding loci using over 150 collections of adult or juvenile steelhead from throughout Washington.

Datasets for Puget Sound, coastal Washington and the lower Columbia River populations were re-analyzed for this report (see Appendix 5-A for a complete description of methods). For each of these regions, a consensus dendrogram was constructed to evaluate the certainty of the genetic relationships among the datasets. The consensus dendrogram was constructed by repeating (or bootstrapping) the following steps 1000 times: 1) resample the allelic frequencies in each dataset; 2) compute the pairwise Cavalli-Sforza and Edwards (1967) chord distances between the allelic frequencies for each dataset; and 3) use the Neighbor-Joining (N-J) algorithm to construct a tree by successive clustering of each of the datasets. From the 1000 repetitions, a consensus dendrogram was constructed by selecting the clusters of datasets, or nodes, that occurred most frequently. Nodal bootstrap values represent the number of times the branching to the right of the node occurred in the 1000 trees analyzed. We considered bootstrap values of greater than 65% to indicate supported nodes and have deleted all lower bootstrap values (indicated nodes with little or no statistical support) to simplify the figures. The labeling of in the dendrograms includes an abbreviation of the stream or hatchery (designated by ‘H’) name, the last two digits of the year of collection, and a one-letter code for the adult return time of the population (‘S’ =summer run; ‘W’ = winter run; or ‘B’ = possible mixed collection containing both summer and winter run fish).

5.2.3 Hatchery Broodstock

Information on the origin and characteristics of broodstock used in artificial production programs was obtained from a wide variety of sources. These included staff working in the facilities, historical records, published papers, and other records maintained by

WDFW. Other existing compilations exist for Puget Sound and the Washington Coast (HSRG 2002; 2003; 2004) and the Columbia basin (NMFS 2003; NMFS 2004).

5.3 Results

5.3.1 Puget Sound

Natural Populations

The following description of the Puget Sound ESU is primarily a summary of information from Busby et al. (1996). The Puget Sound ESU includes streams ranging from the Canadian border (Nooksack River basin), south through Puget Sound and Hood Canal, north and west to the Elwha River, which empties into the eastern Strait of Juan de Fuca (Fig. 5-2). The region lies in the rain shadow of the Olympic Mountains and is significantly drier than the Olympic Peninsula to the west. The relatively protected marine environment of Puget Sound provides an opportunity for both juvenile and adult residence time that is not available to high seas-migrating steelhead in the other ESUs. The elongate geometry of the marine basins and embayments also provides for broad variations in tidal currents, sub-basin flushing capacity, and relative stagnation. This can subsequently be expressed as a vulnerability to pollutant concentration that generally increases toward the South Sound region and into the Hood Canal fjord. Populations in British Columbia were excluded on a biological basis because they tend to primarily migrate to marine waters at age three, whereas those in Washington tend to migrate at age two.

Genetic samples have been taken from steelhead collected at 40 locations within the geographic extent of the Puget Sound ESU and allozyme analysis conducted for 56 polymorphic loci (Phelps et al. 1997). Many of the samples were from juveniles and in some cases may have included a mixture of summer steelhead, winter steelhead, and resident *O. mykiss*. The consensus N-J dendogram revealed little geographic structure among the sample groupings and bootstrap support for the groupings was generally poor.

In the absence of informative genetic analysis, we generally relied on the populations identified in WDF et al. (1993). Identification of these populations was based on the geographic isolation of spawning areas and/or the apparent non-overlap of spawn timing (WDF et al. 1993).

We identified 51 populations that historically were present within the Puget Sound ESU (Table 5-1). Two populations, Baker Summer and Chambers Winter, may have been extirpated. The Baker Summer population was likely extirpated after construction of the Baker dams blocked access to spawning areas in the Baker River. The Chambers

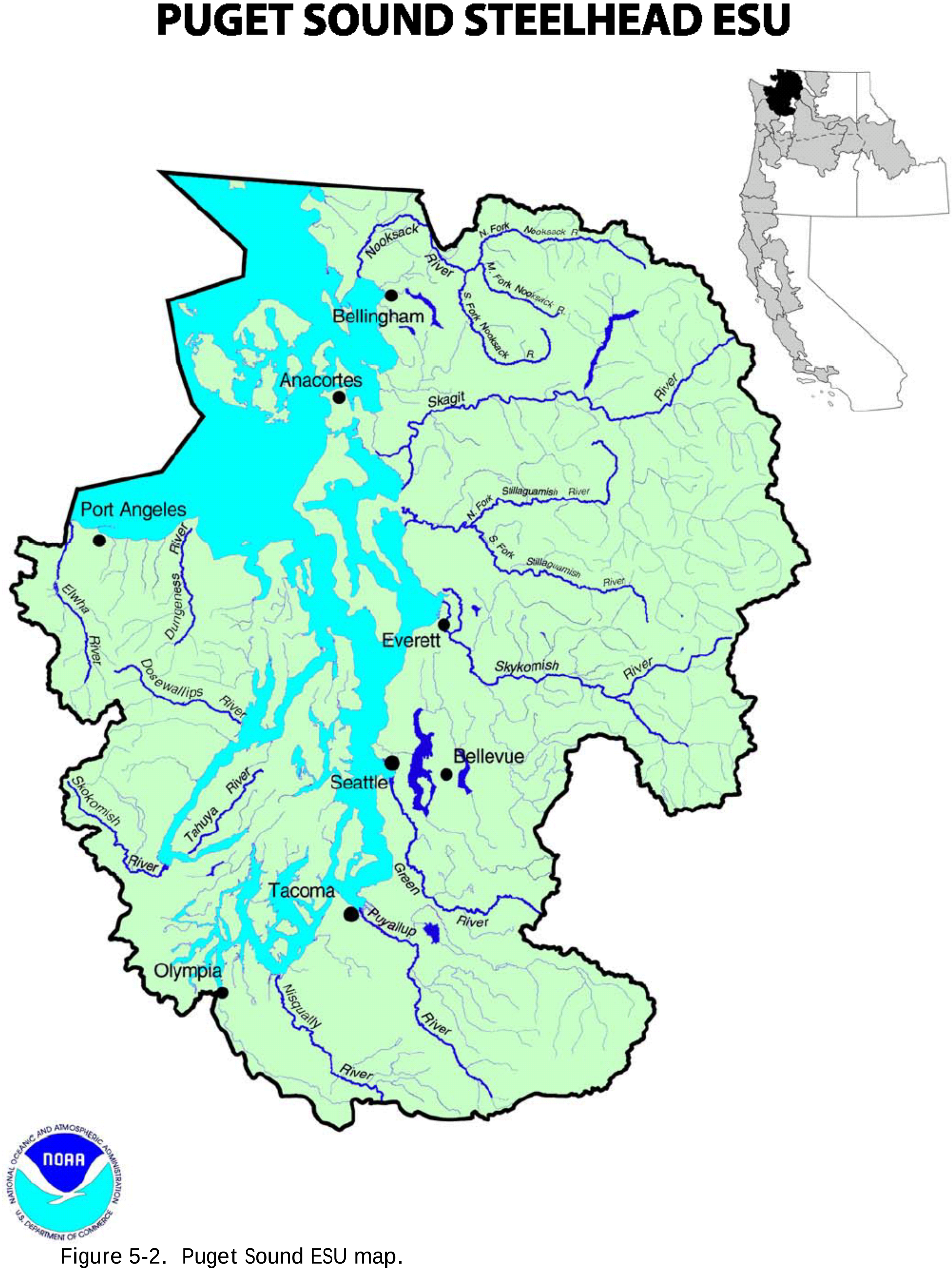


Figure 5-2. Puget Sound ESU map.

Winter population was extirpated, probably as a result of broodstock collection at Chambers Creek and selective breeding at the South Tacoma Hatchery.

Releases of hatchery-origin juveniles may have resulted in the establishment four new populations of steelhead:

> South Fork Stillaguamish Summer. Summer steelhead of Skamamia-origin were introduced into the South Fork Stillaguamish River coincident with the construction of the Granite Falls fish ladder in the mid-1950s. A natural self-sustaining population may now exist, although this is difficult to determine because of the annual release of hatchery-origin steelhead continued through 2002.
>
> South Fork Skykomish Summer. Summer steelhead of Skamamia-origin were introduced into the South Fork Skykomish River coincident with the initiation of a trap-and-haul operation at Sunset Falls in the mid-1950s. Despite the absence of releases of hatchery-origin steelhead into the South Fork Skykomish since 1992, 500-1,200 adults returned to Sunset Fall in each year from 1999 through 2003. Pairwise genotypic differentiation tests indicate significant differentiation among the South Fork Skykomish Sunset Falls population, North Fork Skykomish Summer natural population and Reiter Ponds rearing facility (Skamania-origin). Other measures of genetic similarity (e.g. genetic distance, and F_{ST}) indicate that the Sunset Falls population are more similar to the Reiter Ponds summer hatchery strain than to the indigenous North Fork Skykomish population (Kassler and Hawkins, pers. comm.).
>
> Green Summer. Annual stocking of juvenile summer steelhead of Skamania origin was initiated in 1965. A natural self-sustaining population may now exist, although this is difficult to determine because of the continued introduction of hatchery-origin steelhead. The presence of unmarked steelhead in the catch may be indicative of natural production. An average of 8.7% of the sport and tribal catch of summer steelhead was unmarked in the years 1988 to 2003.
>
> Deschutes Winter. Winter steelhead of Chambers Creek-origin were introduced into the Deschutes River when a fish ladder was installed at Tumwater Falls in 1954. It has been difficult to determine if a naturally self-sustaining population exists because of the continued introduction of hatchery-origin steelhead. It seems unlikely, however, because few unmarked steelhead smolts are captured at a smolt trap operated on the Deschutes River.

Table 5-1. Puget Sound region historical and extant natural steelhead populations.

Historical Population	Extant Population
Nooksack Basin	
Dakota Creek Winter	Dakota Creek Winter
Mainstem/NF Nooksack Winter	Mainstem/NF Nooksack Winter
MF Nooksack Winter	MF Nooksack Winter
SF Nooksack Summer	SF Nooksack Summer
SF Nooksack Winter	SF Nooksack Winter
Samish Winter	Samish Winter
Skagit Basin	
Baker Summer	Potentially Extirpated. Anadromous access to the Baker River lost after construction of the Baker dams. Resident form of *O. mykiss* may remain in the upper watershed.
Mainstem Skagit/Tribs Winter	Mainstem Skagit/Tribs Winter
Finney Creek Summer	Finney Creek Summer
Sauk Summer	Sauk Summer
Sauk Winter	Sauk Winter
Cascade Summer	Cascade Summer
Cascade Winter	Cascade Winter
Stillaguamish Basin	
Stillaguamish Winter	Stillaguamish Winter
Deer Creek Summer	Deer Creek Summer
Not a historical population.	SF Stillaguamish Summer. Summer steelhead of Skamania-origin were introduced into the South Fork Stillaguamish River coincident with the construction of the Granite Falls fish ladder in the mid-1950s.
Canyon Creek Summer	Canyon Creek Summer
Snohomish Basin	
Snohomish/Skykomish Winter	Snohomish/Skykomish Winter
Pilchuck Winter	Pilchuck Winter
NF Skykomish Summer	NF Skykomish Summer
Not a historical population.	SF Skykomish Summer. Summer steelhead of Skamamia-origin were introduced into the South Fork Skykomish River coincident with the initiation of a trap-and-haul operation at Sunset Falls in the mid-1950s. Genetic analysis indicates significant differentiation from NF Skykomish Summer natural population and Reiter Pond Hatchery (Skamania-origin), but greater similarity to samples from the Reiter Pond Hatchery (Kassler and Hawkins, pers. comm.).
Tolt Summer	Tolt Summer
Snoqualmie Winter	Snoqualmie Winter

Table 5-1 (continued). Puget Sound region historical and extant natural steelhead populations.

Historical Population	Extant Population
Lake Washington Basin	
Lake Washington Winter	Lake Washington Winter
Duwamish/Green Basin	
Not a historical population.	Green Summer. Population originated from summer steelhead of Skamania-origin introduced in 1965.
Green Winter	Green Winter. Genetic analysis indicates significant differentiation from Puyallup Winter.
Puyallup Basin	
Mainstem Puyallup Winter	Mainstem Puyallup Winter
White (Puyallup) Winter	White (Puyallup) Winter
Carbon Winter	Carbon Winter
South Sound Basin	
Chambers Creek Winter	Extirpated.
Nisqually Winter	Nisqually Winter
Not a historical population.	Deschutes Winter. Winter steelhead of Chambers Creek-origin were introduced into the Deschutes River, but presence of naturally sustained population is unlikely.
Eld Inlet Winter	Eld Inlet Winter
Totten Inlet Winter	Totten Inlet Winter
Hammersley Inlet Winter	Hammersley Inlet Winter
Case/Carr Inlets Winter	Case/Carr Inlets Winter
East Kitsap Winter	East Kitsap Winter
Hood Canal	
Dewatto Winter	Dewatto Winter
Tahuya Winter	Tahuya Winter
Union Winter	Union Winter
Skokomish Summer	Skokomish Summer
Skokomish Winter	Skokomish Winter
Hamma Hamma Winter	Hamma Hamma Winter
Duckabush Summer	Duckabush Summer
Duckabush Winter	Duckabush Winter
Dosewallips Summer	Dosewallips Summer
Dosewallips Winter	Dosewallips Winter
Quilcene/Dabob Bays Winter	Quilcene/Dabob Bays Winter
Strait of Juan de Fuca	
Discovery Bay Winter	Discovery Bay Winter
Sequim Bay Winter	Sequim Bay Winter
Dungeness Summer	Dungeness Summer
Dungeness Winter	Dungeness Winter
Morse Cr/Independent Tribs. Winter	Morse Cr/Independent Tribs. Winter
Elwha Summer	Elwha Summer
Elwha Winter	Elwha Winter

Hatchery Broodstock

Hatchery programs in the Puget Sound region generally use broodstock of Chambers origin for winter steelhead programs and broodstock of Skamania origin for summer steelhead programs (Table 5-2). Two exceptions are conservation programs for winter steelhead operated on the Green River and on the Hamma Hamma River.

Table 5-2. Hatchery broodstock, broodstock origin, and other sources of eggs, juveniles, or adults in the last 10 years for hatchery programs located in the Puget Sound region. Parenthetic C included in broodstock name indicates Chambers origin; parenthetic S indicates Skamania origin. Spawn timing is identified relative to local natural population as early (E) or normal (N).

Facility	Broodstock	Spawn Timing	Broodstock Origin	Other Sources
Kendall Creek	Kendall(C) Winter	E	Chambers Winter	Tokul(C) Winter Skagit(C) Winter Bogachiel(C) Winter
Marblemount	Skagit(C) Winter	E	Chambers Winter	
Barnaby Slough	Skagit(C) Winter	E	Chambers Winter	
Whitehorse Ponds	Whitehorse(C) Winter	E	Chambers Winter	
Reiter Ponds	Reiter(S) Summer	E	Skamania Summer	
Tokul Creek	Tokul(C) Winter	E	Chambers Winter	Bogachiel(C) Winter
Palmer Ponds	Palmer(C) Winter	E	Chambers Winter	Tokul(C) Winter Bogachiel(C) Winter VanWinkle(C) Winter
Palmer Ponds	Palmer(S) Summer	E	Skamania Summer	Reiter(S) Summer
Soos [1]	Green Winter	N	Local	
Puyallup	Puyallup(C) Winter	E	Chambers Winter	Tokul(C) Winter Bogachiel(C) Winter
Hamma Hamma[2]	Hamma Hamma Winter	N	Local	
Dungeness	Dungeness(C) Winter	E	Chambers Winter	Bogachiel(C) Winter
Lower Elwha[3]	Elwha(C) Winter	E	Chambers Winter	Bogachiel(C) Winter

[1] Program operated by Muckleshoot Tribe.

[2] Cooperative program with Long Live the Kings.

[3] Program operated by Lower Elwha Klallam Tribe.

5.3.2 Olympic Peninsula

Natural Populations

The following description of the Olympic Peninsula ESU is primarily a summary of information from Busby et al. (1996). The Olympic Peninsula ESU includes the western Strait of Juan de Fuca and the Olympic Peninsula from west of the Elwha River, around Cape Flattery, and south to include all streams that drain into the Pacific Ocean North of Grays Harbor (Fig. 5-3). A rare, temperate rain forest ecosystem dominates the western slopes of the thrust-cored Olympic Mountains. Very high annual precipitation rates, restricted land use and access, along with favorable gradient and bedload combinations have produced the most robust wild steelhead stocks in the state. These physical and climatic differences were considered to contribute to the biological distinctiveness of steelhead in the ESU. Genetic analyses by WDFW indicates that populations in the western Strait of Juan de Fuca and the North Coast of Washington are similar to one another, yet distinct from those in other regions of western Washington. Also, the coast region north of Grays Harbor and the Chehalis basin contains fish and amphibians not found on the south coast (presumably reflecting the glacial history of the north coast). This observation provided the BRT with additional evidence that the western Olympic Peninsula should be considered ecologically distinct from other areas.

Genetic samples have been taken from steelhead collected at 15 locations within the geographic extent of the Olympic Peninsula ESU and allozyme analysis conducted for 56 polymorphic loci (Phelps et al. 1997). Many of the samples were from juveniles and in some cases may have included a mixture of summer steelhead, winter steelhead, and resident *O. mykiss*. As in the Puget Sound analysis, the consensus dendogram revealed little geographic structure among the sample groupings and bootstrap support for the groupings was generally poor.

In the absence of informative genetic analysis, we generally relied on the populations identified in WDF et al. (1993). Identification of these populations was based on the geographic isolation of spawning areas and spawn timing (WDF et al. 1993).

We identified 31 populations that historically were present within the Olympic Peninsula ESU (Table 5-3). No populations are known to have been extirpated and no new populations are known to have been established.

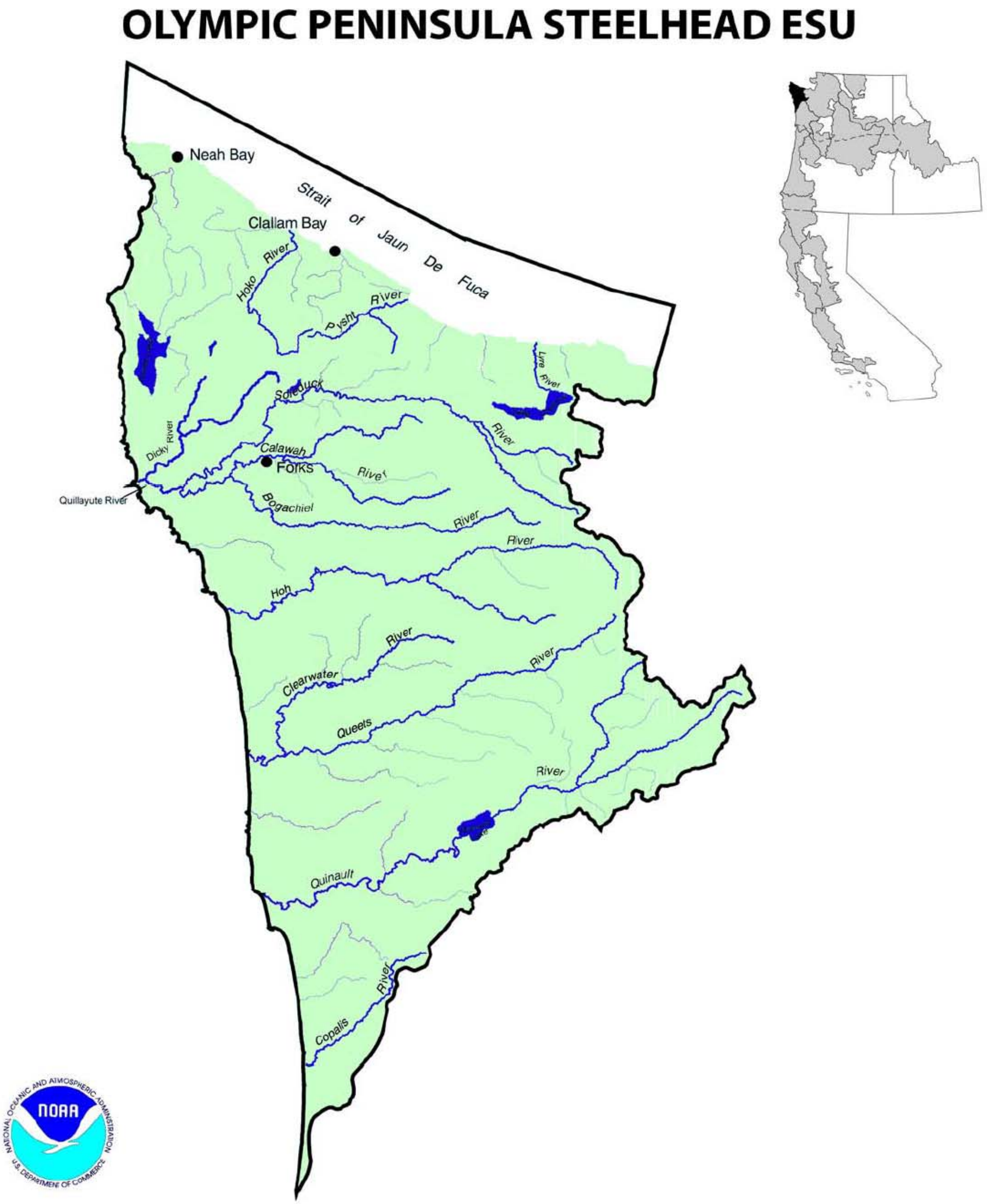


Figure 5-3. Olympic Peninsula ESU map.

Table 5-3. Olympic Peninsula region historical and extant natural steelhead populations.

Historical Population	Extant Population
Strait of Juan de Fuca	
Salt Creek/Independents Winter	Salt Creek/Independents Winter
Lyre Winter	Lyre Winter
Pysht/Independents Winter	Pysht/Independents Winter
Clallam Winter	Clallam Winter
Hoko Winter	Hoko Winter
Sekiu Winter	Sekiu Winter
Sail Winter	Sail Winter
Sooes/Ozette Basin	
Sooes/Waatch Winter	Sooes/Waatch Winter
Ozette Winter	Ozette Winter
Quillayute Basin	
Quillayute/Bogachiel Summer	Quillayute/Bogachiel Summer
Quillayute/Bogachiel Winter	Quillayute/Bogachiel Winter
Dickey Winter	Dickey Winter
Sol Duc Summer	Sol Duc Summer
Sol Duc Winter	Sol Duc Winter
Calawah Summer	Calawah Summer
Calawah Winter	Calawah Winter
Hoh Basin	
Goodman Creek Winter	Goodman Creek Winter
Mosquito Creek Winter	Mosquito Creek Winter
Hoh Summer	Hoh Summer
Hoh Winter	Hoh Winter
Kalaloch Basin	
Kalaloch Winter	Kalaloch Winter
Queets Basin	
Queets Summer	Queets Summer
Queets Winter	Queets Winter
Clearwater Summer	Clearwater Summer
Clearwater Winter	Clearwater Winter
Raft Basin	
Raft Winter	Raft Winter
Quinault Basin	
Lower Quinault/Quinault Lake Winter	Lower Quinault/Quinault Lake Winter
Quinault Summer	Quinault Summer
Upper Quinault Winter	Upper Quinault Winter
Moclips/Copalis Basins	
Moclips Winter	Moclips Winter
Copalis Winter	Copalis Winter

Hatchery Broodstock

Broodstock for hatchery programs in the Olympic Peninsula region originate from a variety of sources (Table 5-4). Broodstock of local origin is used at two hatcheries: 1) Snider Creek; and 2) Lake Quinault Hatchery. The Snider Creek program is conducted in cooperation with the Oympic Peninsula Guides Association with broodstock collected each year from the Sol Duc River. Broodstock for the Lake Quinault steelhead program are collected from Lake Quinault.

Table 5-4. Hatchery broodstock, broodstock origin, and other sources of eggs, juveniles, or adults in the last 10 years for hatchery programs located in the Olympic Peninsula region. Parenthetic C included in broodstock name indicates Chambers origin; parenthetic S indicates Skamania origin. Spawn timing is identified relative to local natural population as early (E) or normal (N).

Facility	Broodstock	Spawn Timing	Broodstock Origin	Other Sources
Hoko [1]	Hoko(C) Winter	E	Chambers Winter	Bogachiel(C) Winter
Makah NFH [2]	Sooes Winter	E	Quinault Winter	
Snider Creek	Sol Duc Winter	E	Local	
Bogachiel	Bogachiel(C) Winter	E	Chambers Winter	
Bogachiel	Bogachiel(S) Summer	E	Skamania Summer	
Quinault NFH [2]	Quinault Winter	E	Unknown	
Lake Quinault[3]	Lake Quinault Winter	N	Local	

[1] Program operated by the Makah Tribe.

[2] Program operated by the Fish and Wildlife Service.

[3] Program operated by the Quinault Indian Nation.

5.3.3 Southwest Washington

Natural Populations

The following description of the Southwest Washington ESU is primarily a summary of information from Busby et al. (1996). The range of this ESU includes all rivers draining into the major embayments of Grays Harbor, Willapa Bay, and the Columbia River up to (but not including) the Cowlitz River (Fig. 5-4). The geomorphology is characterized by the large estuarine environments developed by littoral sediment transport from the Columbia northward along the Pacific Coast. Some streams drain the temperate rain forest terrains of the Olympic Peninsula, but the apparently overriding feature is the large embayment environment common to all stocks in this ESU. Stream hydrology factors, such as gradient, presence of gravels, pools and riffles, and flow conditions are highly variable. The ESU is based on genetic data indicating that steelhead from the South Coast of Washington are distinct from those of the Olympic Peninsula. Relationships with other lower Columbia steelhead stocks were not clear at the time that the ESU was designated. Fish species in the Chehalis basin and the lowest portion of the Columbia River are similar, and sediments from the Columbia are known to be transported to Willapa Bay and Grays Harbor. This information provided the BRT with evidence of an ecological link between the South Coast of Washington and the lowest portion of the Columbia River basin.

We have further subdivided the Southwest Washington ESU into three components, Grays Harbor, Willapa, and Columbia Mouth, in recognition of the significant biological variation within the ESU and the size of the Chehalis Basin. The Chehalis River has the largest drainage area of any river in western Washington and includes the only summer steelhead populations in the ESU.

Genetic samples have been taken from steelhead collected at 15 locations within the geographic extent of the Southwest Washington ESU and allozyme analysis conducted for 56 polymorphic loci (Phelps et al. 1997). Many of the samples were from juveniles and in some cases may have included a mixture of summer steelhead, winter steelhead, and resident *O. mykiss*. A preliminary reanalysis using methods described in the Puget Sound section was conducted to evaluate the relationship between the samples. The consensus dendrogram revealed a geographic structure among the sample groupings with samples from each of the subregions (Grays Harbor, Willapa, Columbia Mouth) tending to form a group (Fig. 5-5).

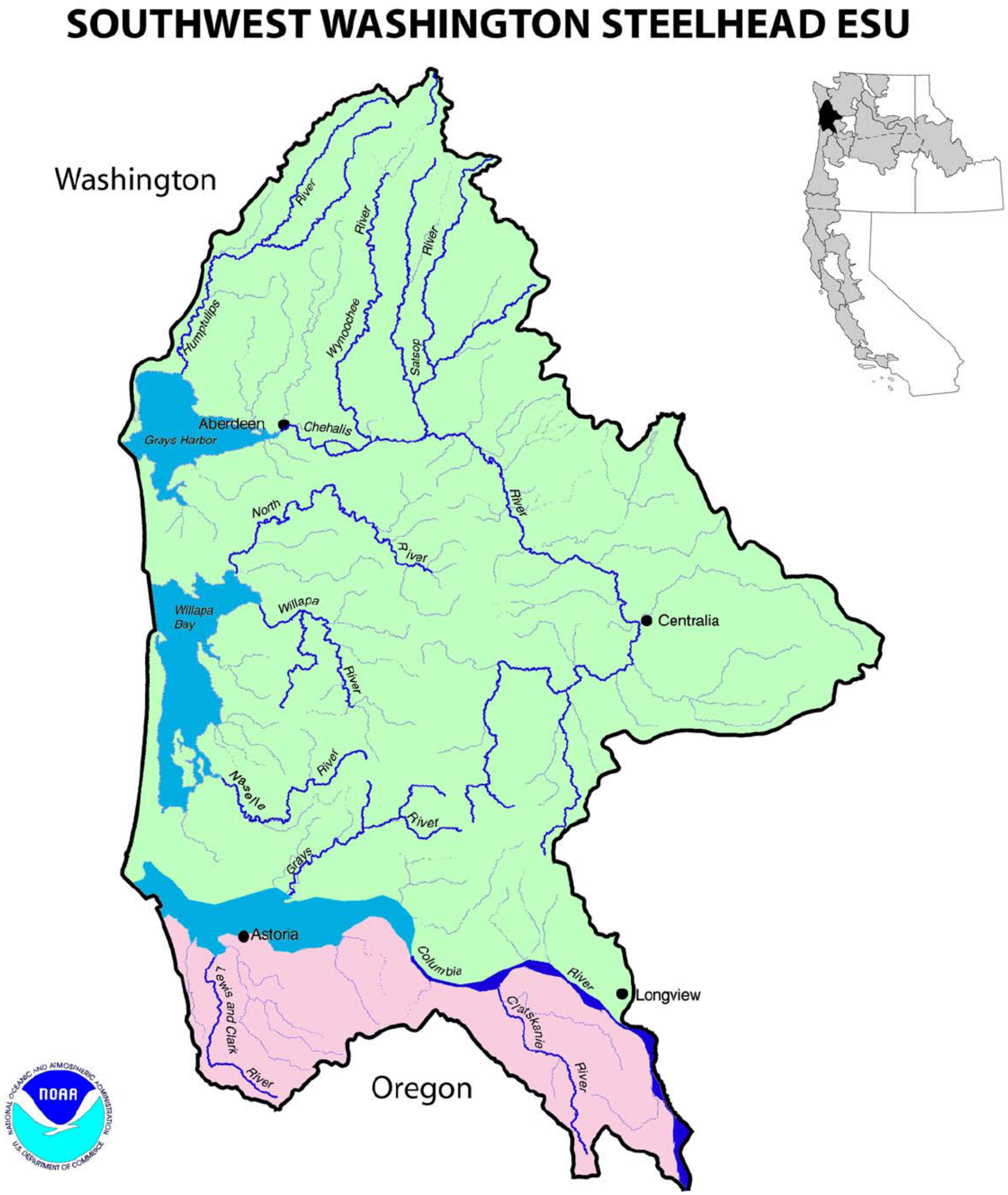


Figure 5-4. Southwest Washington ESU map.

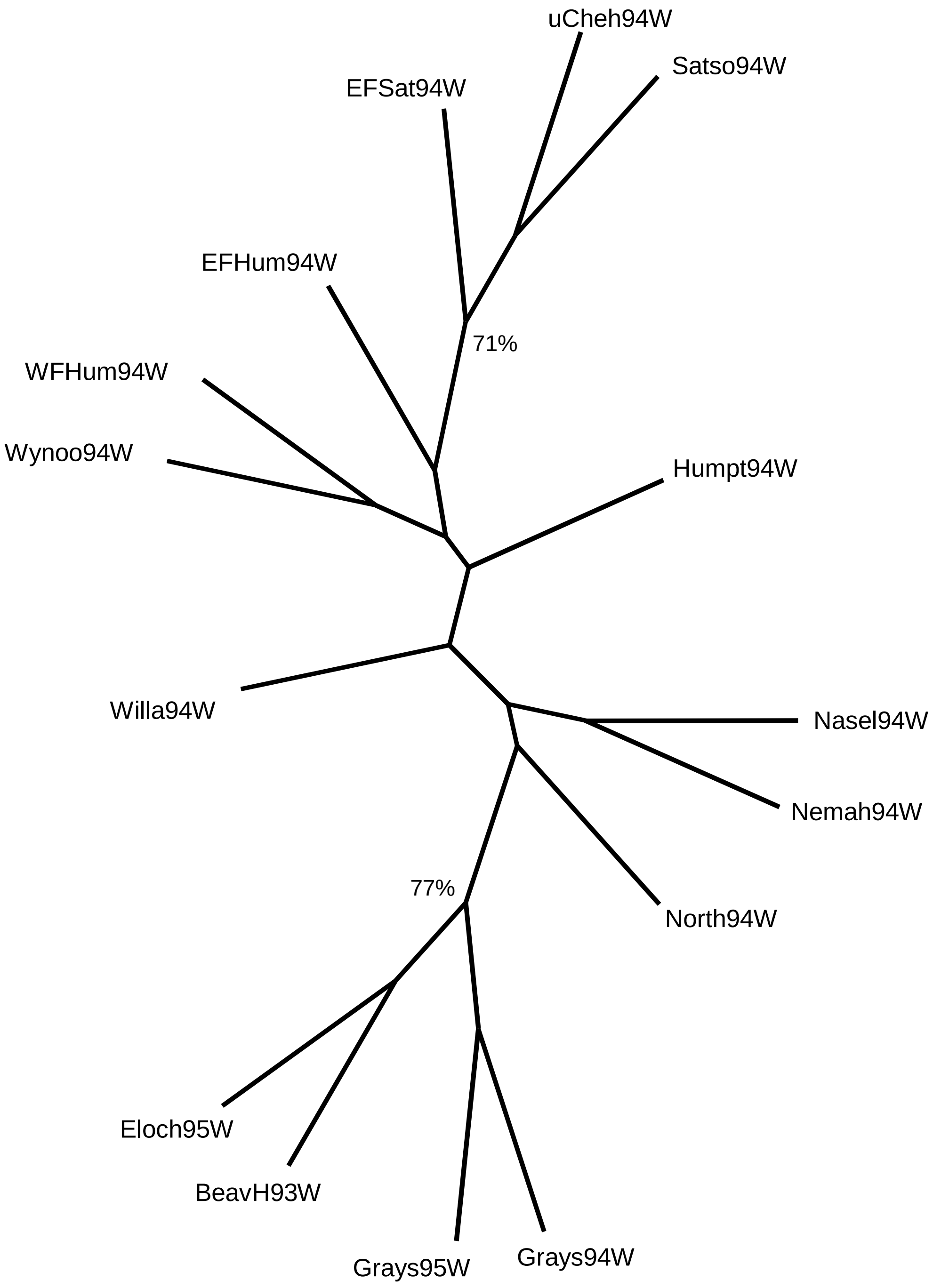


Figure 5-5. Consensus Neighbor-Joining tree for southwestern Washington coast steelhead collections using pairwise Cavalli-Sforza & Edwards chord distances (nodes with more than 60% bootstrap support labeled; using data for 56 allozyme loci).

In the absence of conclusive genetic analysis, we relied on the populations identified in WDF et al. (1993). Identification of these populations was based on the geographic isolation of spawning areas and spawn timing (WDF et al. 1993).

We identified 10 historical populations in Grays Harbor, 6 populations in Willapa Bay, and 3 populations in the Columbia Mouth subregion (Table 5-6). No populations are known to have been extirpated, and no new populations are known to have been established.

Table 5-6. Southwest Washington region historical and extant natural steelhead populations.

Historical Population	**Extant Population**
Grays Harbor	
Chehalis Summer	Chehalis Summer
Chehalis Winter	Chehalis Winter
Hoquiam Winter	Hoquiam Winter
Humptulips Summer	Humptulips Summer
Humptulips Winter	Humptulips Winter
Satsop Winter	Satsop Winter
Skookumchuck/Newaukum Winter	Skookumchuck/Newaukum Winter
South Bay Winter	South Bay Winter
Wishkah Winter	Wishkah Winter
Wynoochee Winter	Wynoochee Winter
Willapa Bay	
Bear River Winter	Bear River Winter
Naselle Winter	Naselle Winter
Nemah Winter	Nemah Winter
North/Smith Winter	North/Smith Winter
Palix Winter	Palix Winter
Willapa Winter	Willapa Winter
Columbia Mouth[1]	
Mill-Abernathy-Germany Winter	Mill-Abernathy-Germany Winter
Skamokawa-Elochoman Winter	Skamokawa-Elochoman Winter
Grays Winter	Grays Winter

[1] Steelhead stocks in the lower Columbia River basin from the mouth up to, but not including the Cowlitz River, are part of the Southwest Washington ESU; those from the Cowlitz through the Wind River are part of the Lower Columbia River ESU.

Hatchery Broodstock

Hatchery programs in the Grays Harbor region use a variety of local and nonlocal broodstock (Table 5-7). The Bingham Creek winter steelhead program was initiated with broodstock captured from the Satsop River. Current broodstock are a mixture of both natural-origin and adult returns from the initial releases from this program, with a minimum of 10% of the broodstock of natural-origin. The Eight Creek Acclimation Pond program is similar, except that the initial source of broodstock was natural-origin adults collected in the Chehalis River above the confluence of the Newaukum River.

All artificial production programs for winter steelhead in the Willapa and Columbia Mouth subregions use broodstock of Chambers origin (tables 5-8 and 5-9).

Table 5-7. Hatchery broodstock, broodstock origin, and other sources of eggs, juveniles, or adults in the last 10 years for hatchery programs located in the Grays Harbor region. Parenthetic C included in broodstock name indicates Chambers origin; parenthetic S indicates Skamania origin. Spawn timing is identified relative to local natural population as early (E) or normal (N).

Facility	Broodstock	Spawn Timing	Broodstock Origin	Other Sources
Humptulips	Humptulips(C) Winter	E	Chambers Winter	Bogachiel(C) Winter Quinault Winter
Lake Aberdeen	VanWinkle(C) Winter	E	Chambers Winter	Bogachiel(C) Winter Humptulips(C) Winter
Lake Aberdeen	Wynoochee Winter	N	Local	
Lake Aberdeen	VanWinkle(S) Summer	E	Skamania Summer	Skykomish(S) Summer
Bingham	Bingham Winter	N	Local	
Skookumchuck	Skookumchuck Winter	N	Local	
Eight [1]	Upper Chehalis Winter	N	Local	

[1] Cooperative program with the Upper Chehalis Fisheries Enhancement Group.

Table 5-8. Hatchery broodstock, broodstock origin, and other sources of eggs, juveniles, or adults in the last 10 years for hatchery programs located in the Willapa Bay subregion. Parenthetic C included in broodstock name indicates Chambers origin; parenthetic S indicates Skamania origin. Spawn timing is identified relative to local natural population as early (E) or normal (N).

Facility	Broodstock	Spawn Timing	Broodstock Origin	Other Sources
Forks Creek	Forks(C) Winter	E	Chambers Winter	Bogachiel(C) Winter
Naselle	Naselle(C) Winter	E	Chambers Winter	Bogachiel(C) Winter Willapa(C) Winter

Table 5-9. Hatchery broodstock, broodstock origin, and other sources of eggs, juveniles, or adults in the last 10 years for hatchery programs located in the Columbia River Mouth subregion. Parenthetic C included in broodstock name indicates Chambers origin; parenthetic S indicates Skamania origin. Spawn timing is identified relative to local natural population as early (E) or normal (N).

Facility	Broodstock	Spawn Timing	Broodstock Origin	Other Sources
Elochoman	Elochoman(C) Winter	E	Chambers Winter	Kalama(C) Winter Lewis(C) Winter
Beaver Creek [1]	Elochoman(C) Winter	E	Chambers Winter	Kalama(C) Winter Lewis(C) Winter

[1] Program identified for historical reference; facility closed in 1999.

5.3.4 Lower Columbia River

Natural Populations

The following description of the Lower Columbia River ESU is primarily a summary of information from Busby et al. (1996). The Lower Columbia ESU includes the Columbia River and its tributaries from the Cowlitz River up to and including the Wind River on the Washington side of the Columbia River, and from the lower Willamette River (below Willamette Falls) through the Hood River (inclusive) in Oregon (Fig. 5-6). The Washington portion is currently dominated by the major habitat disruption and recovery following the 1980 Mt. St. Helens eruption, and the influences of habitat alterations associated with urbanization and construction of Bonneville Dam. Genetic analyses available to the BRT indicated that lower Columbia steelhead were different from those in coastal streams of Oregon and Washington and from those in the upper Willamette River (above Willamette Falls). Steelhead from the Washougal, Wind and Big White Salmon rivers were genetically distinct from those originating from the south coast of Washington. Streams in this ESU drain the western Cascades from the southwestern flanks of Mt. Rainier to Mt. Hood.

The WLCTRT (Myers et al. 2004) identified 19 historical populations of steelhead in the Washington component of the Lower Columbia ESU (Table 5-9). Of these, 14 populations are believed to be currently extant. Four populations of winter steelhead on the Cowlitz River (Cispus, Tilton, Upper Cowlitz, Lower Cowlitz) are believed to have existed historically. However, construction of the Mayfield Dam in 1968 eliminated access to spawning habitat for these populations. Returning adults were taken to the Cowlitz Trout Hatchery to maintain the populations and initiate a late-winter steelhead artificial production program. The resultant late-winter population spawning in the lower Cowlitz River likely includes genetic representation from each of the four historical populations. The North Fork Lewis summer population was likely extirpated after construction of three dams on the North Fork Lewis River eliminated access to 80% of historical spawning and rearing habitat (Myers et al. 2004).

Introgression with hatchery fish of Chambers Creek type origin may have occurred in several of the populations. Although the genetic data are limited, a cluster analysis of samples of winter steelhead from the NF Toutle (Green) (labeled GrTou96W in Fig. 5-8) indicated similarity with samples from the Cowlitz early-winter hatchery program (a Chambers Winter type origin, labeled CowH96W in Fig. 5-8), Cedar Creek-North Fork Lewis (of Chambers Winter type origin, labeled CeLew96W in Fig. 5-8), and the Skamania hatchery winter program (of Chambers Winter type origin, labeled SkamH93W in Fig. 5-8). Potential effects of hatchery programs are discussed in greater detail in Chapter 7.

Figure 5-7. Lower Columbia River ESU map.

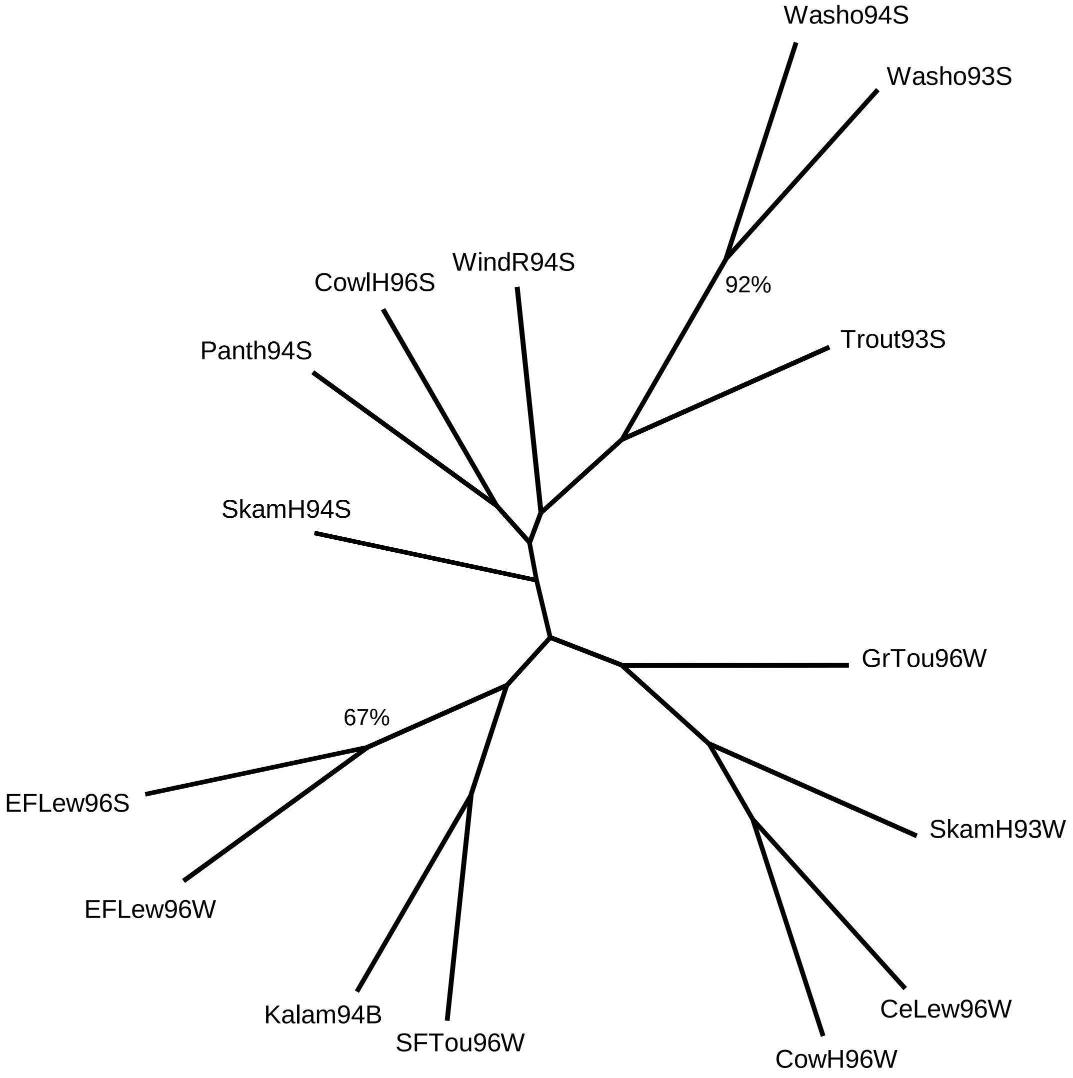


Figure 5-8. Consensus Neighbor-Joining tree for lower Columbia River steelhead collections using pairwise Cavalli-Sforza & Edwards chord distances (nodes with more than 60% bootstrap support labeled; using data for 56 allozyme loci).

Table 5-9. Lower Columbia River region historical and extant natural steelhead populations.

Historical Population	Extant Population
Cispus Winter	Cowlitz River. Composite population resulted from collection of adults for broodstock after construction of Mayfield Dam.
Tilton Winter	
Upper Cowlitz Winter	
Lower Cowlitz Winter	
NF Toutle (Green) Winter	Mainstem/NF Toutle Winter. NF Toutle (Green) population split into two components (Mainstem/NF Toutle Winter and Green Winter) based on analysis that indicates sufficient habitat is present within each component to support an independent population.
	Green Winter. Myers et al. (2004) state genetic analysis "suggest a strong similarity" between sample from Green and nonnative hatchery population. Subsequent WDFW analysis suggest more limited similarity between samples.
SF Toutle Winter	SF Toutle Winter. Genetic analysis indicates an association with other indigenous steelhead populations in this ESU, but significantly different than NF Toutle (Myers et al. 2004).
Coweeman Winter	Coweeman Winter. No genetic analysis available.
Kalama Winter	Kalama Winter. Genetic analysis of a mixed sample of summer and winter juveniles indicates that the population is distinct from hatchery populations (Myers et al. 2004).
Kalama Summer	Kalama Summer. Genetic analysis of a mixed sample of summer and winter juveniles indicates that the population is distinct from hatchery populations (Myers et al. 2004).
NF Lewis Winter	NF Lewis Winter. Myers et al. (2004) state genetic analysis "suggest a strong similarity" between sample from NF Lewis and nonnative hatchery population. Subsequent WDFW analysis suggest more limited similarity between samples.
EF Lewis Winter	EF Lewis Winter. Genetic analysis indicates a strong association with other indigenous steelhead populations in this ESU, but significantly different than NF Lewis Winter (Myers et al. 2004).
NF Lewis Summer	Potentially Extirpated. Construction of 3 dams on the North Fork Lewis River eliminated access to 80% of historical spawning and rearing habitat (Myers et al. 2004).
EF Lewis Summer	EF Lewis Summer. Genetic analysis indicates a strong association with other indigenous steelhead populations in this ESU (Myers et al. 2004).

Table 5-9 (continued). Lower Columbia River region historical and extant natural steelhead populations.

Historical Population	Extant Population
Salmon Creek Winter	Salmon Creek Winter. No genetic analysis available.
Washougal Winter	Washougal Winter. No genetic analysis available.
Washougal Summer	Washougal Summer. Genetic analysis indicates that greatest similarity is to Wind summer population.
Lower Gorge Winter	Lower Gorge Winter. No genetic analysis available.
Upper Gorge Winter	Wind Winter is component in Washington. No genetic analysis available.
Wind Summer	Wind Summer. Genetic analysis from three samples inconclusive.

Hatchery Broodstock

Hatchery programs in the Lower Columbia region typically use broodstock of Chambers Creek origin for winter steelhead programs and Skamania origin for summer steelhead programs (Table 5-10). Two exceptions are the Cowlitz Late Winter program and two programs on the Kalama that collect natural-origin broodstock. Broodstock collection for the Cowlitz Late Winter program was initiated after the construction of Mayfield Dam in 1968 and likely included representation from all four natural populations of winter steehead in the Cowlitz River. The Kalama Winter and Kalama Summer programs are maintained with steelhead collected from the Kalama River.

Table 5-10. Hatchery broodstock, broodstock origin, and other sources of eggs, juveniles, or adults in the last 10 years for hatchery programs located in the Lower Columbia River region. Parenthetic C included in broodstock name indicates Chambers origin; parenthetic S indicates Skamania origin. Spawn timing is identified relative to local natural population as early (E) or normal (N).

Facility	Broodstock	Spawn Timing	Broodstock Origin	Other Sources
Cowlitz Trout	Cowlitz(C) Winter	E	Chambers Winter	
Cowlitz Trout	Cowlitz Late Winter	N	Local	
Cowlitz Trout	Cowlitz(S) Summer	E	Skamania Summer	
Kalama Falls	Kalama(C) Winter	E	Chambers Winter	Elochoman(C) Winter Beaver(C) Winter
Kalama Falls	Kalama Winter	N	Local	
Kalama Falls	Kalama Summer	N	Local	
Kalama Falls	Kalama(S) Summer	E	Skamania Summer	
Merwin	Lewis(C) Winter	E	Chambers Winter	
Merwin	Lewis(S) Summer	E	Skamania Summer	
Skamania	Skamania(C) Winter	E	Chambers Winter	Elochoman(C) Winter Lewis(C) Winter Beaver(C) Winter Kalama(C) Winter
Skamania	Skamania(S) Summer	E	Skamania Summer	

5.3.5 Middle Columbia River

The following description of the Middle Columbia River ESU is primarily a summary of information from Busby et al. (1996). The Middle Columbia River ESU extends upstream from the Wind River through the Yakima River in Washington (excluding the Snake River System) and includes tributaries to the Columbia River originating in Oregon up through the Walla Walla River (Fig. 5-9). This intermontane area of Columbia plateau basalts is characterized by much drier weather and harsh seasonal temperature extremes, with little moderation from the shrub-dominated vegetation cover. Steelhead in the ESU are considered part of an inland genetic lineage. Genetic analyses available to the ICRT showed that steelhead from middle Columbia streams are distinct from Snake River populations. Analyses of naturally spawning steelhead from the upper Columbia were not available to the BRT for comparison with middle Columbia stocks; however Wells Hatchery steelhead (upper Columbia basin) were known to be distinct from middle Columbia steelhead. Inclusion of Klickitat and Yakima steelhead in this ESU was debated. The Klickitat has native summer and winter steelhead like the larger systems in the Lower Columbia ESU. No winter steelhead are seen upstream from the Klickitat. Klickitat steelhead were ultimately included in the Middle Columbia ESU based on their genetic similarity to other Middle Columbia stocks. Similarly, although Yakima steelhead were considered for inclusion in the Upper Columbia ESU, they were ultimately placed in the Middle Columbia ESU due to their genetic similarity to Klickitat steelhead and because of similarities to Middle Columbia life history and habitat features.

Nine historical populations have been identified in the Washington component of the Middle Columbia River ESU (Table 5-11)(ICTRT 2003; McClure and Cooney, pers. comm.). Eight of the nine populations are extant. The White Salmon Summer population was extirpated after construction in 1913 of the Condit Dam blocked access to spawning habitat.

Analysis of microsatellite genetic data suggests slight introgression of Skamania-type steelhead into the Naches and Upper Yakima populations (Busack et al. 2005). Samples of approximately 100 juvenile steelhead were collected at Roza Dam (sampled in 2000, 2001, and 2003), the Naches River (sampled in 2004), Toppenish Creek (sampled in 2000 and 2001), and Satus Creek (sampled in 2000 and 2001). Analysis using the STRUCTURE program (Pritchard et al. 2000) indicated that 6-9% of the multi-locus genotype of an average steelhead juvenile sampled in the Naches River or at Roza Dam was consistent with Skamania-type fish. The range was lower, 2-4%, for the samples from Toppenish Creek and Satus Creek. These slight relationships to Skamania-type fish could also be artifacts of shared polymorphisms or shared ancestry rather than introgression (Utter 1998; Busack et al. 2005).

MIDDLE COLUMBIA RIVER STEELHEAD ESU

Figure 5-7. Middle Columbia River ESU map.

Introgression with hatchery-origin rainbow trout may also have occurred in the Naches and Upper Yakima populations (Campton and Johnston 1985; Phelps et al. 2000). Phelps et al. (2000) concluded from an admixture analysis of parental source (Long 1991) that hatchery-origin rainbow trout were responsible for more than 10% of the gene pool for samples from Wilson Creek (Upper Yakima tributary) and the Roza trap. Potential effects of hatchery programs are discussed in greater detail in Chapter 7.

Table 5-11. Middle Columbia River region historical and extant natural steelhead populations.

Historical Population	Extant Population
White Salmon Summer	None. Condit Dam, constructed in 1913, blocked passage to spawning habitat.
Klickitat Summer-Winter	Klickitat Summer-Winter. Genetic analysis indicates differentiation from other populations (Phelps et al. 2000). Spawning area overlap and genetic samples from the sport fishery do not show strong segregation of summer and winter- run fish (ICTRT 2003).
Rock Creek Summer	Rock Creek Summer. No genetic analysis available.
Walla Walla Summer	Walla Walla Summer. Analysis indicates genetically distinct from Touchet Summer (ICTRT 2003) (Narum et al. In press).
Touchet Summer	Touchet Summer. Analysis indicates genetically distinct from Walla Walla Summer (ICTRT 2003) (Bumgarner et al. 2004).
Satus Creek Summer	Satus Creek Summer. Analysis indicates genetically distinct from other populations in the Yakima subbasin (McClure and Cooney, pers. comm.).
Toppenish Creek Summer	Toppenish Creek Summer. Analysis indicates genetically distinct from other populations in the Yakima subbasin (McClure and Cooney, pers. comm.).
Naches Summer	Naches Summer. Analysis indicates genetically distinct from other populations in the Yakima subbasin (ICTRT 2003). Some introgression with hatchery-origin rainbow trout and steelhead may have occurred (Phelps et al. 2000; Busack et al. 2005).
Upper Yakima Summer	Upper Yakima Summer. Analysis indicates genetically distinct from other populations in the Yakima subbasin (ICTRT 2003) with substantial gene flow between resident and anadromous *O. mykiss* (Pearsons et al. 1998). Some introgression with hatchery-origin rainbow trout and steelhead may have occurred (Phelps et al. 2000; Busack et al. 2005).

Hatchery Broodstock

The Touchet Summer endemic steelhead program was initiated in 2000 and uses broodstock collected from the Touchet River (Table 5-12). Program protocols require that no more than 35% of the broodstock is to be of hatchery-origin.

Table 5-12. Hatchery broodstock, broodstock origin, and other sources of eggs, juveniles, or adults in the last 10 years for hatchery programs located in the Middle Columbia River region. Spawn timing is identified relative to local natural population as early (E) or normal (N).

Facility	Broodstock	Spawn Timing	Broodstock Origin	Other Sources
Lyons Ferry	Touchet Summer	N	Local	
Lyons Ferry	Lyons Ferry	E	Wells Wallowa[1]	

[1] The Wallowa program was initiated with adults collected at Ice Harbor Dam in 1976, adults collected at Little Goose Dam in 1977-1978, and embryos from Pahsimeroi Hatchery in 1979 (Whitesel et al. 1998).

5.3.6 Upper Columbia River

The following description of the Upper Columbia River ESU is primarily a summary of information from Busby et al. (1996). The Upper Columbia River ESU encompasses the Columbia River System upstream of the Yakima River to the U.S.-Canada border. Passage up the Columbia River itself is blocked at Chief Joseph Dam (Fig. 5-8). The rivers in this ESU drain the Northern Cascades and the Okanogan Highlands physiographic provinces, which feature a complex geology that includes glacial, volcanic and marine terrains. These have been deeply incised to produce generally low gradient streams beyond the headwaters. Extremes in temperature, precipitation and snowpack accumulation produce erratic cold water temperatures and stream flows which tend to extend growth and maturation periods beyond those typical of the coastal rivers of the Pacific Northwest. Life histories of Upper Columbia steelhead are similar to those of other inland populations in that after returning from saltwater, most hold in freshwater for nearly a year before spawning. Although most steelhead smolt at age two (Wenatchee 66%; Methow and Okanogan 78%) in the Upper Columbia region (Murdoch, pers. comm.), smolting can take place as late as age seven (Mullan et al. 1992). This prolonged juvenile freshwater residence is probably the result of very cold stream temperatures. Due to a lack of trapping facilities, little is known about steelhead destined for the Entiat River.

Eleven populations are believed to have existed in this ESU historically (Table 5-13)(ICTRT 2003; McClure and Cooney, pers. comm.). Six of the populations (Sanpoil, Kettle/Colville, Pend Oreille, Kootenay, Spokane, and Hangman) were extirpated after construction of the Grand Coulee Dam in 1939 blocked access to more than 50% of the river miles previously accessible to steelhead originating from this ESU (NRC 1996). The status of the Okanogan and Crab Creek populations is uncertain. Analysis suggests that sufficient habitat was present historically to support independent populations and limited surveys have revealed small numbers of natural-origin fish using Omak Creek in recent years (ICTRT 2003; Arterburn, pers. comm.).

Genetic analysis on three of the extant populations (Wenatchee, Entiat, and Methow) has been difficult for three reasons: 1) the Grand Coulee Fish Maintenance Project (Fish and Hanavan 1948) probably resulted in the mixing of steelhead from all areas upstream of Rock Island Dam; 2) artificial production programs released juvenile steelhead that originated from broodstock of unknown origin collected at Wells Dam or Priest Rapids Dam; and 3) genetic samples were often small and collected from juvenile fish (Chapman et al. 1994; Ford et al. 2001). However, three general conclusions were: 1) introgression of steelhead of Skamania-origin has not occurred (Chapman et al.

Figure 5-12. Upper Columbia River ESU map.

1994); 2) there are significant differences in allele frequencies among the samples (Chapman et al. 1994; Ford et al. 2001); and 3) there is little or no geographic structure to observed differences in allele frequencies (Chapman et al. 1994; Ford et al. 2001).

Table 5-13. Upper Columbia River region historical and extant natural steelhead populations.

Historical Population	Extant Population
Crab Creek	Uncertain. Population identification based on size of drainage area, spawning distribution, and presence of resident *O. mykiss* that showed high genetic differentiation from hatchery stocks (Bettles 2004). Resident component likely more dominant and critical to the long-term persistence of the population (ICTRT 2003).
Wenatchee	Wenatchee. Population identification based on genetic data, size of drainage area, and spawning distribution (ICTRT 2003).
Entiat	Entiat. Population identification based on genetic data, size of drainage area, and spawning distribution (ICTRT 2003).
Methow	Methow. Population identification based on genetic data, size of drainage area, and spawning distribution (ICTRT 2003).
Okanogan	Uncertain. As limited number of natural-origin returns with a large proportion of hatchery-origin spawners (ICTRT 2003).
Sanpoil	Extirpated.
Kettle/Colville	Extirpated.
Pend Oreille	Extirpated.
Kootenay	Extirpated.
Spokane	Extirpated.
Hangman Creek	Extirpated.

Hatchery Broodstock

Broodstock collection for hatchery programs throughout the Upper Columbia region occur at the Eastbank and Wells hatcheries (Table 5-14).

The Eastbank steelhead program was modified in 1998 to collect hatchery and natural-origin adults (goal is 50% natural-origin) at Dryden and Tumwater dams on the Wenatchee River. For brood years 1997 through 2002, an average of over 50% of the broodstock collected was of natural-origin (Murdoch et al. 1998; 2000a; 2000b; 2001; Tonseth et al. 2004).

The Wells Hatchery steelhead program was initiated in the late-1960s with broodstock captured at Priest Rapids Dam. Broodstock in more recent years have been collected at Wells Dam and at the Wells Hatchery, with contributions from both hatchery and natural-origin adults (Chapman et al. 1994; Snow 2004). The Wells steelhead program broodstock collection goal was modified in 2003 to include 33% natural-origin adults.

In 2003, the Colville Tribes initiated a local broodstock collection program, collecting steelhead returning to Omak Creek (Arterburn, pers. comm.). Eggs are incubated and juvenile steelhead are reared at the Colville Trout Hatchery. This is a conservation program with the goal of releasing 20,000 smolts in the Okanogan subbsasin.

Table 5-14. Hatchery broodstock, broodstock origin, and other sources of eggs, juveniles, or adults in the last 10 years for hatchery programs located in the Upper Columbia region. Spawn timing is identified relative to local natural population as early (E) or normal (N).

Facility	Broodstock	Spawn Timing	Broodstock Origin	Other Sources
Eastbank	Eastbank	E	Wenatchee[1]	Wells Priest Rapids Dam [2]
Wells	Wells	E	Priest Rapids Dam	
Cassimer Bar	Okanogan	N	Local [3]	

[1] Broodstock collected at Dryden and Tumwater dams.

[2] Hatchery and natural-origin broodstock collected at Priest Rapids Dam for the 1997 brood year.

[3] Program operated by the Confederated Tribes of the Colville Reservation; broodstock collected in Omak Creek.

5.3.7 Snake River Basin

The following description of the Snake River ESU is primarily a summary of information from Busby et al. (1996). The Snake River ESU extends from the Snake River mouth in SE Washington into NE Oregon and much of Idaho (Fig. 5-13). Streams originate in the area of mature, eroded landscape dominated by the exposed granitic terrains of the large Idaho Batholith. This results in rivers draining extensive, open, low relief areas in a warmer and more alkaline setting than the other geographic regions. Subbasins in the Washington component of the ESU differs in that the streams arise from the relatively low elevation, basalt dominated Blue Mountains. This ESU also has migration distances and spawning elevations that are generally greater than the other populations in the state. Most of these populations are thought to be fairly well isolated from populations outside the Snake basin. Genetic and meristic data available to the BRT both indicated that Snake basin steelhead are distinct from those outside the basin.

The ICTRT identified 40 populations of steelhead that historically existed in the Snake River Basin ESU (McClure and Cooney, pers. comm.). Only four of those populations have spawning areas located at least partially in Washington (Table 5-15): 1) Tucannon; 2) Asotin Creek; 3) Lower Grande Ronde; and 4) Joseph Creek. Additional small aggregations of spawning steelhead utilize small streams that enter the Snake between the Tucannon River and the Oregon state boundary. These groups do not meet the criteria for a population as defined by the ICTRT, and therefore were grouped based on proximity to identified populations (e.g., Alpowa and Almota were grouped with Asotin; Couse and Tenmile were grouped with Asotin).

Table 5-15. Snake River Basin region historical and extant natural steelhead populations.

Historical Population	Extant Population
Tucannon	Tucannon. Genetic analyses indicate similarity with Asotin; populations identified as independent based on distance between spawning areas (ICTRT 2003).
Asotin Creek	Asotin Creek. See Tucannon comments.
Lower Grande Ronde	Lower Grande Ronde. Genetic samples from this area formed a distinct cluster and spawning areas were well-separated from other potential populations (ICTRT 2003).
Joseph Creek	Joseph Creek. Genetic samples from this area formed a distinct cluster and spawning areas were well-separated from other potential populations (ICTRT 2003).

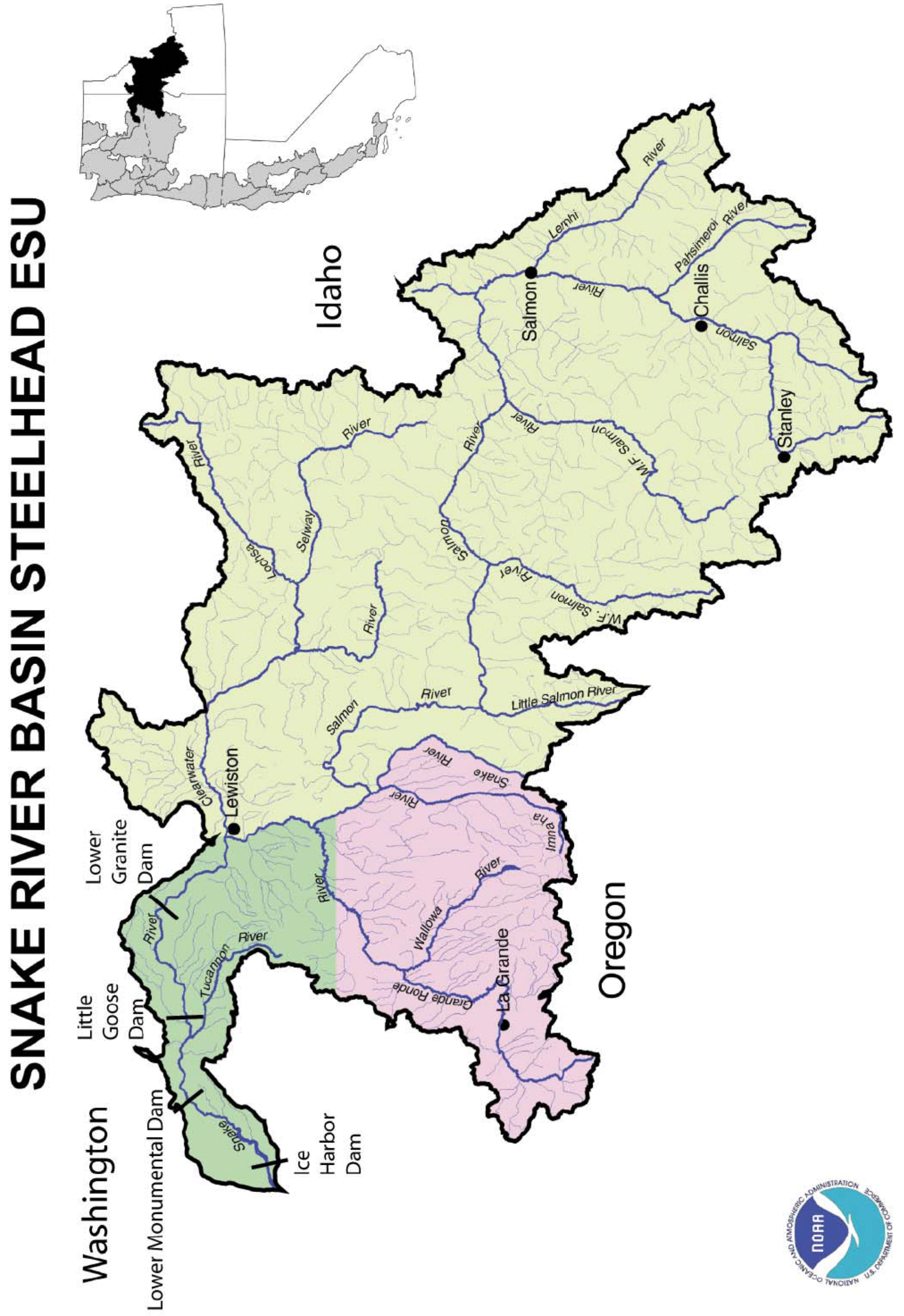


Figure 5-13. Snake River Basin ESU map.

Hatchery Broodstock

The Wallowa stock is the orginal source of broodstock for several WDFW and ODFW hatchery programs (Table 5-16). It was originally derived steelhead trapped at Ice Harbor and Little Goose dams (Whitesel et al. 1998). The stock is therefore likely made up of both “A” and “B” run steelhead from the Snake River basin, and could include fish from Asotin, Clearwater, Salmon and Grande Ronde basins.

The Cottonwood Acclimation Pond program was initiated in 1984 with the Wallowa stock. A permanent adult trapping site was installed in Cottonwood Creek to trap hatchery broodstock beginning in 1992. Prior to that and for a few years following, WDFW received eggs from ODFW in order to reach program goals.

The Lyons Ferry steelhead program was initiated in 1982 using Wallowa and Wells broodstock. In subsequent years, returning adult steelhead were trapped at the Lyons Ferry Hatchery. Because of the location of the broodstock collection site relative to other hatchery programs in the Snake Basin, Lyons Ferry broodstock is likely to have included adults of Skamania (likely very small contribution), Pahsimeroi (contributed in two years), Oxbow (contributed in two years), and Clearwater origin (likely small contribution)(Schuck 1998; Schuck pers. comm.).

The Tucannon endemic broodstock program was initiated in 2000 in response to concerns that had been raised about the non-local nature of the steelhead broodstock used at the Lyons Ferry Hatchery. Natural-origin broodstock are captured at the Lower Tucannon Trap located at rkm 17.7 (Bumgarner et al. 2004).

Table 5-16. Hatchery broodstock, broodstock origin, and other sources of eggs, juveniles, or adults in the last 10 years for hatchery programs located in the Snake Basin region. Spawn timing is identified relative to local natural population as early (E) or normal (N).

Facility	Broodstock	Spawn Timing	Broodstock Origin	Other Sources
Cottonwood	Cottonwood	N	Wallowa[1]	
Lyons Ferry	Lyons Ferry	E	Wells Wallowa[1]	
Lyons Ferry	Tucannon	N	Local	

[1] The Wallowa program was initiated with adults collected at Ice Harbor Dam in 1976, adults collected at Little Goose Dam in 1977-1978, and embryos from Pahsimeroi Hatchery in 1979 (Whitesel et al. 1998).

5.4 Discussion

Limitations of Population Analysis

Accurate identification of steelhead populations requires collecting and carefully analyzing biological data on spawning locations, spawn timing, and genetic characteristics of spawning aggregations. In our review of the data available for steelhead in Washington, we found numerous cases where basic biological data are currently not available. Exact spawning locations are not known for 17 (or 12%) of currently identified populations. Good data for spawn timing are not available for 29 (or 21%) of the populations. Improved confidence in our definition of populations will require the identification, prioritization, and collection of additional data on spawning location, spawn timing, and genetic characteristics.

Genetic analysis is potentially a powerful tool for identifying population and metapopulation structure. However, results from allozyme analysis of samples from juveniles in Puget Sound, the Olympic Peninsula, and Southwest Washington were often inconclusive. The lack of geographic structure and the inconsistent grouping of samples could result from several factors. These include: 1) insufficient genetic variability in the 56 loci used for the analysis; 2) samples that include a mixture of run timing (summer and winter), life history types (resident and anadromous), or populations; 3) insufficient sample sizes; 4); variable but significant levels of genetic introgression from one or both hatchery strains of steelhead (Chambers Creek hatchery winter-run and Skamania Hatchery summer-run) historically released into many of these rivers; or 5) a population structure characterized by substantive gene flow across broad geographic areas. Although the latter explanation cannot be completely dismissed, population structure has been identified at a relatively fine scale in western Washington when steelhead samples are carefully selected and analyzed (Marshall et al. 2004; Kassler and Hawkins, pers. comm.).

Population structure should be frequently reviewed to maximize the value of new data collection efforts and rapidly improving techniques for genetic analysis. Careful review and analysis of genetic and other biological data by the WLCTRT and ICTRT has resulted in substantial improvement in our understanding of the population structure of steelhead in the Columbia Basin. A systematic review of the structure of populations in the Puget Sound, Olympic Peninsula, and Southwest Washington ESUs has not been conducted since 1992. Building on the tools developed by the WLCTRT and ICTRT, a consistent procedure for evaluating population structure should be defined and applied in these ESUs.

Population Structure

The hierarchy in the genetic organization of steelhead is based on locally adapted populations. Maintenance of this hierarchy assures not only the short-term production of steelhead from natural habitat, but also the continuing evolution and preservation of the species. Our analysis indicates that substantial loss of historical populations has occurred in some ESUs in Washington (Table 5-17). The percent of historical populations remaining in each ESU ranges from 100% in the Olympic Peninsula and Southwest Washington ESUs to only 45% in the Upper Columbia ESU. The loss of historical anadromous populations has generally resulted from the construction of dams that block access to spawning areas. However, continued human population growth and development in Washington have the potential to place additional populations at risk through a variety of mechanisms (Lackey 2003).

Table 5-17. Summary of historical population, number of historical populations remaining, and percent of historical populations remaining.

ESU	Number of Historical Populations	Number of Historical Populations Remaining	% of Historical Populations Remaining
Puget Sound	51	49	96%
Olympic Peninsula	31	31	100%
Southwest Washington	19	19	100%
Lower Columbia River [1]			
Within Washington	19	14 [2]	74%
Total ESU	28	23	82%
Middle Columbia River [3]			
Within Washington	9	8	89%
Total ESU	20	18	90%
Upper Columbia River [3]	11	5	45%
Snake River Basin [3]			
Within Washington	4	4	100%
Total ESU	40	25	62%
All			
Within Washington	144	130	90%
Total ESU	200	170	85%

[1] Source is Myers et al. (2004)
[2] Based on loss of 4 winter populations in the Cowlitz River. A late-run winter steelhead population on the Cowlitz River may retain some characteristics of all historical populations.
[3] Source is McClure and Cooney (pers. comm.).

Riddell (1993) anticipated many of the current questions posed in recovery planning by suggesting that resource managers would more frequently be asked “what to conserve” and policy makers would have to consider “at what cost”. Riddell noted that the simplest answer to the first question was "Everything" but, pragmatically, a broad range of potentially conflicting societal objectives are likely to make that infeasible (Lackey 2003). Science can help answer the first question by evaluating the biological consequences of the loss of a population, and a number of approaches have been proposed (Riddell 1993; Allendorff et al. 1997; McElhany et al. 2000). Many similarities exist among the approaches and we have restated the central themes below:

1) Has the population been unaffected by the introduction of exogenous species and/or has the habitat occupied not been disrupted by anthropogenic activities (Riddell 1993; Allendorff et al 1997)?
2) Does the population exhibit unique genetic traits (Riddell 1993, Allendorff et al. 1997)?
3) Does the population occupy atypical habitat or express unusual phenotypic traits (Riddell 1993; Allendorff et al. 1997)?
4) Is the population a member of a native assemblage of species that is unusual or rare for steelhead (Allendorff et al. 1997)?
5) Does the population or group of populations provide a dispersed spatial distribution within an ESU (McElhany et al. 2000)?
6) Is the population necessary to provide connectivity among the components of a metapopulation (McElhany et al. 2000)?

New Populations

In a small number of cases, steelhead populations have been introduced into watersheds where they were not present historically. Generally, hatchery populations have been introduced by WDFW to take advantage of newly accessible habitat where upstream passage at waterfalls was provided or to provide a new opportunity for harvest. Despite this spatial separation, these introduced populations may have ecological or genetic interactions with an indigenous population. Past and future introductions should be carefully evaluated relative to genetic and ecological interactions with existing populations of steelhead and the native assemblage of species.

5.5 Findings and Recommendations

Finding 5-1. Short-term abundance and long-term persistence of the steelhead resource requires viable, locally-adapted, diverse populations, but a substantial loss of population structure has occurred in some, but not all regions. The percentage of historical populations remaining in 7 Washington regions ranges from 45%-100%. The two regions with 100% of the historical populations remaining - Olympia Peninsula and Southwest Washington - are both located on the Washington coast. The Upper Columbia River region has the smallest percentage of the historical populations remaining (45%).

Recommendation 5-1. Pursue opportunities to preserve and restore population structure, spatial structure, and within-population diversity through careful review of harvest, hatchery, and habitat management and implementation of improved strategies.

Finding 5-2. The population structure of steelhead in the Puget Sound, Olympic Peninsula, and Southwest Washington regions is uncertain. Inadequate genetic samples are currently available and new tools developed and applied by technical recovery teams have not been systematically applied in these regions.

Recommendation 5-2. Evaluate the population structure of steelhead in the Puget Sound, Olympic Peninsula, and Southwest Washington regions. Evaluate assumptions of the 1992 comanager analysis and, building on the tools developed by the Puget Sound, Willamette/Lower Columbia, and Interior Columbia technical recovery teams, define and implement a consistent procedure for evaluating population structure.

Finding 5-3. Steelhead life history diversity creates significant challenges for adequate sampling and accurate genetic analysis. Genetic analysis is potentially a powerful tool for identifying population and metapopulation structure. However, genetic analyses of previous samples from juveniles of potentially mixed life history types were often inconclusive. Newer genetic markers, such as single nucleotide polymorphisms (SNPs) and microsatellites, may enhance the power of genetic analyses, but the development and implementation of improved sampling protocols will be required.

Recommendation 5-3. Focus future collection of genetic samples in areas with significant uncertainty in population structure. Collect genetic samples for microsatellite or SNP analysis with methods that assure run timing and life history type are known. Conduct analyses using high-resolution DNA markers appropriate to research objectives.

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Appendix 5-A. Methods for Genetic Analysis

Genetic analyses from external sources (ICTRT 2003; Myers et al. 2004) and WDFW were used to help identify steelhead populations. WDFW analyses were generally based on 156 collections of juveniles or adults collected from 1993 through 1996 (see Phelps et al. 1994; 1997). These investigators conducted horizontal starch-gel electrophoresis to analyze variation at 56 enzyme-coding loci using over 150 collections of adult or juvenile steelhead from throughout. Only sub-sets of data for Puget Sound, coastal Washington and the lower Columbia River populations were re-analyzed for this report. The 56 loci in the data set were: *mAAT-1; sAAT-1,2; sAAT-3; ADA-1; ADA-2; ADH; mAH-1; mAH-2; mAH-3; mAH-4; sAH; ALAT; CK-A1; CK-A2; CK-C1; CK-C2; FH; GAPDH-3; bGLUA; GPI-A; GPI-B1; GPI-B2; G3PDH-1; IDDH-1; IDDH-2; mIDHP-1; mIDHP-2; sIDHP-1,2; LDH-A1; IDH-B1; LDH-B2; LDH-C; sMDH-A1,2; sMDH-B1,2; ME; mMEP-1; sMEP-1; sMEP-2; MPI; NTP; PEPA; PEPB-1; PEPD-1; PEP-LT; PGK-2; PGM-1; PGM-1r; PGM-2; PNP; mSOD; sSOD-1;* and *TPI-3*.

Regional datasets were run through the program CONVERT v1.3 (Glaubitz 2003) to calculate allele frequencies for each collection and create input files for subsequent analyses using other programs. Genetic relationships among collections were explored using dendrogram analysis. Tools within the program PHYLIP v3.57 (Felsenstein 1989) were used to generate genetic distance matrices and dendrograms as indicated. SEQBOOT was used to generate multiple data sets that were resampled versions of each original input data set; 1000 bootstrapped data sets from the original allele frequency input file were created for each subset of steelhead collections (alleles were resampled with replacement to create new data sets with allele frequencies reflecting this resampling). GENDIST was used to compute pairwise Cavalli-Sforza and Edwards (1967) chord distances from the set of allele frequencies for each collection. For these analyses, 1000 Cavalli-Sforza and Edwards distance matrices (one for each bootstrapped data set) were created. The routine NEIGHBOR was used to implement the Neighbor-Joining (N-J) method of Saitou and Nei (1987) to construct a tree by successive clustering of OTUs (operational taxonomic units); 1000 dendrograms based on the distance matrices were thus created. CONSENSE was then used to create a consensus tree from the 1000 neighbor-joining dendrograms, including the bootstrap values for each of the nodes on the tree. These nodal bootstrap values represent the number of times the branching to the right of the node occurred in the 1000 trees analyzed for each data set. Trees were visualized, along with associated bootstrap values, using the TREEVIEW v.1.4 program (Page 1996). We considered bootstrap values of greater than 65% to indicate supported nodes and have deleted all lower bootstrap values (indicated nodes with little or no statistical support) to simplify the figures. The labeling of OTUs in the N-J dendrograms includes an abbreviation of the stream or hatchery (designated by ‘H’) name, the last two digits of the year of collection, and a one-letter code for the adult return time of the population (‘S’ =summer run; ‘W’ = winter run; or ‘B’ = possible mixed collection containing both summer and winter run fish).

Chapter 6
Diversity and Spatial Structure

Key Questions:

a) *How have anthropogenic factors such as habitat modification, fishery management, and artificial production programs affected the diversity and spatial structure of steelhead populations?*
b) *What was the distribution of summer and winter steelhead in each region prior to European settlement?*
c) *How has the range of summer and winter steelhead changed from the pre-settlement distribution? What factors caused the change in distribution?*

6.1 Introduction

Diversity and spatial structure are two characteristics of a population that affect population viability (McElhany et al. 2000). We describe and apply methods to evaluate the diversity and spatial structure of extant populations of steelhead in Washington.

> *"…can we doubt (remembering that many more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and procreating their kind?" "Hence, I look at individual differences, though of small interest to the systematist, as of the highest importance for us…"*
>
> *Charles Darwin, The Origin of Species*

The diversity and spatial distribution of steelhead can be viewed as a hierarchical organization of multiple spatial and temporal scales. The organization can range from the relatively fine scale of habitat patch utilization to the distribution of populations throughout the range of the species. Riddell (1993) schematically represented this relationship using an inverted triangle to illustrate the cumulative contribution of each level of the hierarchy to the diversity of the species. Characteristics of the environment at the lower levels of the hierarchy drive the adaptations of populations and provide the basic unit for the diversity of the species. Two higher levels of this organization, the ESUs and populations of steelhead in Washington, were discussed in Chapter 5, Population Structure. In this chapter we evaluate the status of Washington populations of steelhead at a finer level of the hierarchy - within population diversity and spatial structure.

6.1.1 Diversity

Diversity is the variation among individuals in the expression of a trait. These differences can be the result of genetic differences between individuals, difference in the environment to which they were exposed, or both. Differences in traits that are strictly of genetic origin are often referred to as genotypic differences. Phenotypic differences result from the interaction of genetic and environmental factors.

As Darwin first argued in 1895 in *The Origin of Species*, the variation in individuals is a key condition necessary for natural selection and the evolution of species:

> "Can it, then, be thought improbable, seeing that variations useful to man have undoubtedly occurred, that other variations useful in some way to each being in the great and complex battle of life, should occur in the course of many successive generations. If such do occur, can we doubt (remembering that many more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and procreating their kind?" "Hence, I look at individual differences, though of small interest to the systematist, as of the highest importance for us, as being the first steps towards such slight varieties as are barely thought worth recording in works on natural history."

Since Darwin reshaped our concept of the functioning of the natural world, the importance of diversity for the persistence of a species and population viability has become a central tenet of conservation biology. McElhany et al. (2000) identified three general reasons to consider diversity when assessing the viability of a population:

1) Variation in traits allows a species to use a wider array of environments than would be possible in the absence of diversity.
2) Diversity provides the opportunity for some individuals, and the population, to persist when short-term changes occur in the environment.
3) Genetic diversity provides the basis for adaptation to long-term changes in the environment and maintenance of the population.

General guidelines for assuring that the diversity of a population is consistent with viability are provided in Box 6-1.

6.1.2 Spatial Structure

Spatial structure can be related to the viability and production potential of a population. Spatial dispersion provides a hedge against the loss of a population from a catastrophic event or, at a larger scale, the loss of a metapopulation (Ruckelshaus et al. 2003). Catastrophic events include a wide variety of phenomena such as volcanic activity, mud slides, toxic chemical spills, and disease epidemics which can pose a significant risk to population viability (Lande 1993; Mangel and Teir 1994). The hierarchical organization of a salmonid species, Riddell (1993) concluded, implies that maintaining maximum biological diversity, and production potential, necessarily means conserving populations and the habitats on which they depend.

These considerations suggest that an evaluation of spatial structure is important for at least five reasons (see McElhany et al. 2000 for a more detailed review):

Photo 3-1. Dams and other structures can limit the spatial extent of steelhead populations and reduce the viability and production potential of steelhead populations.

- spatial structure affects biological diversity;
- a dispersed spatial structure provides a hedge against the loss of biological diversity from catastrophic events (Ruckelshaus et al. 2003);
- the spatial and temporal distribution, quantity, and quality of habitat (landscape structure) dictates how effectively juvenile and adult salmon can bridge freshwater, estuarine, nearshore and marine habitat patches during their life cycle (Simenstad 2000; Mobrand et al. 1997;
- loss of spatial structure may affect extinction risk in ways not readily apparent from short-term observations of abundance data (Cooper and Mangel 1999); and
- maintenance of spatial structure maintains production potential (Riddell 1993).

General guidelines for assuring that the spatial structure of a population is consistent with viability are provided in Box 6-2.

Box 6-1. Diversity Guidelines

These general guidelines for assuring that the diversity of a population is consistent with viability were provided in *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units* (McElhany et al. 2000). Application of the guidelines requires careful consideration of many population and watershed specific factors.

“1. **Human-caused factors such as habitat changes, harvest pressures, artificial propagation, and exotic species introduction should not substantially alter variation in traits such as run timing, age structure, size, fecundity, morphology, behavior, and molecular genetic characteristics.** Many of these traits may be adaptations to local conditions, or they may help protect a population against environmental variation. A mixture of genetic and environmental factors usually causes phenotypic diversity, and this diversity should be maintained even if it cannot be shown to have a genetic basis.

2. **Natural processes of dispersal should be maintained. Human-cased factors should not substantially alter the rate of gene flow among populations.** Human caused inter-ESU stray rates that are expected to produce (inferred) sustained gene flow rates greater than 1% (into a population) should be cause for concern. Human caused intra-ESU stray rates that are expected to produce substantial changes in patterns of gene flow should be avoided.

3. **Natural processes that cause ecological variation should be maintained**. Phenotypic diversity can be maintained by spatial and temporal variation in habitat characteristics. This guideline involves maintaining processes that promote ecological diversity, including natural habitat disturbance regimes and factors that maintain habitat patches of sufficient quality for successful colonization.

4. **Population status evaluations should take uncertainty about requisite levels of diversity into account.** Our understanding of the role diversity plays in Pacific salmonid viability is limited. Historically, salmonid populations were generally self-sustaining, and the historical representation of phenotypic diversity serves as a useful “default” goal in maintaining viable populations.”

Box 6-2. Spatial Structure Guidelines

These general guidelines for assuring that the spatial structure of a population is consistent with viability were provided in *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units* (McElhany et al. 2000). Application of the guidelines requires careful consideration of many population and watershed specific factors.

"1. **Habitat patches should not be destroyed faster than they are naturally created.** Salmonid habitat is dynamic, with suitable habitat being continually created and destroyed by natural processes. Human activities should not decrease either the total area of habitat OR the number of habitat patches. This guideline is similar to the population growth rate criterion—i.e., a negative trend has deterministically negative affects on viability—though the relationship between decreasing number of patches and extinction risk is not necessarily linear.

2. **Natural rates of straying among subpopulations should not be substantially increased or decreased by human actions.** This guideline means that habitat patches should be close enough together to allow appropriate exchange of spawners and the expansion of the population into underused patches, during times when salmon are abundant (see Guideline 3). Also, stray rates should not be much greater than pristine levels, because increases in stray rates may negatively affect a population's viability if fish wander into unsuitable habitat or interbreed with genetically unrelated fish.

3. **Some habitat patches should be maintained that appear to be suitable or marginally suitable, but currently contain no fish.** In the dynamics of natural populations, there may be time lags between the appearance of empty but suitable habitat (by whatever process) and the colonization of that habitat. If human activity is allowed to render habitat unsuitable when no fish are present, the population as a whole may not be sustainable over the long term.

4. **Source subpopulations should be maintained.** Some habitat patches are naturally more productive than others. In fact, a few patches may operate as highly productive source subpopulations that support several sink subpopulations that are not self-sustaining. Protecting these source patches should obviously be of the highest priority. However, it should be recognized that spatial processes are dynamic and sources and sinks may exchange roles over time.

5. **Analyses of population spatial processes should take uncertainty into account.** In general, there is less information available on how spatial processes relate to salmonid viability than there is for the other VSP parameters. As a default, historic spatial processes should be preserved because we assume that the historical population structure was sustainable but we do not know whether a novel spatial structure will be."

6.2 Methods

Prior evaluations of the diversity and spatial structure of salmonids have often been subjective with limited or no explicit linkage to population viability. The WLCTRT (2003), for example, developed a qualitative description of the characteristics of within-population diversity associated with five levels of population persistence (0-40%, 40% -50%, 75 – 95%, 95 - 99%, > 99% over a 100-year time frame), but provided little justification for the risk levels. The WLCTRT (2003) concluded "Clearly we need to know far more that we do now about the spatial structure and fish-habitat relationships to be able to say with confidence that a given spatial structure will support a population over a sustained period of time." Similarly, with respect to within-population diversity, the WLCTRT states "When establishing criteria for within-population diversity, there is considerable uncertainty in defining how much life-history diversity is enough to sustain a population at VSP levels." In the absence of a defined procedure for relating spatial structure and diversity to population viability, we have chosen to simply categorize the extent of changes relative to the historical population (low, moderate, or high).

To evaluate diversity and spatial, we selected three characteristics of populations which seemed likely to be related to viability and for which information was frequently available: 1) genotypic and phenotypic variability; 2) the spatial extent of the population; and 3) an index of spatial structure and connectivity.

6.2.1 Diversity

We evaluated the magnitude of change in the diversity of the population using three metrics: 1) phenotypic characteristics; 2) effective size depression; and 3) and gene flow (Table 6-1). Changes in the phenotypic characteristics of individuals can be the most tangible evidence of loss in the diversity of a population. Our criteria, although similar to the ICTRT (2004), specifically focuses on fitness-related traits of naturally produced steelhead.

Hatchery programs can potentially reduce the effective size of a population if: 1) broodstock for the hatchery program originates from a relatively small part of a composite population of hatchery and natural-origin adults; 2) survival rates of hatchery-origin fish are significantly greater than fish of natural origin; and 3) returning adults from the hatchery program subsequently spawn in the natural environment. We evaluated the potential for a depression in the effective size of a population using the methods of Wang and Ryman (2001) and the criteria in the Benefit-Risk Assessment Program (BRAP) (WDFW 2001).

Gene flow from steelhead that did not originate from the population can reduce the diversity and fitness of a population. Our criteria for gene flow vary depending upon whether the source originated from inside or outside of the GDU of the population. We evaluated gene flow using the criteria in BRAP (WDFW 2001).

Table 6-1. Criteria for categorizing the magnitude of change associated with modifications to the diversity of the population.

Factor	**Magnitude of Change**		
	Low	**Moderate**	**High**
Phenotypic Characteristics	Significant change in mean or variability of < 2 fitness-related traits of naturally produced fish (e.g., migration timing, age structure, size at age).	Loss of 1 trait or significant change in mean or variability of 2 fitness-related traits of naturally produced fish (e.g., migration timing, age structure, size at age).	Loss of > 1 trait and significant change in mean or variability > 2 fitness-related traits of naturally produced fish (e.g., migration timing, age structure, size at age).
Effective Size	Effective size depression low risk to population (Appendix 6-B).	Effective size depression moderate risk to population (Appendix 6-B).	Effective size depression high risk to population (Appendix 6-B).
Gene Flow	Gene flow estimated or inferred: 1) < 1% from populations outside GDU; 2) < 2% from nontarget populations inside GDU.	Gene flow estimated or inferred: 1) 1% from populations outside GDU; 2) 2-4% from nontarget populations inside GDU.	Gene flow estimated or inferred: 1) >1% from populations outside GDU; 2) > 4% from nontarget populations inside GDU.

6.2.2 Spatial Extent of Population

The spatial extent of each population was evaluated in two ways: 1) the presence or absence of spawners in historical spawning areas; and 2) the range of all life history types in freshwater (Table 6-2).

Metrics and general criteria to evaluate the spawning distribution of a population have been suggested by both the WLCTRT (2003) and ICTRT (2004). The WLCTRT relied on a qualitative analysis that evaluated the extent to which historical areas remained accessible. The ICTRT developed a quantitative analysis of spatial data to define major spawning areas (MSA), or a section of a watershed that historically was sufficiently large to support a spawning aggregation of 500 steelhead. We drew upon both of these assessments and applied the qualitative approach to the areas where MSAs had not been defined (Puget Sound, Olympic Peninsula, Washington Coast, and Lower Columbia).

Workshops with fish biologists and Geographic Information System (GIS) analyses were used to identify the distribution of steelhead currently and prior to European settlement ("Pre-Settlement")(see Appendix 6-A for a complete description of methods). Information on the distribution of summer and winter steelhead prior to European settlement (referred to as the "Pre-Settlement" distribution) is limited. During the mapping workshops with biologists, we solicited expert opinion on what the distribution of steelhead would have been in the absence of artificial obstructions or habitat degradation ("Potential Presence"). Not surprisingly, the biologists were often unwilling to include parts of the watershed with which they were not personally familiar. The likely result was that the "Potential Presence" distribution defined a lower limit for the distribution of steelhead prior to European settlement.

We developed an alternative approach to explore this concern and define an upper limit to the distribution of steelhead prior to European settlement. The two-step methodology built on the information collected on the current distribution of steelhead and the spatial modeling capabilities provided by a Geographic Information System (GIS):

Step 1. Develop a GIS model driven by gradient and current distribution to predict historical the distribution of steelhead.

Step 2. Refine the model predictions through a review process with biologists familiar with the ecological and geomorphic characteristics of each watershed.

We defined the percentage reduction in the range of the population as:

% Loss = (Current Distribution) / (Pre-Settlement Distribution)

Results from the analysis are presented in both a map and summary table format. In the summary tables, the pre-settlement distribution, percent lost, and other statistics are presented by Water Resource Inventory Area (WRIA).[1] The extent of reduction in

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[1] All watersheds within Washington are categorized into one of 62 major watershed basins or WRIAs. The WRIA were formalized under Washington Administrative Code (WAC) 173-500-040 and authorized under the Water Resources Act of 1971, Revised Code of Washington (RCW) 90.54. The original WRIA boundary agreements and judgments were reached jointly by Washington's natural resource agencies Ecology, Department of Natural Resources, and Washington Department of Fish and Wildlife in 1970.

the range was categorized as Low (<%10 reduction), Moderate (10%-30% reduction), or High (>30%) reduction based on the most limiting factor (Table 6-1).

In some watersheds, range extensions have occurred as the result of the introduction of nonindigenous steelhead. These are noted in the text and on the maps, but they are excluded from the summary tables because our primary interest is in determining changes in the spatial structure of the indigenous population.

Table 6-2. Criteria for categorizing the magnitude of change associated with modifications to the spatial extent of the population.

Factor	Magnitude of Change		
	Low	**Moderate**	**High**
Spawning Distribution	1) Absence of spawners from < 10% of MSAs.	1) Absence of spawners from 10%-30% of MSAs.	1) Absence of spawners from > 30% of MSAs.
	2) Absence of spawners from < 10% of pre-settlement spawning areas.	2) Absence of spawners from 10% - 30% of pre-settlement spawning areas.	2) Absence of spawners from > 30% of pre-settlement spawning areas.
Population Range	Pre-settlement range reduced by < 10%.	Pre-settlement range reduced by 10%-30%	Pre-settlement range reduced by > 30%.

6.2.2 Spatial Structure and Connectivity

The spatial structure of the population and connectivity of habitat were evaluated using the Ecosystem Diagnosis and Treatment (EDT) model (Mobrand et al. 1997). In the model, a life history trajectory is defined as the path through time and space of a segment of a population. Trajectories can be initiated at different locations within a watershed, and trajectories that start at the same location can subsequently diverge if a segment of the population spends more or less time in a particular location. A life history trajectory is not sustainable if less than 1 adult is produced for each adult that initiates the trajectory. Reductions in the quality and complexity of channel, floodplain, and estuarine habitat will result in a reduction in the predicted productivity of the habitat. We computed an index of spatial structure and connectivity by comparing the number of trajectories that are currently sustainable with the number that were sustainable prior to European settlement (Table 6-3).

Table 6-3. Criteria for categorizing the magnitude of change associated with modifications to the spatial structure of the population.

Factor	**Magnitude of Change**		
	Low	**Moderate**	**High**
Spatial Structure and Connectivity	Index of spatial structure and connectivity reduced by < 10% relative to pre-settlement value.	Index of spatial structure and connectivity reduced by 10%- 30% relative to pre-settlement value.	Index of spatial structure and connectivity reduced by > 30% relative to pre-settlement value.

6.3 Results

6.3.1 Puget Sound

Our analysis estimates that 8%-26% of the pre-settlement range has been lost for summer steelhead and 3%-21% of the pre-settlement range lost for winter steelhead (Table 6-4)(Figs. 6-1 and 6-2). Significant variation exists among the WRIA in the percentage of the pre-settlement distribution lost. The greatest loss (51%-64%) occurs for summer steelhead in the Dungeness-Elwha WRIA, while relatively small losses are estimated for summer steelhead in the Kitsap (0%-7%) and the Stillaguamish (0%-8%) WRIAs.

Reductions in the range of the distribution have occurred primarily as a result of the construction of impassable barriers such as culverts and dams. Detailed maps of distribution and passage barriers can be obtained through the SalmonScape web site (see Box 5-1), but several of the major barriers at which passage may be provided in the future are identified below:

> Nooksack (WRIA 1). The Bellingham Water Diversion Dam at RM 7.2 blocks access to significant habitat in the Middle Fork Nooksack River. Discussions are underway regarding construction and funding for passage facilities.
>
> Upper Skagit (WRIA 4). Baker Dam blocks access to habitat in the Baker River. A Baker Summer steelhead population may have existed historically, but trap and haul operations currently do not transport summer steelhead.
>
> Green/Duwamish (WRIA 9). Howard Hanson Dam blocks access to the upper Green River. Trap and haul operations have been suspended until smolt passage is provided at the dam, currently targeted for 2008.
>
> Elwha/Dungeness (WRIA 18). The Elwha Dam at RM 4.9 blocks access to the Elwha River. Planning is currently underway to remove both the Elwha Dam and the Glines Canyon Dam.

Range extensions have occurred in four areas as the result of the introduction of non-indigenous steelhead. These are not included in Table 6-4 because the introductions were of nonindigenous steelhead.

> South Fork Stillaguamish Summer Steelhead. Summer steelhead of Skamamia-origin were introduced into the South Fork Stillaguamish River coincident with

the construction of the Granite Falls fish ladder in the mid-1950s. Approximately 121 miles of the watershed are now used by summer steelhead.

South Fork Skykomish Summer Steelhead. Summer steelhead of Skamamia-origin were introduced into the South Fork Skykomish River coincident with the initiation of a trap-and-haul operation at Sunset Falls in the mid-1950s. These introductions appear to have resulted in a self-sustaining population with genetic characteristics that differ from the native North Fork Skykomish populations and summer steelhead of Skamania-origin reared at Reiter Ponds and released into the Snohomish watershed (Kassler and Hawkins, pers. comm.). Approximately 166 miles of the watershed are now used by summer steelhead.

Green River Summer Steelhead. Summer steelhead of Skamania-origin were introduced into the Green River in 1965. Approximately 64 miles of the watershed are now used by summer steelhead.

Deschutes River Winter Steelhead. Winter steelhead of Chambers Creek-origin were introduced into the Deschutes River when a fish ladder was installed at Tumwater Falls in 1954. Approximately 61 miles of the watershed are now used by steelhead, but the production from spawners is unknown.

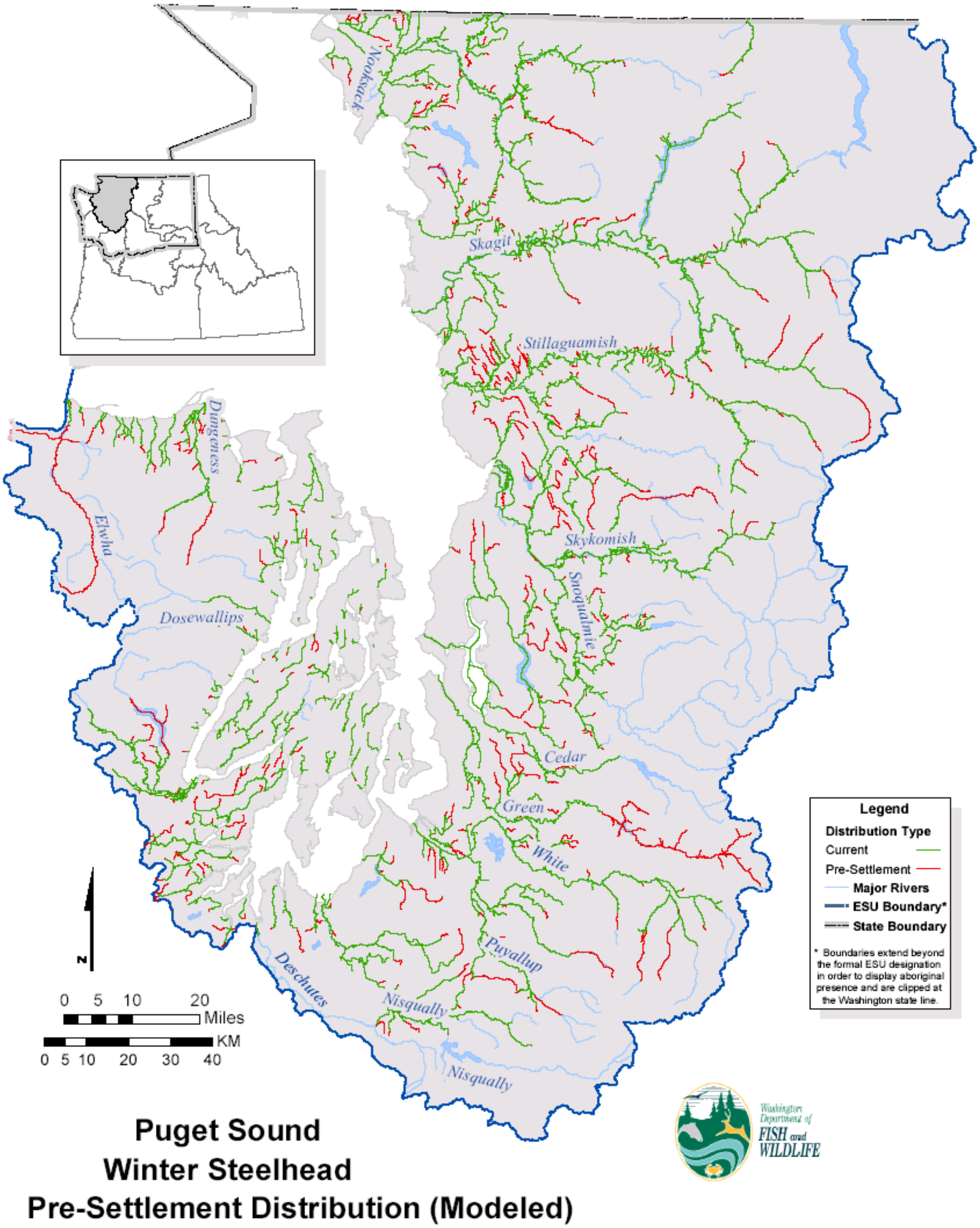

Figure 6-1. Current and predicted pre-settlement distribution of winter steelhead in the Puget Sound region.

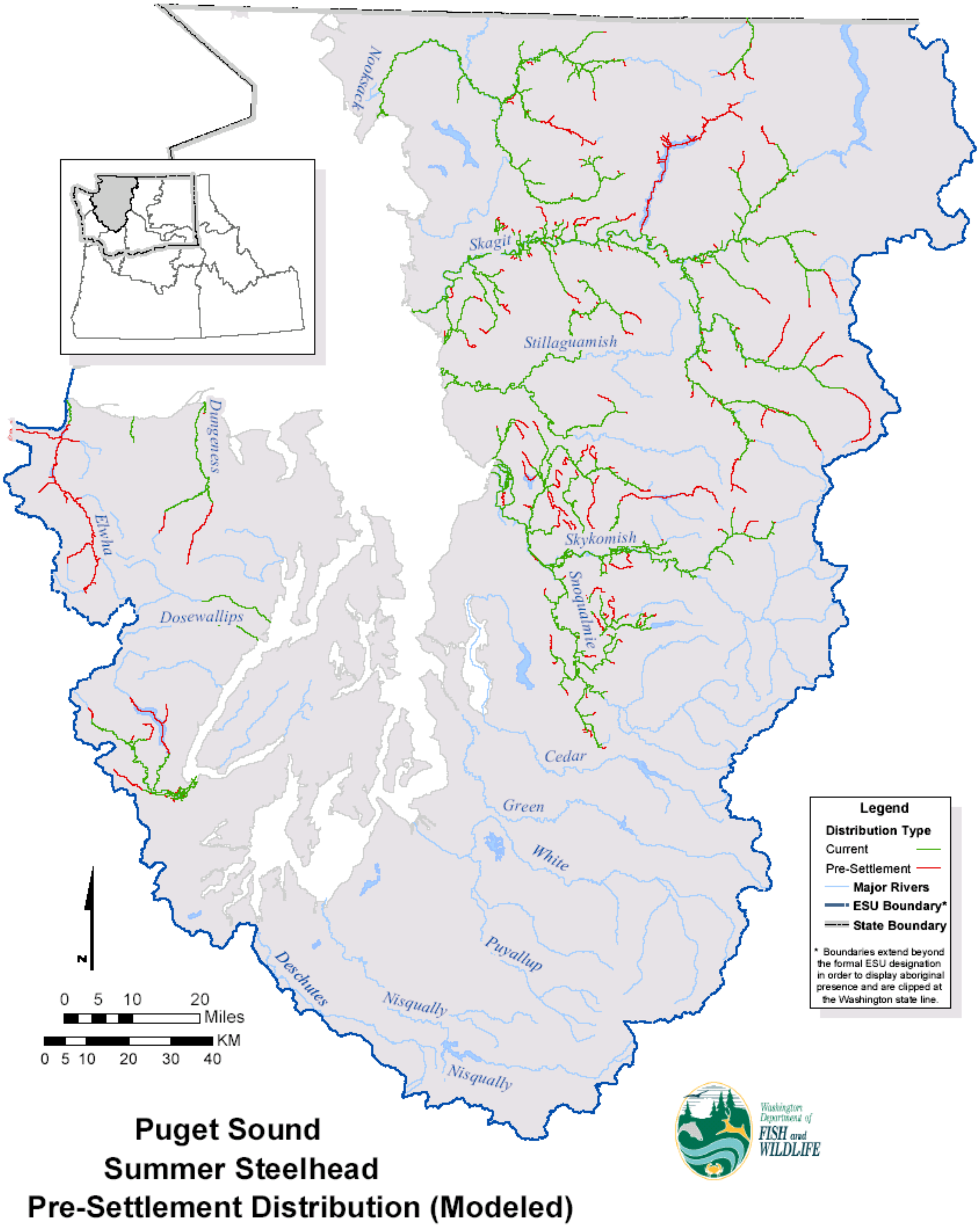

Figure 6-2. Current and predicted pre-settlement distribution of summer steelhead in the Puget Sound region.

Table 6-4. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Puget Sound region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
1 Nooksack					
Summer Steelhead	232-253	2	14-34	220	5% - 13%
Winter Steelhead	411-474	8	13-76	407	1% - 14%
3 Lower Skagit					
Summer Steelhead	165-203	0	0-38	165	0% - 19%
Winter Steelhead	230-277	0	0-47	230	0% - 17%
4 Upper Skagit					
Summer Steelhead	338-438	0	38-138	300	11% - 31%
Winter Steelhead	352-417	0	1-66	351	0% - 16%
5 Stillaguamish					
Summer Steelhead	114-124	0	0-10	114	0% - 8%
Winter Steelhead	245-333	72	0-88	317	-29% - 5%
7 Snohomish					
Summer Steelhead	431-570	0	1-140	431	0% - 24%
Winter Steelhead	433-562	0	1-130	432	0% - 23%
8 Cedar/Sammamish					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	183-226	0	0-44	183	0% - 19%
9 Green/Duwamish					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	175-225	0	59-109	116	34% - 48%
10 Puyallup/White					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	295-377	0	7-88	289	2% - 23%
11 Nisqually					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	171-198	0	7-33	165	4% - 17%
12 Chambers/Clover					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	29-33	0	0-29	29	0% - 11%
13 Deschutes					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	23-35	0	0-13	23	0% - 36%
14 Kennedy/Goldsborough					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	121-179	0	3-60	119	2% - 34%
15 Kitsap					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	163-175	0	1-13	163	0% - 7%
16 Skokomish/Dosewallips					
Summer Steelhead	110-125	0	17-32	93	16% - 25%
Winter Steelhead	143-157	0	19-32	125	13% - 20%

Table 6-4 (continued). Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Puget Sound region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
17 Quilcene/Snow					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	95-97	0	13-14	83	13% - 15%
18 Elwha/Dungeness					
Summer Steelhead	90-123	0	46-78	45	51% - 64%
Winter Steelhead	174-218	0	50-94	125	28% - 43%
Total					
Summer Steelhead	1,482-1,836	2	116-470	1,368	8% - 26%
Winter Steelhead	3,245-3,983	80	171-909	3,155	3% - 21%

Data were generally not available to evaluate changes in the spatial structure or diversity of steelhead in the Puget Sound region (Table 6-5). One exception is the Nisqually River, where the spatial structure of the Nisqually Winter population is predicted to have been reduced by 43% relative to pre-settlement conditions (J. Dorner, pers. comm.). Genetic analyses that compare the characteristics of winter steelhead from samples collected in the mid-1990s from the South Fork Nooksack River and Deer Creek have not yet been completed.

Table 6-5. Magnitude of changes in the spatial extent, spatial structure, and diversity for populations in Puget Sound with information available for spatial structure or diversity.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Dakota Creek Winter	Low – Moderate [1] (1%-14%)	Unknown	Unknown
Mainstem/NF Nooksack Winter		Unknown	Unknown
MF Nooksack Winter		Unknown	Unknown
SF Nooksack Winter		Unknown	[3]
Deer Creek Summer	Low [2] (0%-8%)	Unknown	[3]
SF Stillaguamish Summer		Unknown	Introduced Population
Canyon Creek Summer		Unknown	Unknown
Nisqually Winter	Low - Moderate (4%-17%)	High (43%)	Unknown

[1] Change in spatial extent is for all of WRIA 1 (Nooksack).

[2] Change in spatial extent is for all of WRIA 5 (Stillaguamish).

[3] Analysis not completed.

6.3.2 Olympic Peninsula

Watersheds in this ESU are unusual in that no hydroelectric or diversion dams block the access of steelhead to spawning areas that existed prior to European settlement. On the open Pacific side of the Olympic Peninsula ESU, many individual watersheds extend partly into the generally pristine habitat found in Olympia National Park. The lack of access points often makes it difficult to identify the upper extent of the distribution of steelhead. These factors result in substantial uncertainty in the percentage of the pre-settlement distribution of steelhead still accessible. Our analysis indicates a loss of 0-15% of the pre-settlement distribution of summer steelhead and a loss of 0%-28%for winter steelhead range (Table 6-6) (Figs. 6-3 and 6-4).

Table 6-6. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Olympic Peninsula region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
19 Lyre/Hoko					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	171-254	0	0-83	170	0% - 33%
20 Soleduck/Hoh					
Summer Steelhead	323-367	0	0-44	323	0% - 12%
Winter Steelhead	694-948	0	1-254	693	0% - 27%
21 Queets/Quinault					
Summer Steelhead	206-254	0	0-48	206	0% - 19%
Winter Steelhead	416-582	2	0-166	417	0% - 28%
Total					
Summer Steelhead	529-621	0	0-92	529	0% - 15%
Winter Steelhead	1,280-1,783	2	1-504	1,281	0% - 28%

A limited amount of information was available to evaluate changes in spatial structure and diversity in the Olympic Peninsula region (Table 6-7). Most notably, Currens (pers. comm.) evaluated changes in the genetic characteristics of the Pysht River Winter and Hoko River Winter steelhead populations. Comparing samples from 1975 and 1994, Currens noted that steelhead in both the Pysht River and Hoko River had become more like Chambers Creek steelhead during that period. Currens concluded that the magnitude of the change was “extremely unlikely” to have resulted only from genetic drift alone. “Although we cannot predict the direction of change due to genetic drift in any samples, the magnitude of the change, and the stronger similarity of Chambers Creek steelhead to Strait of Juan de Fuca samples than southern Puget Sound samples, it is highly likely that changes in these populations is due to interbreeding with

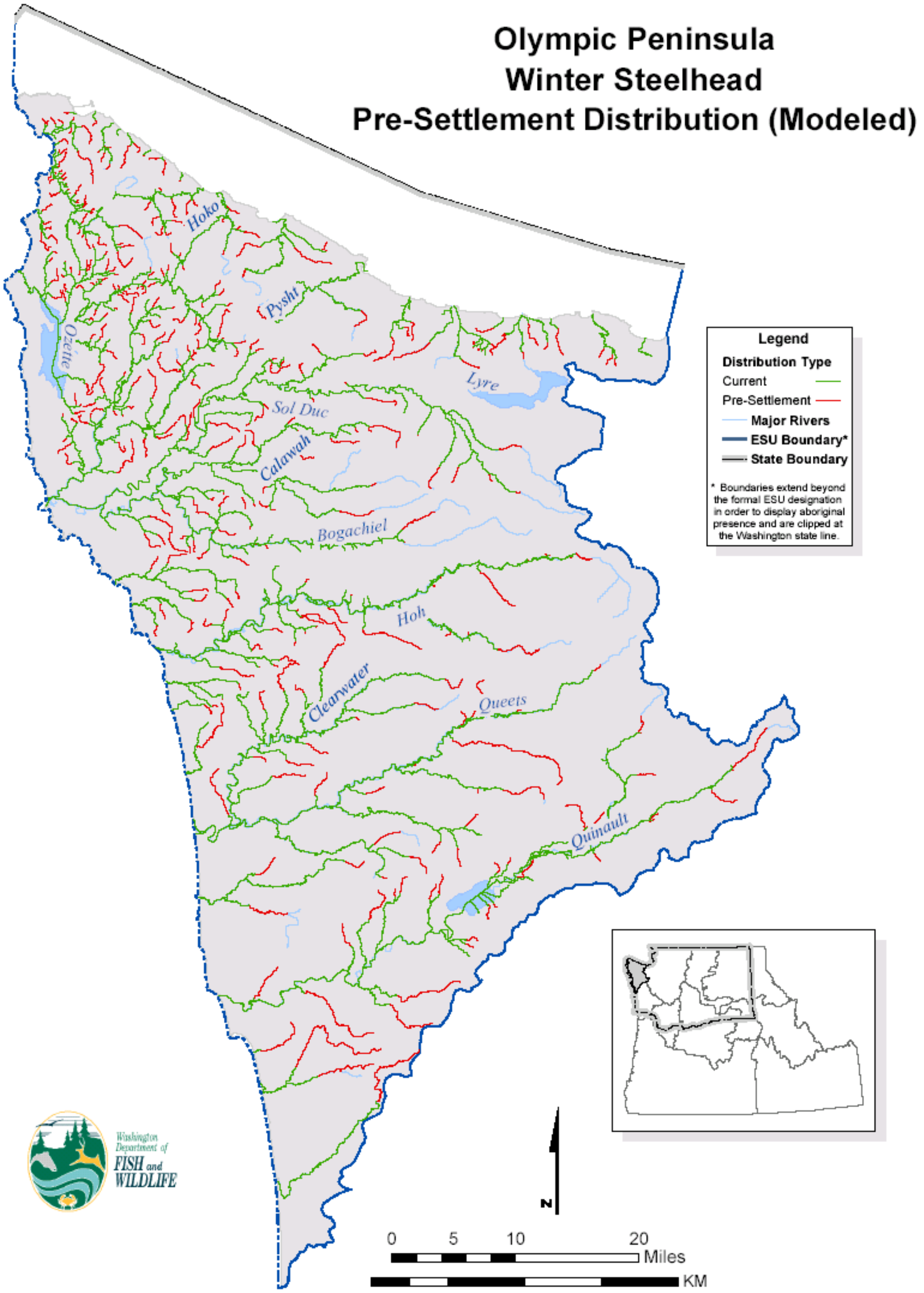

Figure 6-3. Current and predicted pre-settlement distribution of winter steelhead in the Olympic Peninsula region.

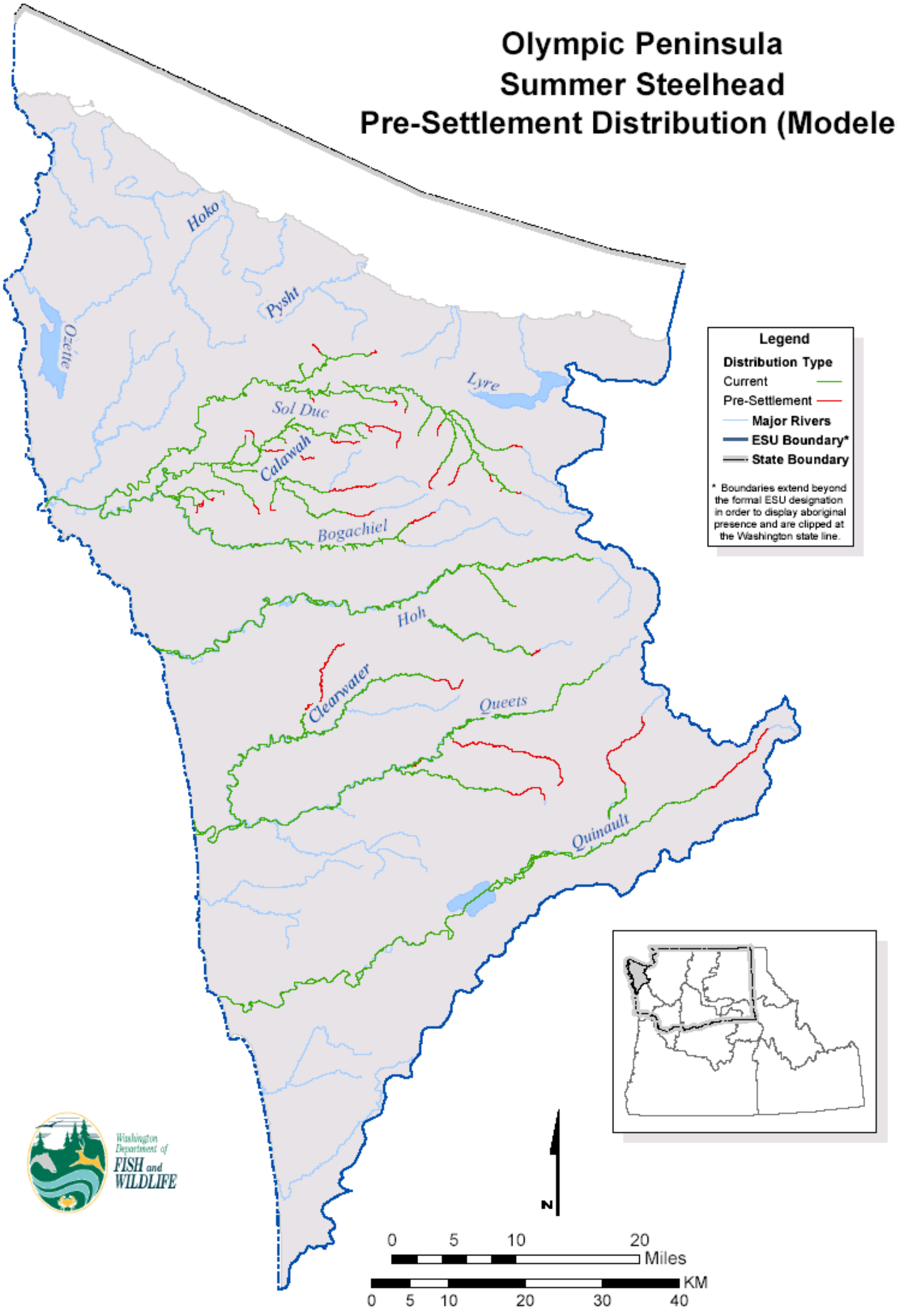

Figure 6-4. Current and predicted pre-settlement distribution of summer steelhead in the Olympic Peninsula region.

Chambers Creek steelhead." Similar analysis for samples from the Sol Duc River have not yet been completed.

Table 6-7. Magnitude of changes in the spatial extent, spatial structure, and diversity for populations in the Olympic Peninsula region with information available for spatial structure or diversity.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Pysht/Independents Winter	Low – Moderate [1] (0%- 33%)	Unknown	High. Estimated gene flow of 11-27% from nonlocal source.
Hoko Winter		Unknown	High. Estimated gene flow of 6-21% from nonlocal source.
Sol Duc Winter	Low – Moderate [2] (0%- 27%)	Unknown	[3]

[1] Change in spatial extent is for all of WRIA 19 (Lyre/Hoko).

[2] Change in spatial extent is for all of WRIA 20 (Soleduck/Hoh).

[3] Analysis not completed.

6.3.3 Southwest Washington

The distribution analysis indicates that a loss of 0%-14% of the pre-settlement distribution of summer steelhead and 3% - 31% loss for winter steelhead in the Southwest Washington region (Table 6-8)(Figs. 6-5 and 6-6). Two major factors limit fish distribution. The Wynoochee Dam blocks access to approximately 46 miles of summer steelhead habitat, and coal mining operations inhibit winter steelhead use of approximately 22 miles of habitat in Packwod and South Hanaford creeks.

Table 6-8. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Southwest Washington region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
22 Lower Chehalis					
Summer Steelhead	163-198	11	12-46	162	0% - 18%
Winter Steelhead	635-897	13	25-265	646	2% - 28%
23 Upper Chehalis					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	607-913	30	29-334	609	0% - 33%
24 Willapa					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	850-1,225	0	40-415	811	5% - 34%
25 Grays/Elochoman					
Summer Steelhead	59-59	0	0	59	0%
Winter Steelhead	464-586	0	21-142	443	4% - 24%
Total					
Summer Steelhead	222-257	11	12-46	222	0% - 14%
Winter Steelhead	2,580-3,621	43	114-1,156	2,509	3% - 31%

Predictions of the change in spatial structure are not available for any populations in the Willapa subregion or for two summer steelhead populations in the Grays Harbor subregion. Analysis indicates that the spatial structure of the remainder of the winter steelhead populations in the Grays Harbor and Columbia Mouth subregions has been reduced by an average of 11% (Table 6-9). The predicted loss of diversity is slightly greater in the Grays Harbor region (13%) than in the Columbia Mouth subregion (7%).

Predictions of the changes in the spatial structure of winter steelhead populations in the Grays Harbor subregion are available through a study funded by the Chehalis Basin Fisheries Task Force, WDFW, U.S. Fish and Wildlife Service, and the U.S. Army Corps of

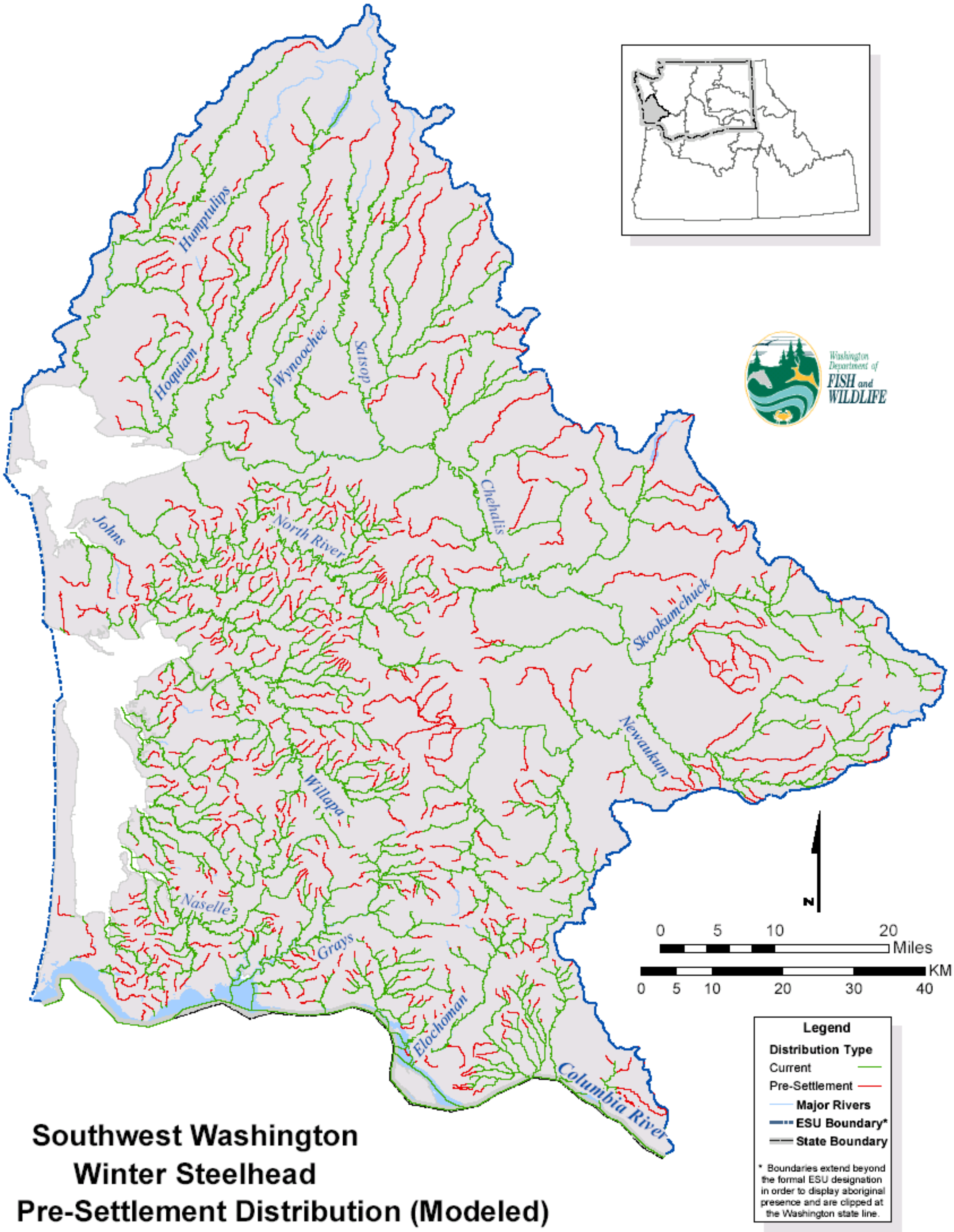

Figure 6-5. Current and predicted pre-settlement distribution of winter steelhead in the Southwest Washington region.

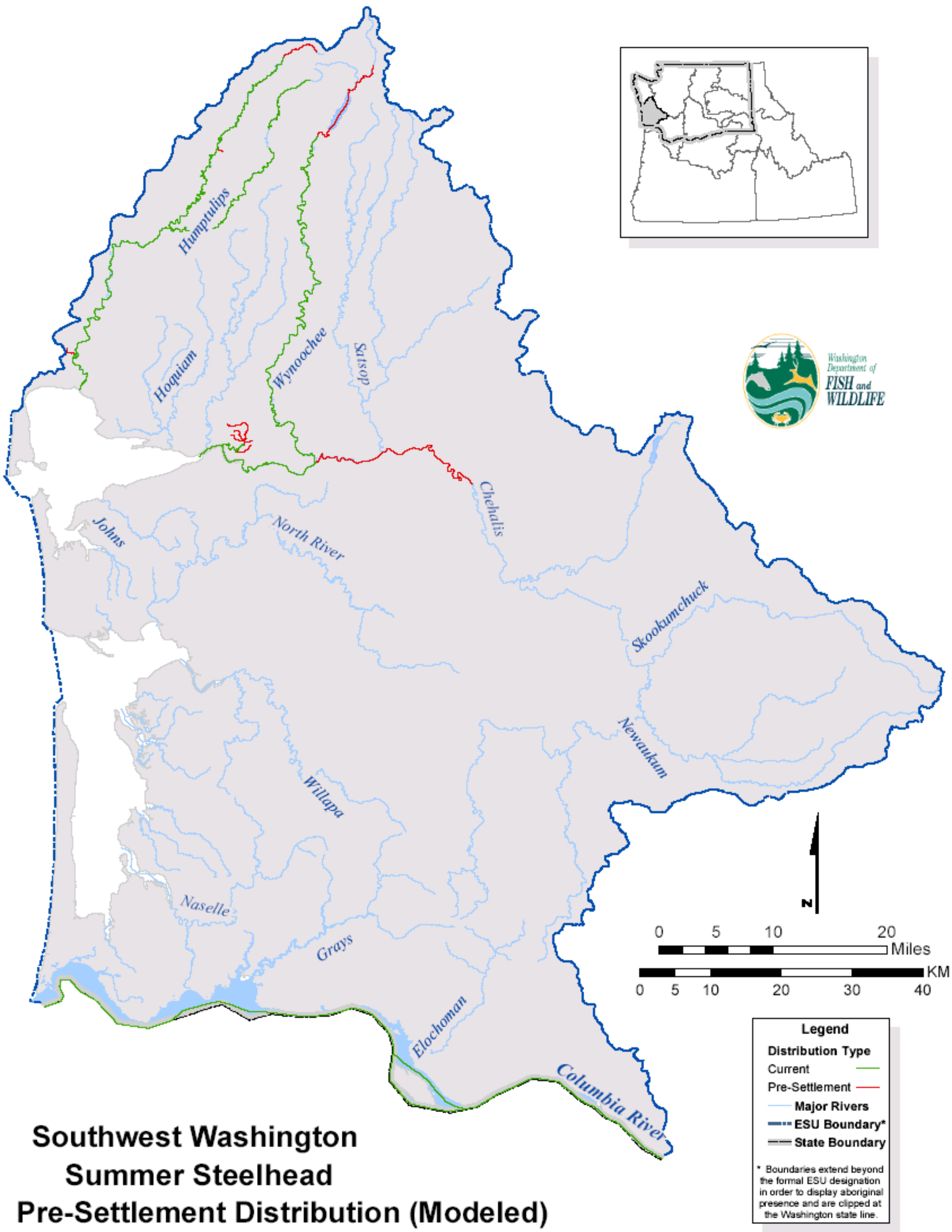

Figure 6-6. Current and predicted pre-settlement distribution of summer steelhead in the Southwest Washington region.

Engineers (Mobrand Biometrics 2003)(Table 6-9). The analysis indicates a more than 20% loss of spatial structure for the Chehalis Winter, Skookumchuck-Newaukum Winter, and South Bay Winter populations. Winter steelhead populations in Grays Harbor are predicted to have lost an average 13% of the spatial structure that existed prior to European settlement.

Analyses for the populations in the Columbia Mouth subregion show a similar range in the percent of spatial structure lost (Table 6-9). The Grays Winter population is predicted to have the largest loss (23%) in spatial structure; a slight increase (3%) is predicted for the Germany Winter population.

No information is available to evaluate the within-population diversity for populations in the Southwest Washington region.

Table 6-9. Magnitude of changes in the spatial extent, spatial structure and diversity of extant populations of steelhead in the Grays Harbor and Columbia Mouth subregions.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Grays Harbor Summer			
Chehalis Summer	Low – Moderate[1] (0%-18%)	Unknown	Unknown
Humptulips Summer		Unknown	Unknown
Summer Average	Low- Moderate (0%-18%)	Unknown	Unknown
Grays Harbor Winter			
Hoquiam Winter	Low – Moderate [1] (2%-28%)	Low (9%)	Unknown
Humptulips Winter		Moderate (16%)	Unknown
Satsop Winter		Low (0%)	Unknown
South Bay Winter		Moderate (20%)	Unknown
Wishkah Winter		Low (3%)	Unknown
Wynoochee Winter		Moderate (11%)	Unknown
Chehalis Winter	Low – High [2] (1%-31%)	Moderate (23%)	Unknown
Skookumchuck/Newaukum Winter	Low – High [3] (0%-33%)	Moderate (26%)	Unknown
Winter Average	Low –High (1% - 31%)	Moderate (13%)	Unknown
Columbia Mouth			
Abernathy-Germany-Mill Winter	Low – High [4] (4%-24%)	Low (2%)	Unknown
Elochoman-Skamokawa Winter		Moderate (13%)	Unknown
Grays Winter		Moderate (23%)	Unknown
Average	Low - Moderate (4%-24%)	Moderate (13%)	Unknown
Southwest Washington Average			
Summer	Low – Moderate (0% - 14%)	Unknown	Unknown
Winter	Low – High (0% - 31%)	Moderate (11%)	Unknown

[1] Change in spatial extent is for all of WRIA 22 (Lower Chehalis).

[2] Change in spatial extent is for all of WRIA 22 (Lower Chehalis) and WRIA 23 (Upper Chehalis).

[3] Change in spatial extent is for all of WRIA 23 (Upper Chehalis).

[4] Change in spatial extent is for all of WRIA 25 (Grays/Elochoman).

6.3.4 Lower Columbia River

Substantial reductions and one increase in the distribution of steelhead have occurred in the Lower Columbia River region (Table 6-10)(Figs. 6-7 and 6-8). A hydroelectric dam on the Lewis River has reduced the pre-settlement distribution of summer steelhead by 34% - 45% and for winter steelhead by 13% - 28%. Although trap-and-haul operations distribute winter steelhead to the Tilton, Cispus, and Upper Cowlitz rivers, approximately 21 miles of habitat accessible prior to European settlement is now covered by reservoirs. A substantial extension of the distribution of winter steelhead occurred in the Wind River when a fishway was provided at Shepard Falls. With the addition of the fishway, the current distribution of winter steelhead is 156% of the pre-settlement distribution.

Table 6-10. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Lower Columbia River region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
26 Cowlitz					
Summer Steelhead	9	0	0	9	0%
Winter Steelhead	1,040–1,296	12	112-367	941	10% - 27%
27 Lewis					
Summer Steelhead	431-521	0	146-237	285	34% - 45%
Winter Steelhead	414-500	95	148-234	362	13% - 28%
28 Salmon/Washougal					
Summer Steelhead	208-246	0	3-40	205	1% - 16%
Winter Steelhead	298-356	0	9-67	289	3% - 19%
29 Wind/White Salmon					
Summer Steelhead	213-257	0	31-75	182	15% - 29%
Winter Steelhead	128-129	106	34-35	200	-55% - 56%
Total					
Summer Steelhead	861-1,034	0	180-353	681	21% - 34%
Winter Steelhead	1,881-2,280	213	304-702	1,791	5% - 21%

The spatial structure index was computed for many populations of steelhead in the Lower Columbia region during the development of the Lower Columbia recovery plan (LCFRB 2004) (Table 6-11). In general, the indices showed a greater loss in spatial structure for populations of winter steelhead (40%) than summer steelhead (12%). The disparity between summer and winter steelhead appeared to be due to two factors. First, summer steelhead often used upper reaches of watersheds where habitat is in

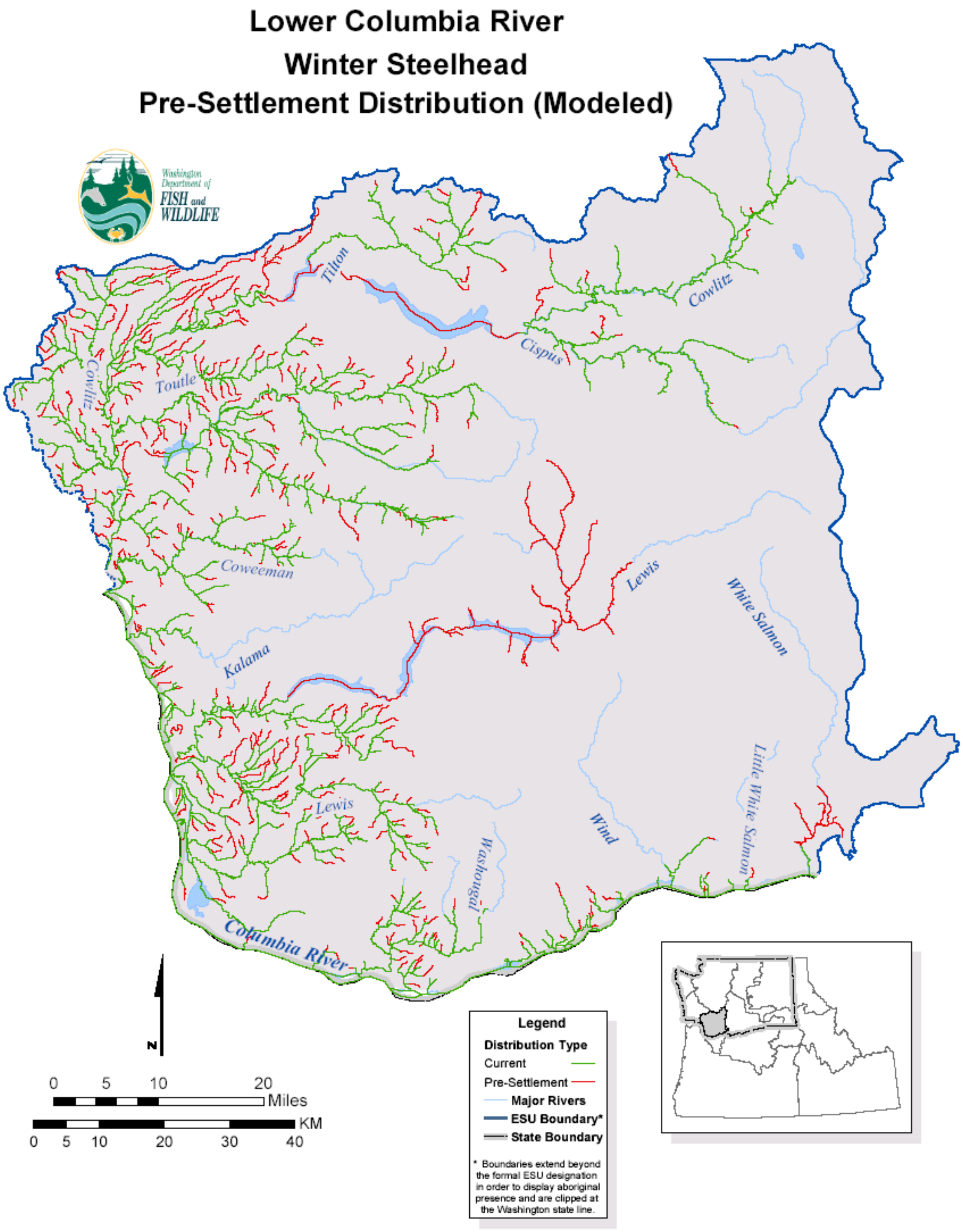

Figure 6-7. Current and predicted pre-settlement distribution of winter steelhead in the Lower Columbia River region.

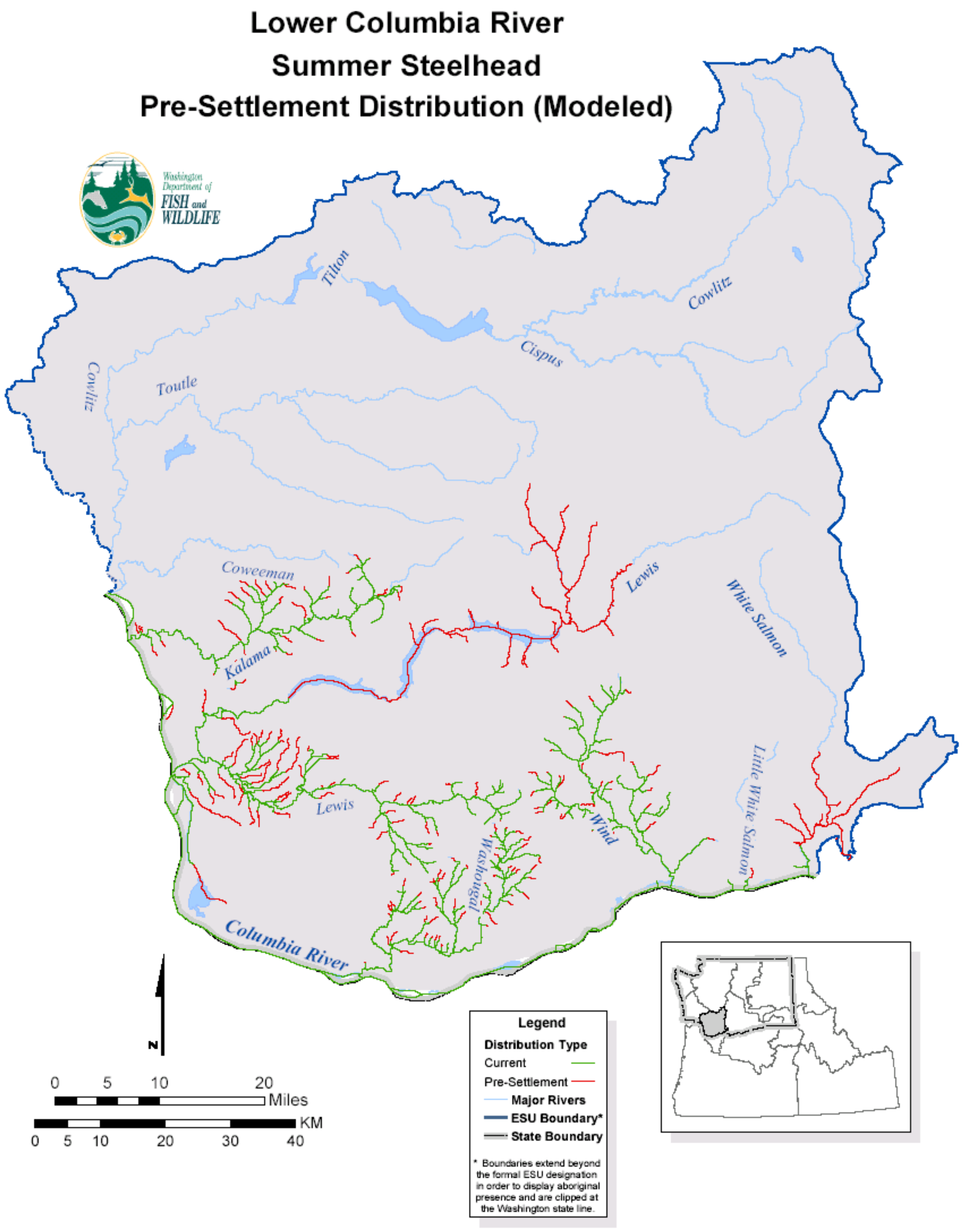
Lower Columbia River
Summer Steelhead
Pre-Settlement Distribution (Modeled)

Figure 6-8. Current and predicted pre-settlement distribution of summer steelhead in the Lower Columbia River region.

better condition. Second, summer steelhead were not historically present in some watersheds with substantial habitat degradation (e.g., Toutle River, Salmon Creek). The loss in spatial structure was predicted to be greatest for the Tilton (79%), Lower Cowlitz Winter (77%), Lower Gorge Winter (62%), and Salmon Winter (61%) populations.

Table 6-11. Magnitude of changes in the spatial extent, spatial structure, and diversity of extant populations of steelhead in the Lower Columbia region.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Lower Columbia Winter			
Cispus Winter	Moderate [1] (10%-27%)	Moderate (13%)	High
Upper Cowlitz Winter		Moderate (16%)	
Tilton Winter		High (79%)	High
Lower Cowlitz Winter		High (77%)	High
Toutle Winter [2]		High (55%)	Unknown
Coweeman Winter		Moderate (14%)	Unknown
Kalama Winter	Moderate [3] (13%-28%)	Low (9%)	[5]
NF Lewis Winter		High (50%)	Unknown
EF Lewis Winter		Moderate (23%)	Unknown
Salmon Winter	Low – Moderate [4] (3%-19%)	High (61%)	Unknown
Washougal Winter		Moderate (28%)	Unknown
Lower Gorge Winter		High (62%)	Unknown
Wind Winter	Increase	High (41%)	Unknown
Lower Columbia Summer			
Kalama Summer	High (34%-45%)	Low (0%)	Unknown
EF Lewis Summer		Low (6%)	Unknown
Washougal Summer	Low – Moderate (1%-16%)	Moderate (28%)	Unknown
Wind Summer	Moderate (15%-29%)	Moderate (12%)	Unknown
Lower Columbia Average			
Summer	Moderate – High (21%-34%)	Moderate (12%)	
Winter	Low – Moderate (5%-21%)	High (40%)	

[1] Change in spatial extent is for all of WRIA 26 (Cowlitz).

[2] Mainstem/NF Toutle, Green, and South Fork Toutle populations aggregated for this analysis.

[3] Change in spatial extent is for all of WRIA 27 (Lewis).

[4] Change in spatial extent is for all of WRIA 28 (Salmon/Washougal).

[5] Genetic analyses not completed.

Information to evaluate reductions in within-population diversity is generally not available for populations within the Lower Columbia region. Loss of genetic diversity for the four Cowlitz populations was categorized as High because of the development of a composite broodstock after the completion of Mayfield Dam. Genetic analyses that compare the characteristics of winter steelhead from samples from the Kalama River in 1994 and prior to 1975 have not yet been completed.

6.3.5 Middle Columbia River

A substantial reduction in the range of summer steelhead has occurred in the Middle Columbia River region (Table 6-12)(Figs 6-9 and 6-10). The greatest reduction in the pre-settlement range has occurred in the Upper Yakima (48%-52%), but substantial reductions are also estimates to have occurred in the Naches (21%-24%) and Rock/Glade (18%-25%) WRIAs. Significant impediments to steelhead distribution in the Yakima River and tributaries are briefly discussed below.

> Rimrock Dam. The Tieton River is a tributary to the Naches River. Tieton Dam blocks access to approximately 48 miles of the upper Tieton River.
>
> Bumping Dam. The Bumping River is a tributary to the Naches River. Bumping Dam blocks access approximately 12 miles of the upper Bumping River.
>
> Cle Elum Dam. The Cle Elum River is a tributary to the upper Yakima River. Cle Elum Dam blocks access to approximately 35 miles of the upper Cle Elum River.
>
> Kachess Dam. The Kachess River is a tributary to the upper Yakima River. Kachess Dam blocks access to approximately 14 miles of the upper Kachess River.
>
> Keechelus Dam. Blocks access to approximately 13 miles of the headwaters of the Yakima River.

Habitat degradation and fragmentation have resulted in a substantial reduction in the spatial structure index for populations in the Middle Columbia River region (Table 6-13). The average loss is 77% and 3 of the 4 populations in the Yakima River are predicted to have lost more than 85% of the spatial structure present prior to European settlement. Smaller but substantial reductions (42%) in spatial structure are predicted for the Klickitat and Satus populations. Freundenthal et al. (2005) found that the gap between the Dry Creek and Satus/Logy MSAs was increasing and concluded that this resulted in a moderate risk to the population.

The within-population diversity of populations within the Yakima subbasin have been extensively analyzed (Busack et al. 2005; Freudenthal et al. 2005). Analysis of microsatellite genetic data suggests slight introgression of Skamania-type steelhead into the Naches and Upper Yakima populations (Busack et al. 2005). Samples of approximately 100 juvenile steelhead were collected at Roza Dam (sampled in 2000, 2001, and 2003), the Naches River (sampled in 2004), Toppenish Creek (sampled in 2000

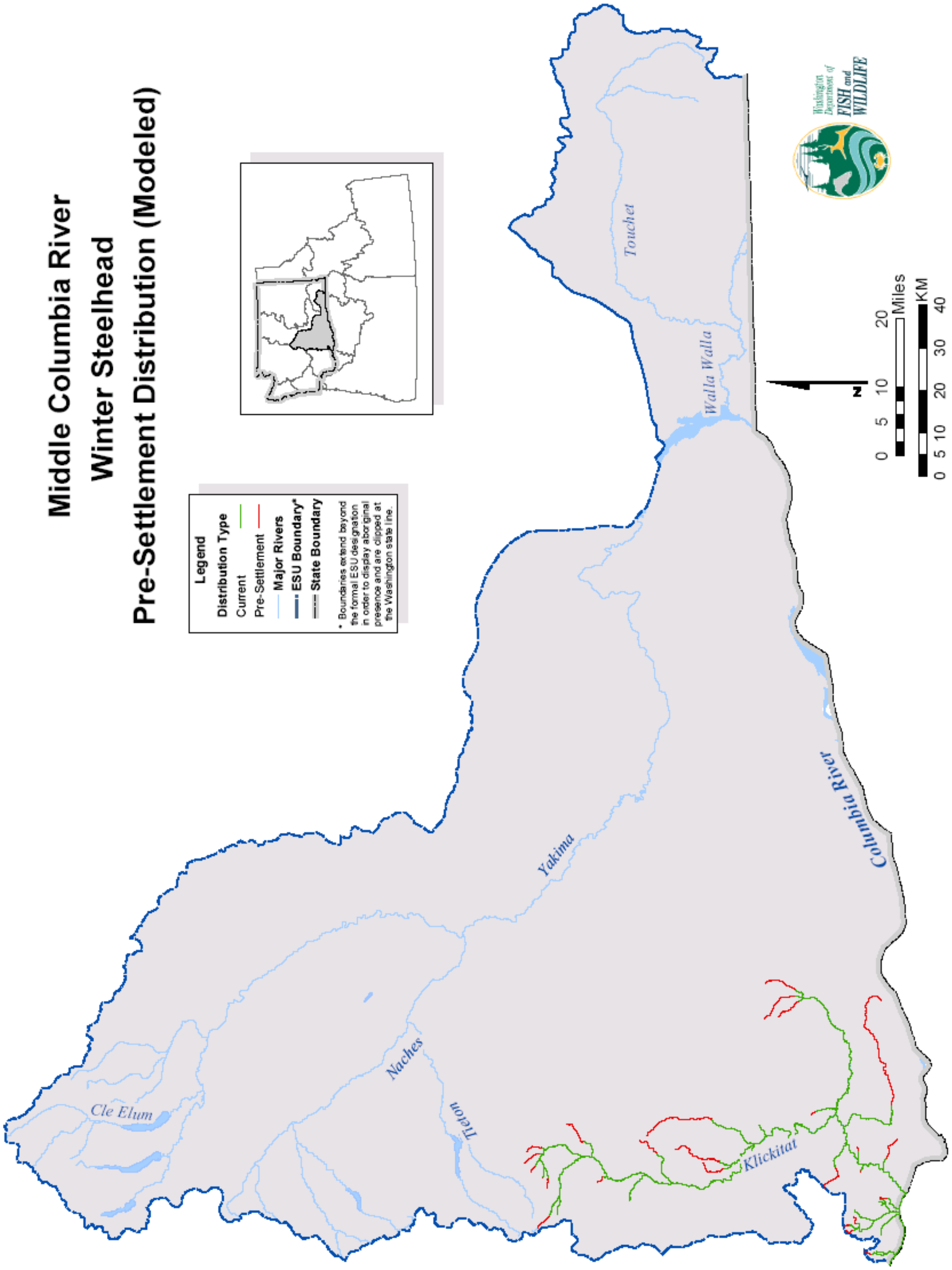

Figure 6-9. Current and predicted pre-settlement distribution of winter steelhead in the Middle Columbia River region.

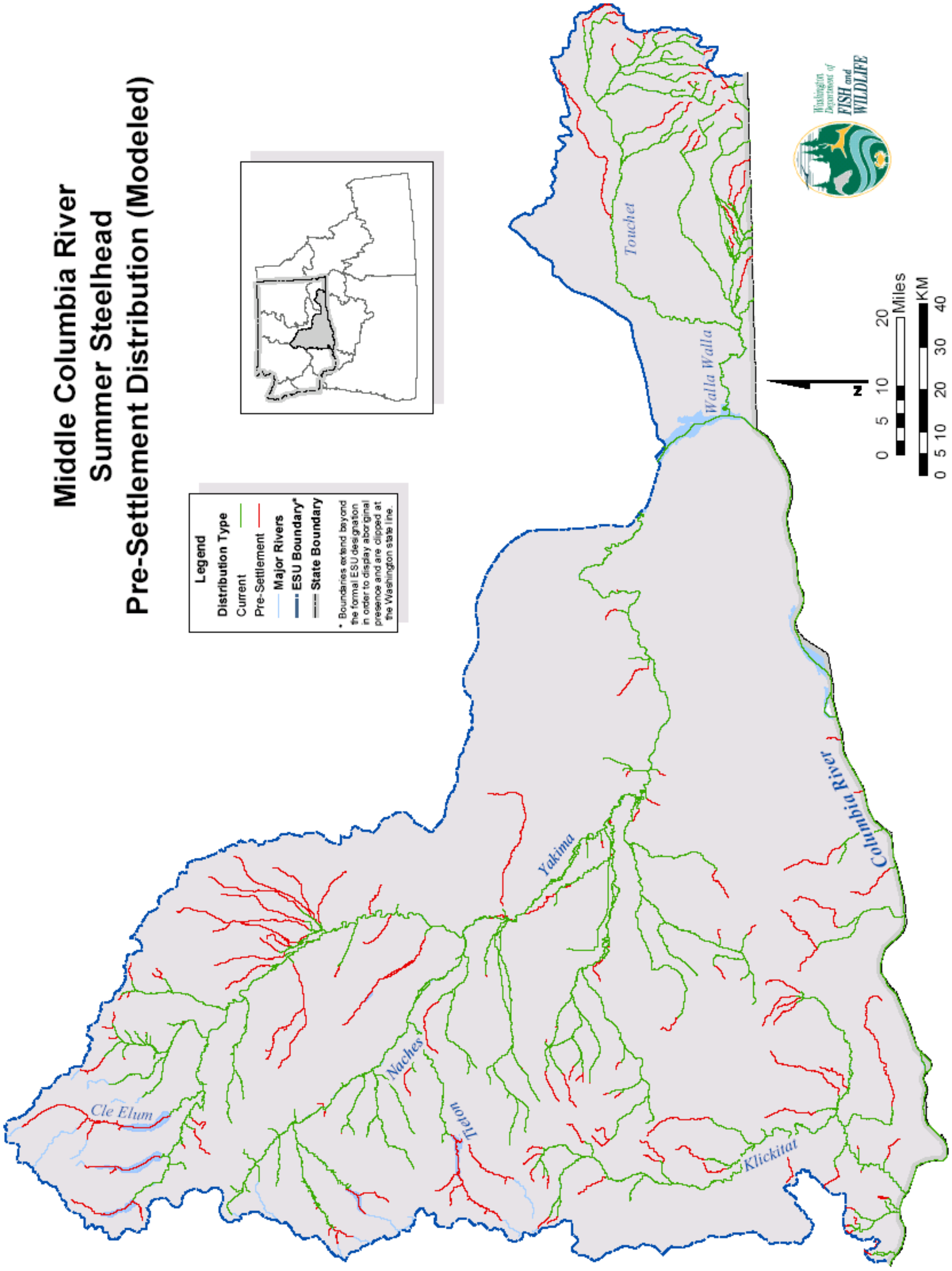

Figure 6-10. Current and predicted pre-settlement distribution of summer steelhead in the Middle Columbia River region.

and 2001), and Satus Creek (sampled in 2000 and 2001). Analysis using the STRUCTURE program (Pritchard et al. 2000) indicated that 6-9% of the multi-locus genotype of an average steelhead juvenile sampled in the Naches River or at Roza Dam was consistent with Skamania-type fish. The range was lower, 2-4%, for the samples from Toppenish Creek and Satus Creek. These slight relationships to Skamania-type fish could also be artifacts of shared polymorphisms or shared ancestry rather than introgression (Utter 1998; Busack et al. 2005).

Introgression with hatchery-origin rainbow trout may also have occurred in the Naches and Upper Yakima populations (Campton and Johnston 1985; Phelps et al. 2000). Phelps et al. (2000) concluded from an admixture analysis of parental source (Long 1991) that hatchery-origin rainbow trout were responsible for more than 10% of the gene pool for samples from Wilson Creek (Upper Yakima tributary) and the Roza trap. Although the release of exogenous resident and anadromous salmonids into the Yakima subbasin has ceased, we categorized the loss of diversity of the Naches and Upper Yakima populations as Moderate because of the residual effects that are remain evident.

Phenotypic traits of the steelhead populations in the Yakima subbasin appear to have been affected in several ways (Freudenthal et al. 2005).

> Juvenile Residence. Short and long-term juvenile rearing strategies in the Naches and Toppenish have been affected by reduced summer flows. Conversely, juvenile residence has been prolonged in the Upper Yakima by increased summer flows and decreased summer temperatures.
>
> Adult Entry. Return timing of adults in all four populations appears to have been delayed by reduced flow and high temperatures in the mainstem of the Yakima River.

Juveniles originating from a non-local GDU (Lyons Ferry) have been released into the Touchet River since 1985 (Schuck 1998). Genetic analysis has been conducted to assess the extent of introgression from the Lyons Ferry stock. Bumgarner et al (2003; 2004) concluded that “the Touchet River wild-stock collections remain distinct from the LFH hatchery stock. Some of this distinction indicates that LFH summer steelhead stock have failed to introgress into the wild-stock population in the Touchet drainage. This conclusion has also been supported from the Dayton adult trap data that suggests that very few hatchery-origin return to the natural spawning areas on the Touchet River”.

No information was available to assess the spatial structure or diversity of the Rock Creek population.

Table 6-12. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Middle Columbia River region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
30 Klickitat					
Summer Steelhead	249-398	0	0-149	249	0% - 37%
Winter Steelhead	209-300	0	0-91	209	0% - 30%
31 Rock/Glade					
Summer Steelhead	192-210	0	34-52	158	18% - 25%
Winter Steelhead	0	0	0	0	NA
32 Walla Walla					
Summer Steelhead	551-654	0	9-113	541	2% - 17%
Winter Steelhead	0	0	0	0	NA
37 Lower Yakima					
Summer Steelhead	617-698	0	31-113	586	5% - 16%
Winter Steelhead	0	0	0	0	NA
38 Naches					
Summer Steelhead	333-347	0	70-84	263	21% - 24%
Winter Steelhead	0	0	0	0	NA
39 Upper Yakima					
Summer Steelhead	517-590	0	233-306	284	45% -52%
Winter Steelhead	0	0	0	0	NA
Total					
Summer Steelhead	2,459-2,898	0	378-816	2,082	15%-28%
Winter Steelhead	209-300	0	0-91	209	7% - 30%

Table 6-13. Magnitude of changes in the spatial extent, spatial structure, and diversity of extant populations of steelhead in the Middle Columbia River region.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Klickitat Summer-Winter	Low – High (0-66%)	High (42%) [1]	Unknown
Rock	Moderate (18%-25%)	Unknown	Unknown
Touchet	High Loss of 1 of 2 MSAs	High (91%)	Low
Walla Walla [2]		High (95%)	Unknown
Satus	Low – Moderate [4] (5%-16%)	High (58%)	Low
Toppenish		High (87%)	Moderate
Naches	Moderate (21%-24%)	High (88%)	Moderate
Upper Yakima	High Loss of 8 of 11 MSAs	High (92%)	Moderate
Middle Columbia River Average	Moderate (15%-28%)	High (77%)	

[1] Four separate analyses were completed for the Klickitat River: 1) summer and winter life history and distribution characteristics; and 2) above and below Castille Falls. Reported index is average value for summer and winter steelhead below Castille Falls.

[2] Analysis was run separately for the mainstem Walla Walla River and tributaries. Reported index is average value for two analyses.

6.3.6 Upper Columbia River

Approximately 43%-52% of the pre-settlement distribution of steelhead has been lost in the Upper Columbia region (Table 6-14)(Fig. 6-11). Although the majority of this is above Grand Coulee Dam, substantial reductions in the distribution of steelhead are evident in other subbasins as well. These include the Entiat (14% - 16% loss), Wenatchee (10% - 34% loss), and Okanogan (0% - 25% loss).

Major barriers include the following. Approximately 22 miles of Icicle Creek, a tributary to the Wenatchee, are blocked by a USFWS hatchery. On the Okanogan River, approximately 30 miles of habitat are blocked by a dam on Salmon Creek.

Table 6-14. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer steelhead in the Upper Columbia River region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
36 Esquatzel Summer Steelhead	105	0	0	105	0%
41 Lower Crab Summer Steelhead	128-181	0	0-53	128	0% - 29%
44 Moses Coulee Summer Steelhead	44-60	0	21-37	23	47% - 62%
45 Wenatchee Summer Steelhead	257-351	0	27-120	231	10% - 34%
46 Entiat Summer Steelhead	96-98	0	14-15	82	14% - 16%
47 Chelan Summer Steelhead	27	0	0	27	0%
48 Methow Summer Steelhead	226-303	0	0-77	226	0% - 26%
49 Okanogan Summer Steelhead	145-195	0	0-50	145	0% - 25%
50 Foster Summer Steelhead	53-55	0	42-45	11	80% - 81%
Above Grand Coulee Dam Summer Steelhead	644	0	644	0	100%
Total Summer Steelhead	1,726-2,018	0	749-1,040	978	43% - 52%

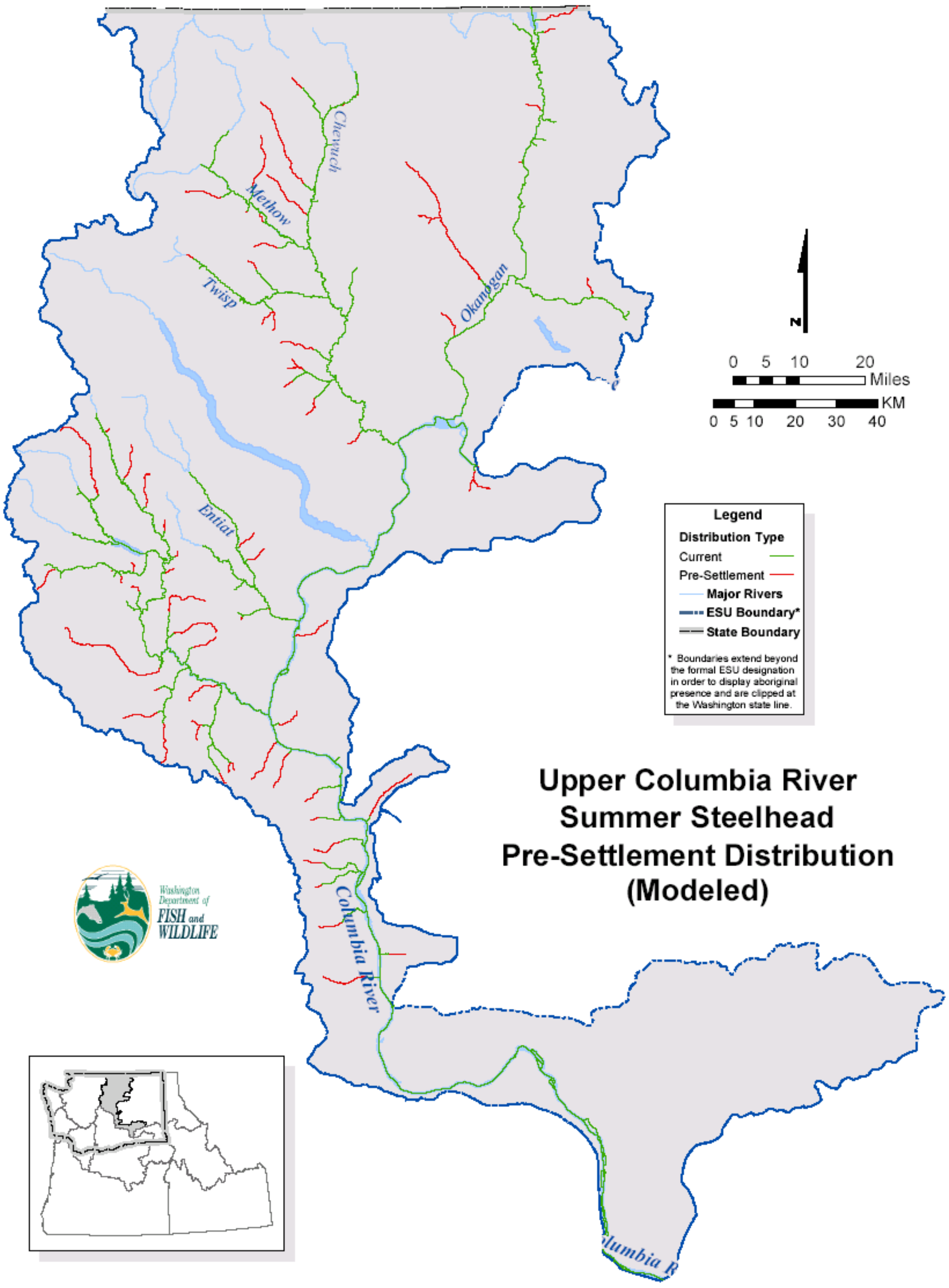

Figure 6-11. Current and predicted pre-settlement distribution of summer steelhead in the Upper Columbia River region.

Predictions of the spatial structure index are available for three steelhead populations in the Upper Columbia region (Table 6-15). The average loss in diversity is predicted to be 79%, with 98% of the diversity predicted to have been lost for the Okanogan population.

The diversity of the Wenatchee, Entiat, Methow, and Okanogan populations of steelhead has been affected by a series of artificial production programs. The Grand Coulee Fish Maintenance Project (Fish and Hanavan 1948) probably resulted in the mixing of steelhead from all areas upstream of Rock Island Dam and artificial production programs subsequently released juvenile steelhead of unknown origin throughout the Upper Columbia region. We categorized the diversity loss of the Okanogan population as High because the large reduction in the abundance has likely had a substantial effect on diversity.

Table 6-15. Magnitude of changes in the spatial extent, spatial structure, and diversity of extant populations of steelhead in the Upper Columbia region.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Crab Creek	Low – Moderate (0%-29%)	Unknown	Unknown
Wenatchee	Moderate - High (10%-34%) Loss of 1 of 4 MSAs	High (73%)	High
Entiat	Moderate (14%-16%)	High (100%)	High
Methow	Low – Moderate (0%-26%)	High (65%)	High
Okanogan	Low - Moderate (0%-25%)	High (98%)	High
Upper Columbia River Average [1]	Moderate - High (11%-31%)	High (79%)	Unknown

[1] Average is only for the five extant populations in the Upper Columbia ESU.

6.3.7 Snake River Basin

Relative to the remainder of the ESU, a relatively small reduction (2%-12%) in the distribution of steelhead has occurred in the Washington component of the Snake River Basin region (Table 6-16).

Table 6-16. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer steelhead in the Snake Basin ESU.

	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
33 Lower Snake Summer Steelhead	67	0	0	67	0%
34 Palouse Summer Steelhead	8	0	0	8	0%
35 Middle Snake Summer Steelhead	913-1,016	0	20-123	893	2% - 12%
Total Summer Steelhead	988-1,091	0	20-123	968	2% - 11%

Spatial structure is predicted to have been reduced by an average of 62% in the Washington component of the Snake River basin (Table 6-17). The largest reduction is predicted for the Asotin population (82%) and the smallest for the Joseph population (48%).

The diversity of steelhead in the Tucannon River may have been affected by the release of juveniles that originated from broodstock from a nonlocal GDU. Juvenile steelhead of Lyons Ferry, Wells, and Wallowa origin have been released into the Tucannon River since 1982 (Schuck 1998). Adults originating from releases of Lyons Ferry type juveniles comprised an average of 70% of the total number of fish sampled at a trap on the lower Tucannnon River (Bumgarner et al. 2003; 2004). Genetic analysis indicates that the Tucannon population remains distinct from the Lyons Ferry, but some introgression has occurred (Bumgarner et al. 2003; 2004). The magnitude of diversity loss is High for the Tucannon River because of the high incidence of Lyons Ferry origin spawners.

Limited information is available to evaluate the diversity of populations in the Grande Ronde River and Asotin Creek. Two artificial production programs release juveniles from a broodstock (Wallowa) initiated with adults collected outside of this GDU. Estimates are not available for the percentage of spawners originating from hatchery

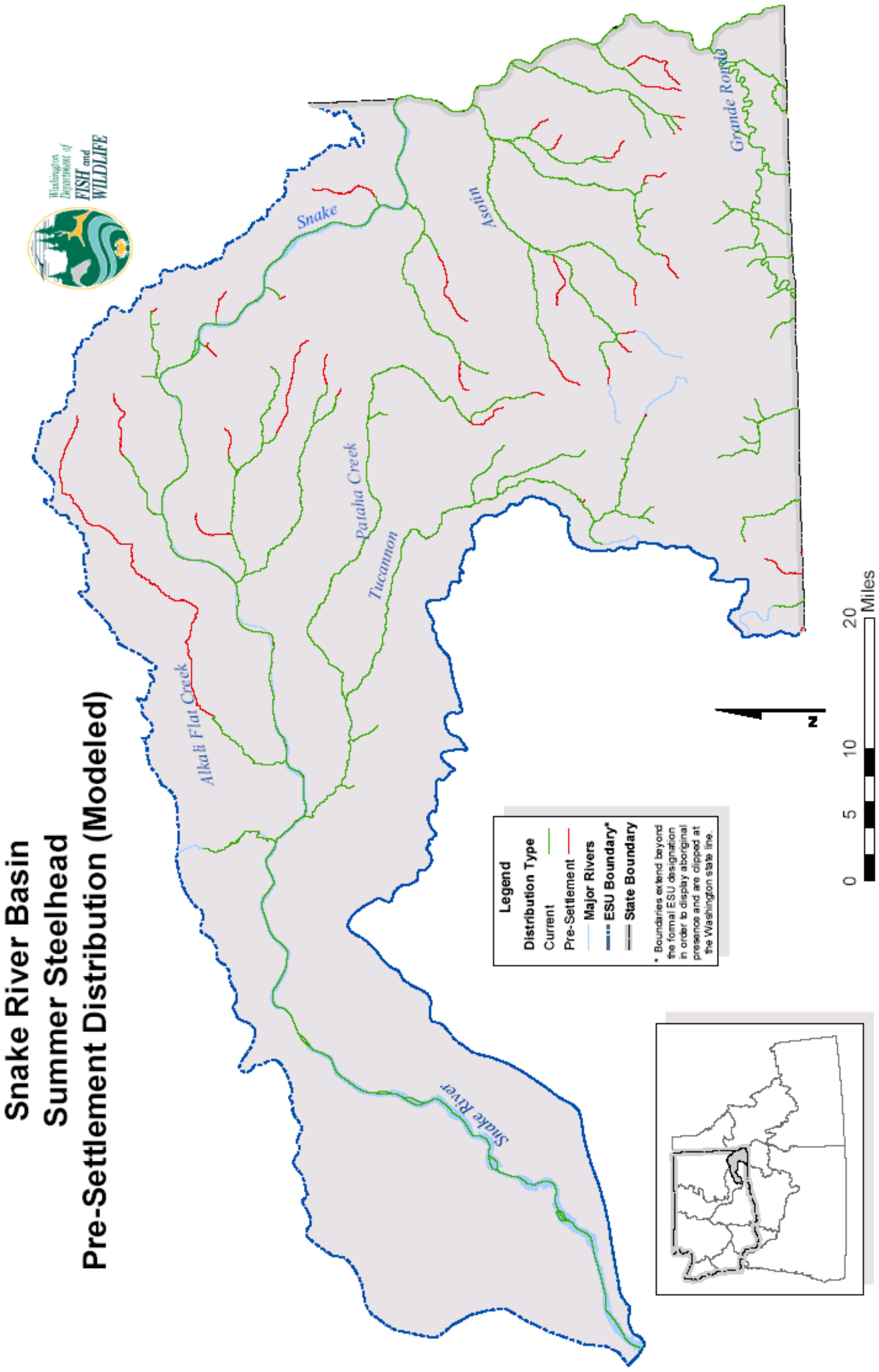

Figure 6-12. Current and predicted pre-settlement distribution of summer steelhead in the Snake River Basin region.

releases. However, NMFS (2004) reviewed data from several traps and hatcheries in the Grande Ronde system and concluded, "there is some information that straying to other Grande Ronde natural production areas is small". NMFS(2004) also reported that "hatchery steelhead have not been reported from Joseph Creek".

Table 6-17. Magnitude of changes in spatial extent, spatial structure, and diversity of extant populations of steelhead in the Washington component of the Snake River Basin region.

Population	**Reduction in Spatial Extent**	**Reduction in Spatial Structure**	**Reduction in Diversity**
Asotin	Low- Moderate [1] (2%-11%)	High (82%)	Unknown
Tucannon		High (66%)	High
Lower Grande Ronde		High (51%)	Unknown
Joseph		High (48%)	Unknown
Snake River Basin Average	Low – Moderate (2% - 11%)	High (62%)	

[1] Change in spatial extent is for all of WRIAs 33 (Lower Snake), 34 (Palouse), and 35 (Middle Snake).

6.4 Discussion

This analysis provides the first cross-state assessment of spatial structure and diversity for any salmonid species in Washington. The results suggest a substantial loss of spatial structure and diversity of steelhead populations in some regions of the state, but also highlight the need for significant improvements in monitoring and analysis.

The reduction in the range of steelhead in Washington was estimated as 9%-27% for winter steelhead and 17%-30% for summer steelhead (Fig. 6-13). Substantial variation existed across the regions, with the smallest reduction in the Snake River Basin region (2%-11%) and the largest reduction in the Upper Columbia River region (43%-52%). Substantial uncertainty existed in the estimate for the reduction of the range in many regions. This was perhaps most evident in the Olympic Peninsula region, where the lack of access points often makes it difficult to identify the upper extent of the distribution of steelhead. The lack of certainty also reflects that only a single variable, gradient, was used in the GIS model to predict the distribution of steelhead.

Despite these limitations, the GIS analysis proved to be a valuable, cost effective method for analyzing spatial data. The graphical display of distribution and barrier data in SalmonScape provided a rapid means to evaluate and check the distribution information, location of populations, and barriers limiting access. The value of the GIS analysis could be substantially enhanced by creating spatial data layers with barriers, by incorporating other variables into the model for predicting fish distribution, and by annually mapping the actual distribution of redds. Mapping the distribution of redds now and in the future will be invaluable as we begin to assess the effectiveness of recovery actions.

A substantial loss in the spatial structure and connectivity of steelhead populations is evident for populations in Washington for which the spatial structure index could be computed (Fig. 6-14). The index was generally not available for populations in the Puget Sound region, Olympic Peninsula region, or the Willapa Bay subregion. In the remainder of the regions, 52% of the populations had a High reduction, 32% had a Moderate reduction, and 16% had a Low reduction in spatial structure and connectivity. All of the populations in the Middle Columbia River, Upper Columbia River, and Snake River basin regions for which an index was computed had a High loss (>30%) of spatial structure (Fig. 6-15).

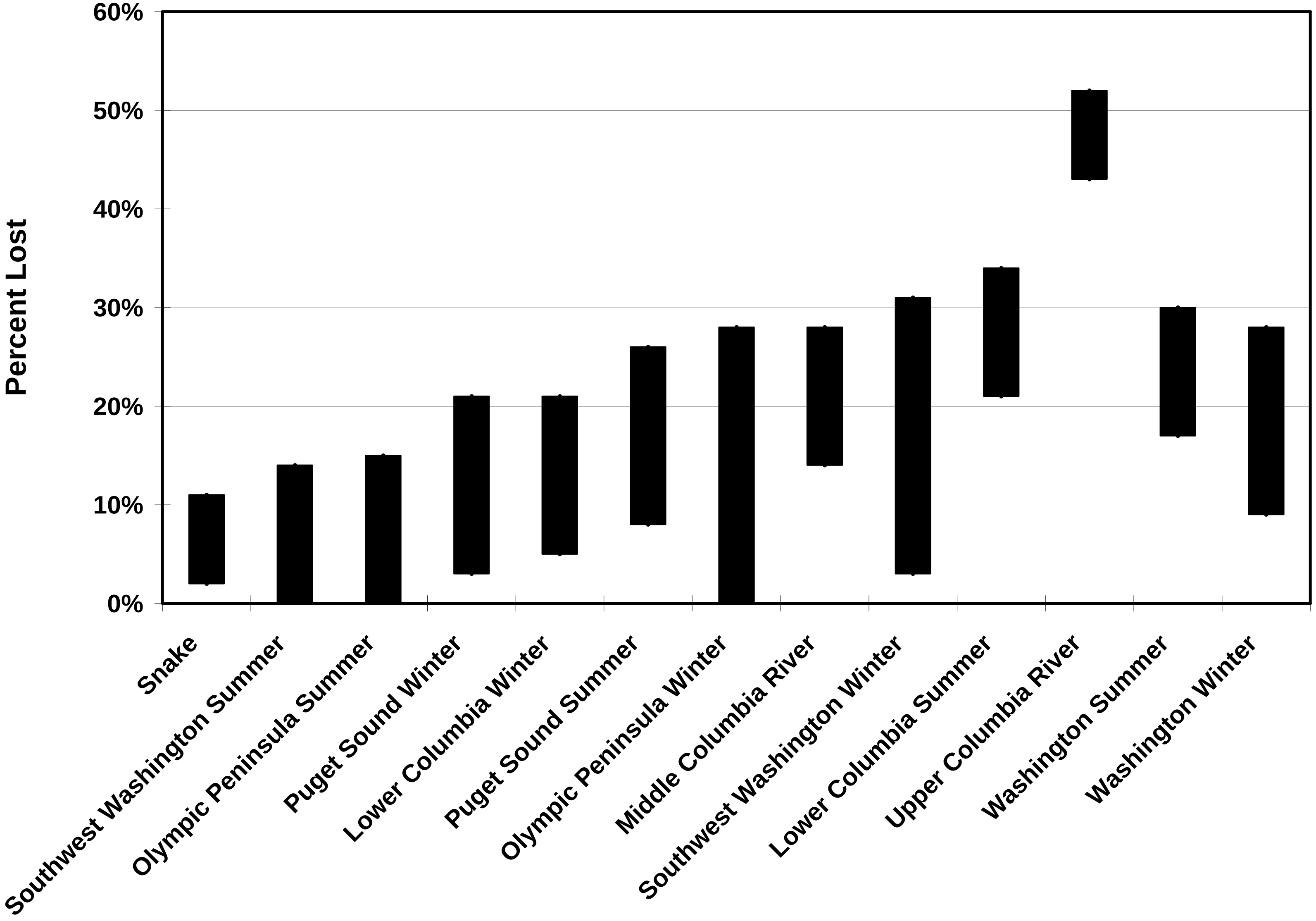

Figure 6-13. Percent reduction in the spatial extent of steelhead in each region in Washington.

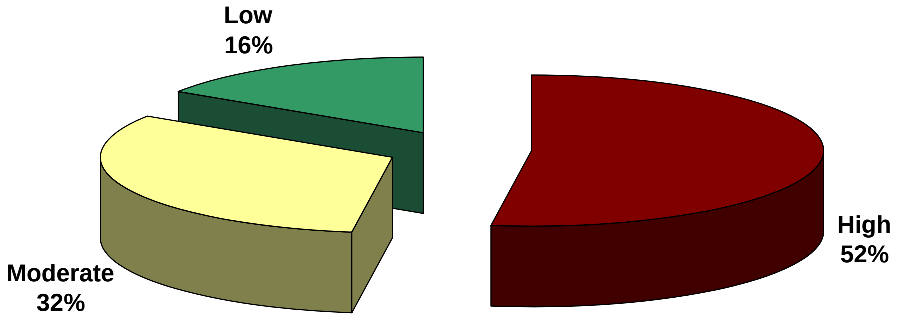

Figure 6-14. Percentage of populations with a High loss of spatial structure. Note that the index was not available for all populations in Washington.

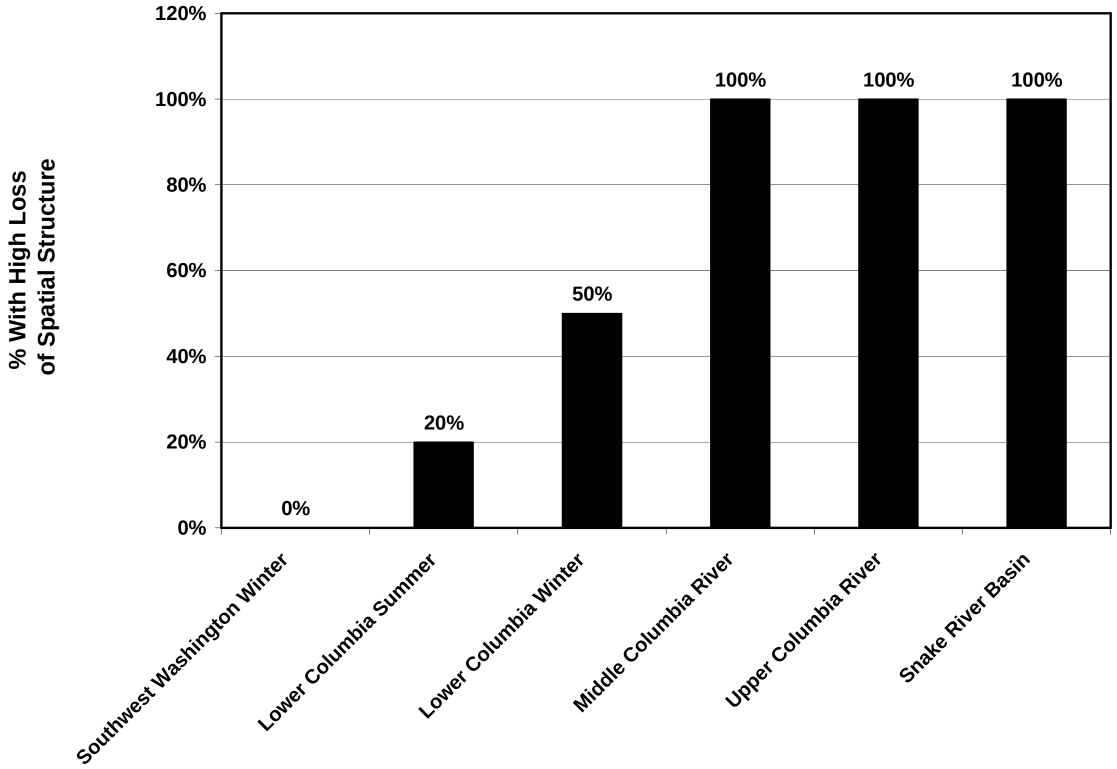

Figure 6-15. Reduction in the spatial structure of steelhead populations in Washington for which the index was computed.

A significant shortcoming exists in our ability to assess changes in the diversity of steelhead populations. Diversity was assessed for only 11% of the populations, typically in locations where research is evaluating the effects of artificial production programs (Yakima-Klickitat Fisheries Project, Snake River Laboratory). Our inability to evaluate changes in diversity is of particular concern given the importance of maintaining within-population diversity, the potential effects of artificial production, harvest, and habitat modifications on diversity, and the reductions in diversity noted in some populations. For populations for which diversity was assessed, 73% of the populations had a High loss of diversity, 20% had a Moderate loss of diversity, and 7% had a Low loss of diversity (Fig. 6-16). We suspect that a more exhaustive search will yield additional diversity data, but this only underscores the need for enhanced data collection, consistent reporting, and improved analyses.

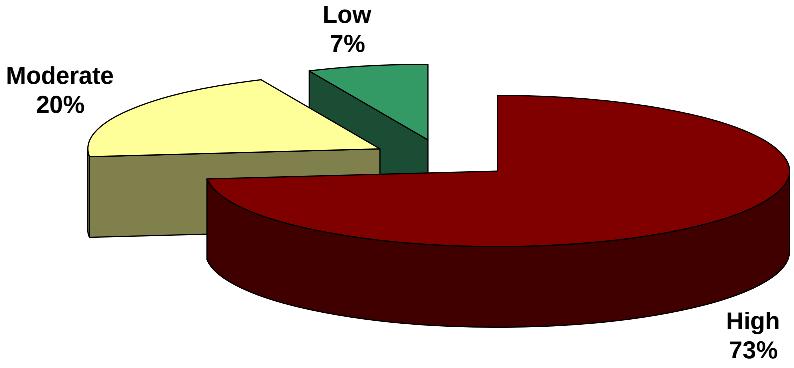

Figure 6-16. Percentage of steelhead populations in Washington that had a Low, Moderate, or High reduction in diversity. Note that the percentage is only for the 15 populations for which the change in diversity was not Unknown.

6.5 Findings and Recommendations

Finding 6-1. A substantial loss of spatial structure and diversity of steelhead populations has occurred in some regions. An estimated 9%-27% of historical winter steelhead habitat and 17%-30% of historical summer steelhead habitat in Washington is no longer accessible or utilized by steelhead. The largest reduction in utilization was in the Upper Columbia region, where an estimated 43%-52% of the historical habitat was no longer used by steelhead. The loss in spatial connectivity was categorized as “High” for 52% of the populations assessed statewide. For the 15 of 134 populations for which a diversity assessment could be completed, 73% had a “High” loss of diversity.

> *Recommendation 6-1.* Pursue opportunities to preserve and restore population structure, spatial structure, and within-population diversity through careful review of harvest, hatchery, and habitat management and implementation of improved strategies.

Finding 6-2. Increased emphasis on monitoring the diversity of *O. mykiss* **populations is needed.** The assessment programs of WDFW, like many other resource management agencies, have traditionally focused on evaluating and monitoring abundance. However, fishery management is rapidly evolving with increased recognition of the importance of diversity in maintaining viable, productive populations. Unlike spawner abundance data, no consistent metrics, protocols, or structure for reporting and analysis of diversity currently exists. The lack of a monitoring program is of special concern for steelhead because of the wide range of life histories expressed by this species, the potential effects of artificial production, fishery harvest, and habitat modifications on diversity, and the reductions in diversity noted in some populations.

> *Recommendation 6-2.* Design and initiate a program to monitor the genotypic and phenotypic characteristics of steelhead populations and a management structure for analysis and reporting. Expanding the scope of the Salmonid Stock Inventory (SaSI) to include data pertaining to diversity and spatial structure as well as spawner abundance data would promote concurrent reporting of all four of the viable salmonid population (VSP) characteristics.

Finding 6-3. A geographic information system (GIS) provides a powerful, cost-effective tool to analyze and present spatial data. Mapping the characteristics of habitat and distribution of redds now and in the future will be invaluable as we begin to assess the effectiveness of improved management strategies and recovery actions.

> *Recommendation 6-3.* Enhance GIS capabilities by creating spatial data layers that identify barriers to fish passage, by incorporating additional variables into the model developed in this paper for predicting fish distribution, and by annually mapping the distribution of redds.

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Appendix 6-A. Methods for GIS Distribution Analysis

Current Distribution

Information on the distribution of summer and winter steelhead was collected during a two-year series of workshops conducted with fish biologists from WDFW, the tribes, and other federal, state, and local agencies. Based upon their experience in each watershed, the biologists reviewed and updated information from two sources: 1) the Limiting Factors Analysis conducted by the Washington Conservation Commission (Smith 2005); and 2) the 1:100,000 scale fish distribution database completed by WDFW in 1998. The biologists were asked to categorize fish distribution and usage according to the following criteria:

> Documented Presence. Stream segments for which steelhead presence is documented in published reports, survey notes, or first-hand sightings. This designation is applied to all stream segments downstream of a documented presence unless otherwise indicated by a formal review group.
>
> Documented Presence-Transported. Stream segments that meet the criteria for “Documented Presence” but for which steelhead presence is maintained by an ongoing fish passage operation (e.g., trap-and-haul) around a manmade barrier.
>
> Documented Presence-Artificial. Stream segments that meet the criteria for “Documented Presence” but which did not historically support steelhead because of the presence of a natural barrier. Current steelhead presence is the result of the removal of a natural barrier through the construction of a fishway, removal of an obstruction, or other factors.
>
> Documented Presence-Historic. Stream segments that formerly meet the criteria for “Documented Presence” based on documentation more than 20 years old at the time of mapping.
>
> Presumed Presence. Stream segments that lack documentation of steelhead use but where, based on the available data and best biological judgment, fish are *presumed* to occur. This presumption is based on the absence of natural or artificial barriers, a stream gradient ≤ 9% for winter steelhead and ≤ 12% for summer steelhead, and the presence of suitable habitat. In determining the suitability of habitat, the biologists considered habitat characteristics, life history requirements, proximity and connectivity to adjacent “Presence Documented” habitat sections, or logical extrapolation of range from similar systems.

> Potential Presence. Stream segments that meet the basic criteria for "Presumed Presence" but which do not currently support steelhead because of the presence of an anthropogenic factor (artificial obstruction or degraded habitat quality) which has a moderate to high potential to be eliminated. "Potential Presence" is not equivalent to the distribution of steelhead prior to European settlement for two reason: 1) it does not include habitat where anthropogenic factors limiting the distribution of steelhead have a low likelihood of being addressed (i.e., it is unlikely that passage above Grand Coulee Dam will be provided in the foreseeable future); or 2) it does not include habitat that biologists were not confident was suitable for use by steelhead.

We subsequently refined the "Presumed Presence" category to identify those areas where the presence of steelhead had historically been blocked by a natural barrier.

> Presumed Presence-Artificial. Stream segments that meet the criteria for "Presumed Presence" but which did not historically support steelhead because of the presence of a natural barrier. Current steelhead presence is the result of the removal of a natural barrier through the construction of a fishway, removal of an obstruction, or other factors.

The origin of steelhead using the stream segment was determined based on the *Salmonid and Steelhead Inventory 2002* (SaSI). Steelhead that are "NonNative" in origin (artificially introduced through hatchery programs) were not included in the maps or presence mileage tables but are discussed in the regional results section. The SaSI assessment of stock origin is available through the WDFW agency web page at http://wdfw.wa.gov/fish/sasi/ or through *http://wdfw.wa.gov/mapping/salmonscape/*.

The distribution information was linked to a 1:24,000 scale hydro-layer and integrated into the WDFW Washington Lakes and Rivers Information System (WLRIS) as a spatial (GIS) dataset. The "Current" distribution of steelhead was defined as:

Current =(Presence Documented) + (Presence Documented Transported) + (Presence Presumed)

Although only information on the "Current" distribution is provided in this report, more detailed maps for individual watersheds and a finer resolution of distribution categories are available through WDFW's SalmonScape web site at *http://wdfw.wa.gov/mapping/salmonscape/*.

The "Range Extension" of steelhead was defined as:

Range Extension = (Presence Documented Artificial) + (Presence Presumed Artificial)

Pre-Settlement Distribution

Information on the distribution of summer and winter steelhead prior to European settlement (referred to as the "Pre-Settlement" distribution) is limited. During the mapping workshops with biologists, we solicited expert opinion on what the distribution of steelhead would have been in the absence of artificial obstructions or habitat degradation ("Potential Presence"). Not surprisingly, the biologists were often unwilling to include parts of the watershed with which they were not personally familiar. The likely result was that the "Potential Presence" distribution defines a lower limit for the distribution of steelhead prior to European settlement.

We developed an alternative approach to explore this concern and define an upper limit to the distribution of steelhead prior to European settlement. The two-step methodology built on the information collected on the current distribution of steelhead and the spatial modeling capabilities provided by a Geographic Information System (GIS):

> Step 1. Develop a GIS model driven by gradient and current distribution to predict historical the distribution of steelhead.
>
> Step 2. Refine the model predictions through a review process with biologists familiar with the ecological and geomorphic characteristics of each watershed.

GIS analysis of the "Pre-Settlement" distribution was conducted only in rivers and streams where steelhead distribution has previously been defined as "Current", "Potential Presence", or "Documented Presence-Historic". The analysis identified stream segments below natural barriers where the gradient did not preclude passage by steelhead. The gradient criteria used for the analysis were ≤ 9% for winter steelhead and ≤ 12% for summer steelhead (SSHEAR 2000) over a contiguous 300 feet stream segment. The initial prediction of the "Pre-Settlement" distribution was defined as:

Lower Limit Pre-Settlement = "Current" + "Presence Potential"
Upper Limit Pre-Settlement = "Current" + "Presence Potential" + GIS Analysis

Maps created from the preliminary analysis were provided to biologists familiar with each watershed for review and refinement. The biologists used their knowledge of watershed characteristics such as riparian conditions, seasonal stream flow, and geomorphology to further constrain the upstream extent of the steelhead distribution. The spatial database was then rebuilt and used to predict the "Upper Limit Pre-

Settlement” distribution of steelhead with the exception of the area above Chief Joseph Dam.

The “Pre-Settlement” distribution of summer steelhead above Chief Joseph Dam was defined based on a 250K scale map from the Dec 1999 draft publication: *Conservation of Columbia Basin Fish: Building a Conceptual Recovery Plan Draft December1999* prepared by The Federal Caucus *www.bpa.gov/federalcaucus*. Refinements to the Upper Columbia Basin distribution will occur in the immediate future when additional information is received by WDFW.

A range contraction for steelhead was defined as:

Lower Limit Range Contraction = (Lower Limit Pre-Settlement) – (Current + Range Extension)
Upper Limit Range Contraction = (Upper Limit Pre-Settlement) – (Current + Range Extension)

Appendix 6-B. Methods for GIS Distribution Analysis

The Benefit-Risk Assessment Procedure (WDFW 2001) was used to identify the potential risk of effective size depression associated with artificial production programs. The table below summarizes the risk associated with different percentages of reduction in the effective size of the population at different levels of population abundance.

Categorization of Risk Associated with Effective Size Depression				
	Census Size of Composite Population			
		<1000/mean age	1000-1500/mean age	>1500/mean age
Percentage Effective Size Reduction	10	High	Moderate	Low
	20	High	Moderate	Low
	30	High	High	Moderate
	40	High	High	Moderate
	>40	High	High	High

Chapter 7

Abundance and Productivity

Key Questions:

a) *How has the production potential of the population been affected by anthropogenic factors?*
b) *What are the SaSI 2002 status ratings for natural populations of steelhead?*
c) *What are the short-term and long-term trends in the abundance and productivity of naturally-spawning populations of steelhead?*
d) *What have been the temporal trends in smolt-to-adult return rates and how have these trends affected population performance?*
e) *What is the relative extinction risk of each population?*

7.1 Introduction

Abundance and productivity are directly related to sustainable fishing opportunities and population viability. NOAA Fisheries has developed general guidelines for population productivity and abundance to assure population viability (see Box 7-1 and Box 7-2). In this chapter, we assess the abundance and productivity of steelhead populations of Washington by comparing the historical and current production potential, evaluating trends in escapement and smolt-to-adult return rates, and conducting population viability analysis.

Box 7-1. Productivity Guidelines

These general guidelines for assuring that the productivity of a population is consistent with viability were provided in *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units* (McElhany et al. 2000). Application of the guidelines requires careful consideration of many population and watershed specific factors.

"1. **A population's natural productivity should be sufficient to maintain its abundance above the viable level.** A population meeting or exceeding abundance criteria for viability should, on average, be able to replace itself. That is, spawner: spawner ratios or cohort-replacement ratios should fluctuate around 1.0 or above. Natural productivity is typically measured as the ratio of naturally produced spawners born in one broodyear to the number of fish spawning in the natural habitat during that broodyear; population abundance estimates at other life-history stages may also be used, provided such estimates span the entire life cycle (e.g., smolt to smolt estimates).

2. **A viable salmonid population that includes naturally spawning hatchery fish should exhibit sufficient productivity from naturally-produced spawners to maintain population abundance at or above viability thresholds in the absence of hatchery subsidy.** In a strict sense, this guideline suggests that the mean Natural Return Ratio (NRR) for a viable population should fluctuate around 1.0, indicating negligible hatchery influence on the population. In a practical sense, the requirement that a viable population be demographically independent of a hatchery population suggests that a viable population's mean NRR not be less than approximately 0.9, but this estimate neglects other issues related to the influence of hatchery fish on natural production. A viable population should not exhibit a trend of proportionally increasing contributions from naturally spawning hatchery fish.

3. **A viable salmonid population should exhibit sufficient productivity during freshwater lifehistory stages to maintain its abundance at or above viable thresholds—even during poor ocean conditions.** A population's productivity should allow it both to exploit available habitat and exhibit a compensatory response at low population sizes. When spawner abundance is below the long-term mean, there should be a corresponding increase in per capita smolt production, even though such an increase may not suffice to offset declines in marine survival.

4. **A viable salmonid population should not exhibit sustained declines in abundance that span multiple generations and affect multiple broodyear-cycles.** "Sustained" declines are those that continue longer than the typical lag in response associated with a population's generation time. Thus, sustained declines differ from rapid transitions between one stable level and another (e.g., changes in abundance related to large-scale, low frequency environmental forcing such as those related to oceanic regime shifts). They also differ from short-term, severe perturbations in abundance, such as those related to strong El Niño events that are followed by relatively rapid recovery.

Box 7-1. Productivity Guidelines (continued)

5. **A viable salmonid population should not exhibit trends or shifts in traits that portend declines in population growth rate.** Changes in such traits, such as size and age of spawners, that affect population growth rate are often more easily and precisely quantified than are changes in abundance and thus, may provide earlier indication of declining population growth rate. For example, reduced size of mature individuals in a population may indicate reduced fecundity, lessened ability to reach spawning grounds, a decreased capacity for constructing redds that are deep enough to resist bed scour, or other factors that contribute to reduced production of offspring. Likewise, increasing age-at return may reduce a population's intrinsic productivity by exposing adults to greater pre-reproductive spawning risk.

6. **Population status evaluations should take into account uncertainty in estimates of population growth rate and productivity-related parameters.** To estimate long-term trends and spawner-recruit ratios, it is important to have an adequate time series of abundance. Unfortunately, such time series, when they exist at all, are often short, contain large observational errors, or both. These constraints may greatly limit the power of statistical analyses to detect ecologically significant trends before substantial changes in abundance have occurred.

Box 7-2. Abundance Guidelines

These general guidelines for assuring that the abundance of a population is consistent with viability were provided in *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units* (McElhany et al. 2000). Application of the guidelines requires careful consideration of many population and watershed specific factors.

"1. **A population should be large enough to have a high probability of surviving environmental variation of the patterns and magnitudes observed in the past and expected in the future.** Sources of such variation include fluctuations in ocean conditions and local disturbances such as contaminant spills or landslides. Environmental variation and catastrophes are the primary risks for larger populations with positive long-term average growth rates.

2. **A population should have sufficient abundance for compensatory processes to provide resilience to environmental and anthropogenic perturbation.** In effect, this means that abundance is substantially above levels where depensatory processes are likely to be important and in the realm where compensation is substantially reducing productivity. This level is difficult to determine with any precision without high quality long-term data on population abundance and productivity, but can be approximated by a variety of methods.

3. **A population should be sufficiently large to maintain its genetic diversity over the long term.** Small populations are subject to various genetic problems, including loss of genetic variation, inbreeding depression, and deleterious mutation accumulation, that are influenced more by effective population size than by absolute abundance.

4. **A population should be sufficiently abundant to provide important ecological functions throughout its life-cycle.** Salmonids modify both their physical and biological environments in various ways throughout their life cycle. These modifications can benefit salmonid production and improve habitat conditions for other organisms as well. The abundance levels required for these effects depend largely on the local habitat structure and particular species' biology.

5. **Population status evaluations should take uncertainty regarding abundance into account.** Fish abundance estimates always contain observational error, and therefore population targets may need to be much larger than the desired population size in order to be confident that the guideline is actually met. In addition, salmon are short-lived species with wide year-to-year abundance variations that contribute to uncertainty about average abundance and trends. For these reasons, it would not be prudent to base abundance criteria on a single high or low observation. To be considered a VSP, a population should exceed these criteria on average over a period of time.

7.2 Methods

7.2.1 Historical and Current Production Potential

We used predictions from the Ecosystem Diagnosis and Treatment (EDT) model (see Box 7-3) (Mobrand et al. 1997) to compare the equilibrium abundance of populations under environmental conditions that existed prior to European settlement ("pre-settlement") and currently. The EDT model relates characteristics of aquatic habitat to life-stage specific estimates of population productivity and capacity. Stage specific estimates are linked using the recursion formula of Mousalli and Hillborn (1986) to define a Beverton-Holt stock production function:

$$R = \frac{aS}{1 + {aS}/{b}},$$

where S is the number of spawners, R is the adult recruitment, a is intrinsic productivity, and b is the carrying capacity. The equilibrium abundance (N_{eq}), or production potential, is the number of spawners that would occur in the absence of fishing harvest and is computed as:

$$N_{eq} = b(1 - \frac{1}{a}).$$

Changes in both the intrinsic productivity and carrying capacity affect the equilibrium abundance.

7.2.2 SaSI Status and Short Term Abundance Trends

In Washington, salmonid stocks are identified and rated healthy, depressed, critical, unknown or extinct in the Salmonid Stock Inventory (WDF et al. 1993; WDFW 2003). Healthy status means that production (generally based on some measure of abundance such as spawner escapement, sport harvest, or juvenile counts) is consistent with the habitat (or goals for the stock), and is within the natural variation for the stock. Depressed status means that production is lower than expected, but not so low that permanent genetic damage to the stock is likely. Critical status means that production is so low that permanent damage to the stock is likely or has already occurred. Unknown status reflects insufficient abundance data used to adequately rate status (e.g. escapement is not monitored). The status of some SaSI stocks, including Deschutes steelhead, was not rated in 2002 because WDFW and tribal biologists

Box 7-3. Ecosystem Diagnosis and Treatment Model

McConnaha (2000) described the Ecosystem Diagnosis and Treatment (EDT) model as "an analytical tool relating habitat features and biological performance to support fish and wildlife planning. It captures a wide range of information and makes it accessible to planners, decision-makers and scientists as a working hypothesis of the ecosystem. EDT acts as an analytical framework that brings together information from empirical observation, local experts, other models and analysis.

EDT differs from models often used in fish and wildlife management and offers important features that can augment conventional methods. EDT is best described as a scientific model (see Hilborn and Mangel, *The Ecological Detective*). A scientific model attempts to explain the mechanisms behind phenomenon to form an overall hypothesis. This contrasts with more conventional statistical models. These provide correlation-based predictions of events without necessarily explaining the underlying mechanism. As a scientific model, EDT constructs a working hypothesis of a subbasin as a basis for planning and for comparison of alternative futures. This hypothesis provides measurable metrics to gauge progress and testable hypotheses to refine knowledge. EDT helps us understand and describe the inevitable complexity of ecological systems in order to plan effective recovery strategies. A statistical model, on the other hand, seeks to reduce complexity to a small number of predictive or correlated variables. A scientific model like EDT provides the hypothesis while a statistical model can provide the test.

The premise of EDT is simple: habitat forms the template for biological performance. Species perceive habitat based on their genetically based potential. The result is species abundance, productivity, diversity and population structure. Although EDT can become complicated due to the fine-scale complexity of its ecological description, it important to bear in mind the underlying simplicity of its premise.

EDT has two major components: a detailed description of the habitat and a set of rules or hypotheses that define an understanding of how a species perceives or responds to that habitat. Habitat units are defined as stream segments based on gradient and stream network. Environmental conditions in each habitat unit are described by 46 attributes that collectively define our understanding of how fish perceive their surroundings. The rules estimate life stage productivities and capacities in the form of the Beverton-Holt relationship. Integrating over a life history trajectory provides population abundance, productivity and diversity.

The environmental attributes and rules in EDT provide, respectively, monitoring attributes and research hypotheses. This provides a framework for accountability, monitoring and research. The environmental description and rules within EDT can be developed and tested through a variety statistical models and research. In this way, EDT presents a scientifically based framework for natural resources planning and action."

concluded that no significant natural production occured, and the presence of small numbers of spawners resulted primarily from the annual returns of first-generation hatchery fish.

Steelhead SaSI status is assessed by local WDFW and tribal biologists who examine abundance data (escapement, harvest, juvenile counts, etc.). If no marked negative trend in abundance is seen, escapement goals are generally being met, and abundance is consistent with the available habitat, the stock is rated Healthy. If a negative trend in abundance is evident, and/or stock abundance falls consistently below the goal for the stock, or if the stock performs below that level expected given the habitat potential available, then stock status is rated depressed or critical. Depressed or critical ratings are made subjectively depending on the condition of the stock. Resident phenotypes were not included in the assessment because information is generally lacking on the abundance and reproductive interactions of resident and anadromous *O. mykiss* in Washington.

We also compared the average abundance of steelhead in 1999 through 2004 relative to 1994 through 1998 to provide a short-term assessment of population performance. In contrast to the SaSI ratings, this assessment is sensitive to annual management actions (e.g., fishery harvest rates, passage) and environmental factors (e.g., flooding, marine survival). The abundance of populations was characterized as increasing, decreasing, or unchanged, where the latter was defined as 10 fish or less difference in the average abundance in the two time periods.

7.2.3 Smolt-to-Adult Return

Estimates of smolt-to-adult return (SAR) rates can often be useful in interpreting observed trends in escapement or recruits per spawners. Since a SAR measure survival from the smolt stage to adult return, it is entirely independent of freshwater survival factors like spawner density and incubation conditions. Trends that are observed reflect factors that act during smolt outmigration and marine residence. Since many populations from a geographic region may have a similar marine distribution, indices from a subset of populations can often help explain survival trends that are occurring on a large geographic scale. Estimates of SAR rates from natural-origin stocks are of the greatest value because they directly measure the attribute of interest. However, estimating the natural steelhead smolt production from watersheds can be difficult and expensive. In the absence of estimates of the natural production of smolts and the subsequent return of adults, SAR indices obtained from the release of hatchery-origin smolts can be used as a surrogate. To avoid confounding the effects of hatchery practices and marine survival conditions, hatchery practices should remain as consistent as possible.

We attempted to select hatchery programs with consistent rearing methods and where estimates of the escapement were available. However, in most cases, the SAR estimates are indices rather than survival rates since not all returning fish are enumerated. This inevitably will underestimate the SAR for smolts released from hatchery programs. The selected programs are summarized briefly below:

> Skagit Winter Hatchery, Quinault Winter Hatchery, Humptulips Winter Hatchery. A SAR index was estimated for each year by dividing the total return (recreational catch, commercial catch, and escapement) of hatchery-origin adults by the total number of smolts released two years previously. This is a SAR index because the escapement of all returning hatchery-origin adults is not enumerated and not all hatchery-origin steelhead return after two summers in marine waters.
>
> Elochoman Winter Hatchery, Washougal Winter Hatchery, Washougal Summer Hatchery. A SAR index was estimated for each year by dividing the total return (recreational catch and hatchery rack escapement) of hatchery-origin adults by the total number of smolts released two years previously. This is a SAR index because the escapement of all returning hatchery-origin adults is not enumerated and not all hatchery-origin steelhead return after two summers in marine waters.
>
> Elwha Winter. A SAR index was estimated for each year by dividing the total return (recreational and commercial catch of natural and hatchery-origin steelhead, and hatchery rack escapement) by the total number of smolts released two years previously. This is an index because the catch includes some fish of natural-origin, all adults do not return after two summers in marine waters, and the escapement of all returning hatchery-origin adults is not enumerated.
>
> Puyallup Winter Hatchery, Quillayute Winter Hatchery. A SAR index was estimated for each year by dividing the total return (recreational catch, commercial catch, hatchery rack return, and number of hatchery-origin adults spawning in the river) by the number of smolts released two years previously. This is a SAR index because the escapement of all returning hatchery-origin adults is not enumerated and not all hatchery-origin steelhead return after two summers in marine waters.
>
> Kalama Winter Hatchery, Kalama Summer Hatchery. A SAR index was estimated for each year by dividing the total return (recreational catch and hatchery rack escapement) of hatchery-origin adults by the total number of

smolts released two years previously. Allocation of catch between summer and winter steelhead for the return years 1976/77 through 1995/96 based on examination of fish at the Kalama Falls trap. Allocation of catch subsequent to 1995/96 based on WDFW catch accounting periods.

Wells Hatchery. A SAR index was estimated for each brood year by dividing the brood return in multiple years to Wells Dam by the number of smolts released in the brood year (WDFW 2002; C. Snow, pers. comm.).

Lyons Ferry Hatchery, Touchet Acclimation Pond. A SAR index was estimated for each brood year by adding the estimated total number of CWT recoveries in catch and escapement by the number of CWTs released (WDFW 2005a).

For some analyses a standardized SAR index was computed by dividing the SAR index by the average SAR index for smolts entering the ocean in the years 1992 through 1995. This was the first four-year period for which a SAR index was available for each of the release locations.

7.2.4 Population Viability Analysis

Steelhead abundance varies in response to freshwater or marine survival, harvest mortality, and the effects of hatchery programs. Often productivity or survival cannot be measured directly, however changes in recruitment or escapement can inform managers about population trends and consequently about extinction risk. Population viability analysis (PVA) is one method that can be used to estimate the rates of change in steelhead abundance and the probability of extinction.

Dennis et al. (1991) proposed an approach for PVA that has been broadly applied and refined for application to salmonid populations. Dennis et al. noted that the survival or extinction of a population is inherently stochastic and developed a rigorous statistical model for estimating growth rates and extinction risk. The stochastic exponential growth model includes one parameter to describe the underlying growth rate of the population and a second to capture annual variation resulting from process error. Process error is variability associated with natural processes (i.e., environmental conditions) and contrasts with measurement error, or errors associated with inaccurate measurement of variables.

Application of the methods of Dennis et al. (1991) to estimate variation in the growth rate may result in estimates of extinction that are biased high if measurement error exists in the observed data. Confounding of measurement error and process error will often result in an estimate of annual variation that is positively biased. In an attempt to separate out the process error, Holmes and Fagan (2002) proposed an alternative approach that they concluded improved the estimation of process error, however, they acknowledged their approach was biased. More recently, Staples et al. (2004) refined the Dennis et al. (1991) method by including appropriate covariance terms, which provided information to separate the process from the measurement error, and resulted in producing unbiased estimates of process error.

We used the population viability analysis of Staples et al. (2004) to estimate trends in wild abundance for 83 populations in Washington State because it provides the ability to estimate both measurement and process error. Data used to quantify trends in wild steelhead populations with the PVA model consist of annual measures of escapement and/or total run size (i.e., escapement plus harvest). Annual measures of mature steelhead in freshwater do not include other important population components such as the large, immature fish still in marine waters or juveniles in freshwater that have yet to migrate to sea. The sum total of all these components comprises a populations abundance at any given point in time, hence the measures used represent a subset of the total population. But as Dennis et al. (1991) point out, the model’s properties are flexible enough so that generally any linear combination of age or stage classes will fulfill the assumptions (e.g., Dennis et. al. 1991 applied it to counts of adult female grizzly bears). Results of the PVA analysis for each population presented in this section should be approached with caution. Populations of particular interest can and should include more site-specific data for a complete analysis, e.g. age composition, resident phenotype influence, and/or habitat parameters.

We chose to limit analyses to those populations with at least estimates of escapement since this portion of the mature run usually constitutes a sizeable fraction, frequently the largest component, of the total mature run. We considered trends for populations with only estimated sport catch as likely to be much more inaccurate.

Using the method of Staples et al. (2004) to estimate trend and process error, we used the estimator for extinction probabilities from Dennis et al. (1991). For these calculations, we defined a quasi extinction level as an escapement estimate of 63 spawners or less, and estimated the probability of arriving at this number in t years for each population:

$$P[T \le t] = \Phi\left(\frac{-x_d + |\hat{\mu}|t}{\hat{\tau}\sqrt{t}}\right) + e^{\frac{2x_d|\hat{\mu}|}{\hat{\tau}^2}}\Phi\left(\frac{-x_d - |\hat{\mu}|t}{\hat{\tau}\sqrt{t}}\right),$$

where $x_d = \ln\left(\frac{63}{\hat{N}_{last}}\right)$;

T = time to extinction;

$\hat{N}_{last}$ = last observed abundance;

$\hat{\mu}$ = estimate of the instantaneous rate of change;

$\hat{\tau}^2$ = estimated process error variance;

Φ = the Normal cumulative distribution function,

t = years.

The quasi extinction level was derived from a threshold of an effective populations size of 50 to minimize the loss of diversity associated with random genetic effects at small population sizes (Frankel and Soule 1981; Nelson and Soule 1987). The ratio of effective population size to census population (N_c) was assumed to be 0.20, and the average generation length was assumed to be four years. The number of census spawners to achieve a per generation effective population size of 50 is then given by:

$$N_c = \frac{50}{(0.20)(4)}$$

All populations with a declining abundance, or a last observed abundance less than 63 will have an extinction probability equal to 1. Hence, the probability is more accurately interpreted as the conditional probability of reaching the extinction threshold of 63 in 100 years given an estimate of a non-decreasing population. The probability $\pi\left(x_d, \mu, \sigma^2\right)$ that the extinction threshold is attained is

$$\pi\left(x_d, \mu, \sigma^2\right) = \begin{cases} 1, \ \mu \leq 0 \\ e^{\frac{-2\mu x_d}{\sigma^2}}, \mu > 0. \end{cases}$$

Confidence intervals for extinction probabilities were estimated using parametric bootstrap methods, for a $\hat{\mu} \sim N\left(\hat{\mu}, \tau^2/n\right)$, where n is the number of log-ratios of abundance in the data set, and a process error, τ^2 with a chi-square distribution of

$$\frac{\hat{\tau}^2}{n} \cdot \chi^2_{n-3} .$$

Viability results were categorized using the methods of Allendorf et al. (1997). Risks or extinction were categorized as Very High if the population had at least a 50% probability of extinction in 5 years; High if the population had a risk of extinction of 20% within 20 years; 3) Moderate if the population had a risk of extinction of 5% within 100 years; and 4) Low if the populations had a risk of extinction of less than 5% within 100 years.

7.3 Results

7.3.1 Puget Sound

Synopsis. A substantial decline in the abundance of the anadromous form of O. mykiss has occurred in many rivers in Puget Sound during the last 20 years. The 2002 SaSI status assessment rated 5 (20%) populations as Healthy, 19 as Depressed (76%), and 1 (4%) as Critical. The decline in abundance likely linked, at least in part, with reductions in smolt-to-adult return (SAR) rates. The average SAR index for hatchery smolts released in the Puget Sound region declined from a peak of 7.0% for smolts entering the ocean in 1983 to 0.2% in 1996 and has remained low since that time. Population viability analysis was used to assess the relative risk of extinction of populations of winter steelhead. Of the 14 populations assessed, 4 (29%) were assessed with a relatively High risk of extinction and 3 (21%) with a Very High risk of extinction. Extinction risk may be biased high for some populations because resident O. mykiss were not explicitly considered in the population viability analysis. On March 26, 2006, NOAA Fisheries proposed listing the Puget Sound DPS as Threatened under the ESA (71 FR 15666)

ESA Status

NOAA Fisheries proposed listing the Puget Sound DPS as Threatened under the ESA on March 26, 2006 (71 FR 15666). A NOAA Biological Review Team reviewed the status of the ESU in 2005 (NMFS 2005). The scores for overall risk category ranged from “neither at risk of extinction nor likely to become so” to “at risk of extinction” in the foreseeable future. However, a majority of the team supported a conclusion that steelhead in the Puget Sound ESU are likely to become at risk of extinction in the future – but are not currently in danger of extinction.

Pre-Settlement and Current Production Potential

The production potential is the average number of spawners expected in the absence of fishing. Comparing the pre-settlement and current production potential provides an assessment of how anthropogenic induced changes have affected the ability of the population to support fisheries and maintain abundance and productivity consistent with a viable population.

The Nisqually Winter population is currently the only population of steelhead in the Puget Sound region for which predictions of historical and current production potential are available. The predicted current production potential of 2,130 is 57% less than the predicted historical production potential of 4,939 (J. Dorner, pers. comm.).

Status and Short-Term Abundance Trend

The 2002 SaSI status assessment rated 20% of the populations as Healthy, 76% as Depressed, and 4% (1 population) as Critical (see Appendix 7-A for population specific assessments). The one critical population, Lake Washington, had an escapement of less than 50 fish in each year from 2000 through 2004. However, resident *O. mykiss* are abundant within this watershed (Fleishcher 2005). The five Healthy populations are distributed throughout the Puget Sound ESU: 1) Samish Winter; 2) South Fork Skykomish Summer; 3) Tolt Summer; 4) Green Winter; and 5) Discovery Bay Winter. A status assessment could not be completed for 27 populations (52%) because of insufficient data.

Table 7-1. Status of steelhead populations in the Puget Sound region.

Run timing	Number of Populations	Populations with unknown status	Populations with known status			
			Number	Healthy (%)	Depressed (%)	Critical (%)
Summer	16	12	4	2 (50%)	2 (50%)	0 (0%)
Winter	36	15	21	3 (14%)	17 (81%)	1 (5%)
All	52	27	25	5 (20%)	19 (76%)	1 (4%)

A decline in abundance in recent years is generally evident from the analysis of short-term trends in escapement (Table 7-1 and Fig. 7-1)(see Appendix 7-A for population specific assessments). Only 21% of the populations had an increase in the average escapement from 1999 through 2004 relative to the period 1994 through 1998; 67% of the populations had a reduction in the average escapement. Greatest reductions were evident for the Carbon Winter (-50%), Pilchuck Winter (-51%), Snohomish/Skykomish Winter (-55%), and Lake Washington Winter (-79%) winter populations. The average escapement of the Hamma Hamma Winter population increased by more than 300% as the result of a artificial production program. Excluding the Hamma Hamma population, escapements decreased by an average of 23% in 1999 through 2004 relative to the prior five years.

The Nooksack River is the only major river system in this region lacking a historical time series of escapement data. Surveys conducted in this basin in 2003-2004 indicated that a substantial winter steelhead population may exist, with a estimated escapement of over 1,500 spawners.

Table 7-2. Short-term trend in escapement for steelhead populations in the Puget Sound region. Base years are 1994 through 1998; years for comparison are 1999 through 2004.

Run timing	Number of populations	Populations without spawner data	Populations with spawner data			
			Number	Increasing (%)	Unchanged (%)	Decreasing (%)
Summer	16	12	4	1 (25%)	1 (25%)	2 (50%)
Winter	36	17	20	4 (20%)	2 (10%)	14 (70%)
All	52	29	24	5 (21%)	3 (12%)	16 (67%)

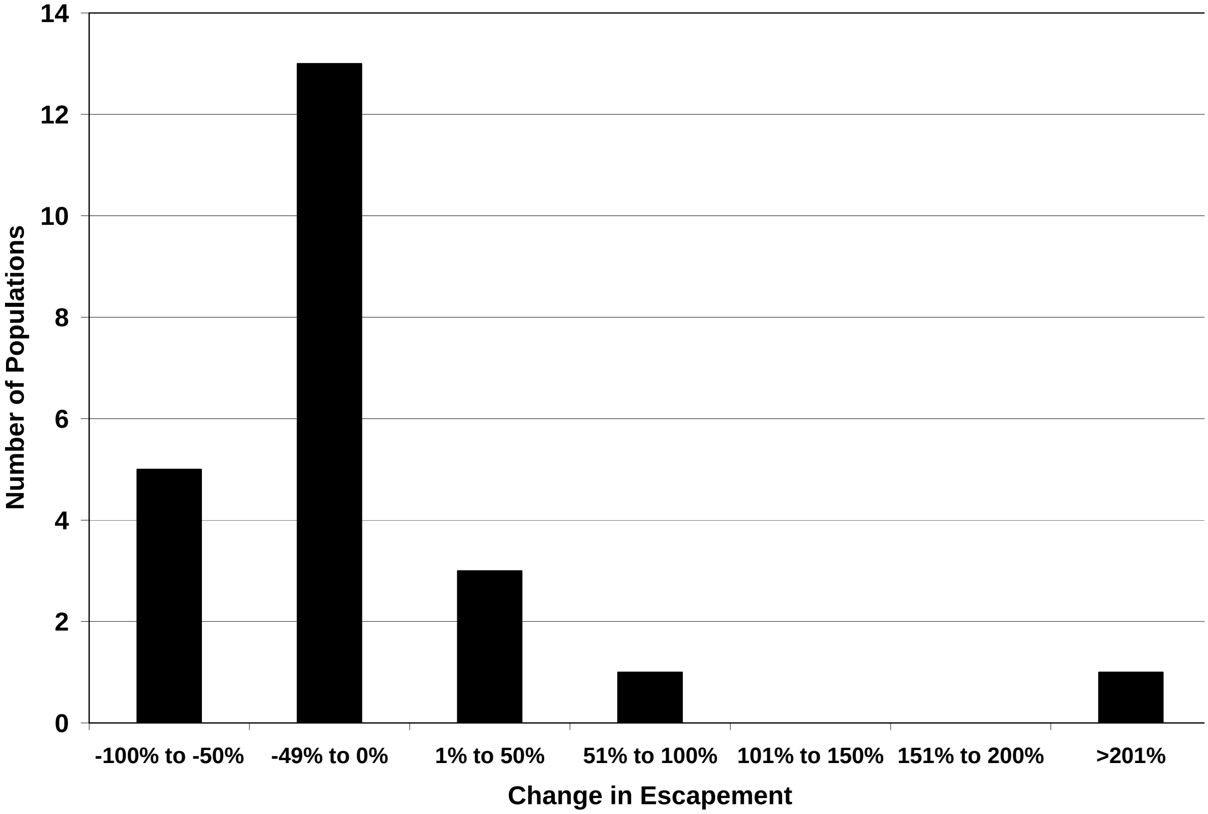

Figure 7-1. Change in the average escapement for populations of steelhead in the Puget Sound region in 1999 through 2004 relative to the average escapement in 1993 through 1998.

Smolt-to-Adult-Return

Indices for the smolt-to-adult return (SAR) rate were estimated for hatchery releases of winter steelhead into the Skagit River, the Puyallup River, and the Elwha River (Fig. 7-2). All three rivers showed a similar pattern with the largest SAR indices occurring for smolts entering the ocean in 1983. The average SAR index declined from a peak of 7.0% for smolts entering the ocean in 1983 to 0.2% in 1996. The average SAR index has remained at a low level since that time, ranging from 0.2% to 0.5% for hatchery smolts entering the ocean in the period from 1997 through 2002.

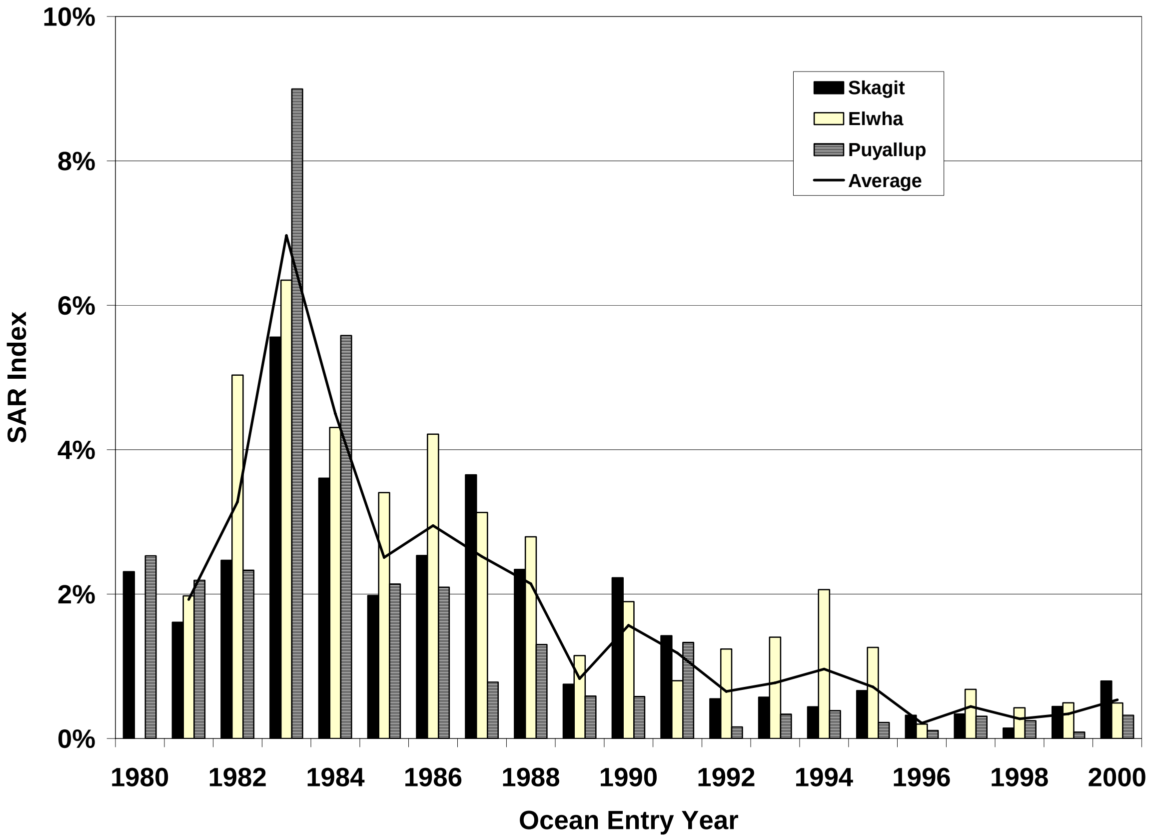

Figure 7-2. SAR indices for hatchery-origin winter steelhead smolts released into the Skagit, Elwha, and Puyallup rivers.

Population Viability Analysis

Population viability analyses are critically dependent upon correctly identifying population structure. Uncertainty in our understanding of population structure is higher in the Puget Sound region because a systematic review has not been recently conducted (see Chapter 5, Population Identification). The results from the population viability analysis described below should be considered preliminary until that review is completed.

The population growth rate could be estimated for 20 populations with a time series of at least 8 years of escapement data or indices of escapement (Table 7-3). A negative population growth rate was estimated for 12 (60%) of the populations. Five populations had p-values of less than or equal to 0.11 for a statistical test of the null hypothesis that the growth rate was nonnegative. These populations were distributed throughout the Puget Sound ESU: 1) the Stillaguamish Winter population in North Puget Sound; 2) the Carbon Winter and Nisqually Winter populations in South Puget Sound; 3) the Skokomish Winter population in Hood Canal; and 4) the Morse Creek-Independents population in the Strait of Juan de Fuca.

Population viability analysis was used to assess the relative risk of extinction for each population with a times series of at least 8 years of escapement data. Confidence intervals of the risk of extinction were generally wide at the 20 and 100-year time horizons (see Appendix 7-B) which suggests that the results should be used with caution and only to broadly assess the relative extinction risk of the populations. Of the 14 populations assessed, 7 (50%) were characterized with a relatively Low risk of extinction, 4 (29%) with a relatively High risk, and 3 (21%) with a Very High risk of extinction (Table 7-3). None of the populations with a relatively High or Very high risk of extinction were located in North Puget Sound, while 2 of the 3 populations with a Very High risk of extinction (Lake Washington Winter and Mainstem Puyallup Winter) are located in South Puget Sound.

All of the population viability analyses were conducted under the assumption that only anadromous spawners contribute to the abundance of each population. This assumption may result in estimates of extinction risk that are too high because the presence of resident forms of *O. mykiss* may reduce the likelihood of extinction. Perhaps the most extensive data exists for resident *O. mykiss* in the Cedar River. The abundance of resident fish of greater than 200 mm fork length in 2003 was estimated as 17,468 fish, or approximately 800 fish per mile (Fleischer 2005).

Table 7-3. Growth rate, p-value for statistical test ($H_0 : \mu \geq 0$), estimated process error ($\hat{\tau}^2$), and relative risk of extinction for populations of steelhead in the Puget Sound region.

Population	Last Escapement	Growth Rate		$\hat{\tau}^2$	Relative risk
		Estimate	p-value		
Samish Winter	930	+0.06	0.69	0.33	Low
Skagit Winter	7,332	+0.01	0.63	0.04	Low
Stillaguamish Winter	[1]	-0.07	<0.01	<0.01	[1]
Snohomish-Skykomish Winter	2,188	+0.02	0.63	0.10	Low
Pilchuck Winter	1,336	+0.04	0.68	0.19	Low
Tolt Summer	[1]	-0.05	0.32	0.20	[1]
Snoqualmie Winter	708	-0.03	0.26	0.03	Low
Lake Washington Winter	44	-0.16	0.16	0.54	Very High
Green Winter	2,383	+0.02	0.70	0.03	Low
Mainstem Puyallup Winter	91	-0.06	0.16	0.07	Very High
White (Puyallup) Winter	184	-0.01	0.43	0.14	High
Carbon Winter	410	-0.07	0.02	0.02	High
Nisqually Winter	730	-0.07	0.02	0.02	High
Dewatto Winter	[1]	-0.01	0.37	<0.01	[1]
Tahuya Winter	[1]	+0.01	0.58	0.10	[1]
Skokomish Winter	223	-0.08	<0.01	<0.01	High
Dosewallips Winter	[1]	+0.03	0.79	<0.01	[1]
Duckabush Winter	[1]	+0.02	0.57	<0.01	[1]
Discovery Bay Winter	40	-0.03	0.29	0.08	Very High
Morse Creek-Independents Winter	121	-0.01	0.11	0.01	Low

[1] Estimate of escapement is an index so population viability could not be quantitatively analyzed.

7.3.2 Olympic Peninsula

Synopsis. Populations of winter steelhead in the Olympic Peninsula region were generally rated as Healthy in the 2002 SaSI assessment. Only one population, Lower Quinault/Quinault Lake Winter, was rated as Depressed and no populations were rated as Critical. Short-term trends in escapement are also generally positive for winter steelhead in the Olympic Peninsula region. Average escapement increased in 1999 through 2004 relative to the prior five years for eight populations (62%) and decreased in only three populations. Smolt-to-adult return (SAR) rates have declined from the peak levels observed in the early 1980s, but remain on average at the highest level (approximately 4%) of any region in the state. Population viability analysis indicated that the relative risk of extinction was Low for all populations with the exception of Salt Creek Winter.

ESA Status

Populations of steelhead in the Olympic Peninsula ESU are not listed under the ESA.

Pre-Settlement and Current Production Potential

Predictions of pre-settlement and current production potential are not available for any populations of steelhead in the Olympic Peninsula region.

SaSI Assessment and Short-Term Trends

Populations of winter steelhead in the Olympic Peninsula region were generally rated as Healthy in the 2002 SaSI assessment (Table 7-4) (see Appendix 7-A for population specific assessments). Only one population, Lower Quinault/Quinault Lake Winter, was rated as Depressed and no populations were rated as Critical. However, status assessments were not possible for 52% of the populations of any run timing, and no status assessments were possible for summer steelhead.

Short-term trends in escapement were also generally positive for winter steelhead in the Olympic Peninsula region (Table 7-5 and Fig. 7-3)(see Appendix 7-A for population specific assessments). Average escapement increased in 1999 through 2004 relative to the prior five years for eight populations (62%) and decreased in only three populations. In two of the three latter populations (Sol Duc Winter and Hoh Winter), the average escapement remained greater than the escapement goal. Escapements increased by an average of 4% in 1999 through 2004 relative to the prior five years for populations in the Olympic Peninsula region.

Table 7-4. Status of steelhead populations in the Olympic Peninsula region.

Run timing	Number of Populations	Populations with unknown status	Populations with known status			
			Number	Healthy (%)	Depressed (%)	Critical (%)
Summer	7	7	0	NA	NA	NA
Winter	24	11	13	12 (92%)	1 (8%)	0 (0%)
All	31	18	13	12 (92%)	1 (8%)	0 (0%)

Table 7-5. Short-term trend in escapement for steelhead populations in the Olympic Peninsula region. Base years are 1994 through 1998; years for comparison are 1999 through 2004.

Run timing	Number of Populations	Populations without spawner data	Populations with spawner data			
			Number	Increasing (%)	Unchanged (%)	Decreasing (%)
Summer	7	7	0	NA	NA	NA
Winter	24	11	13	8 (62%)	2 (15%)	3 (23%)
All	31	18	13	8 (62%)	2 (15%)	3 (23%)

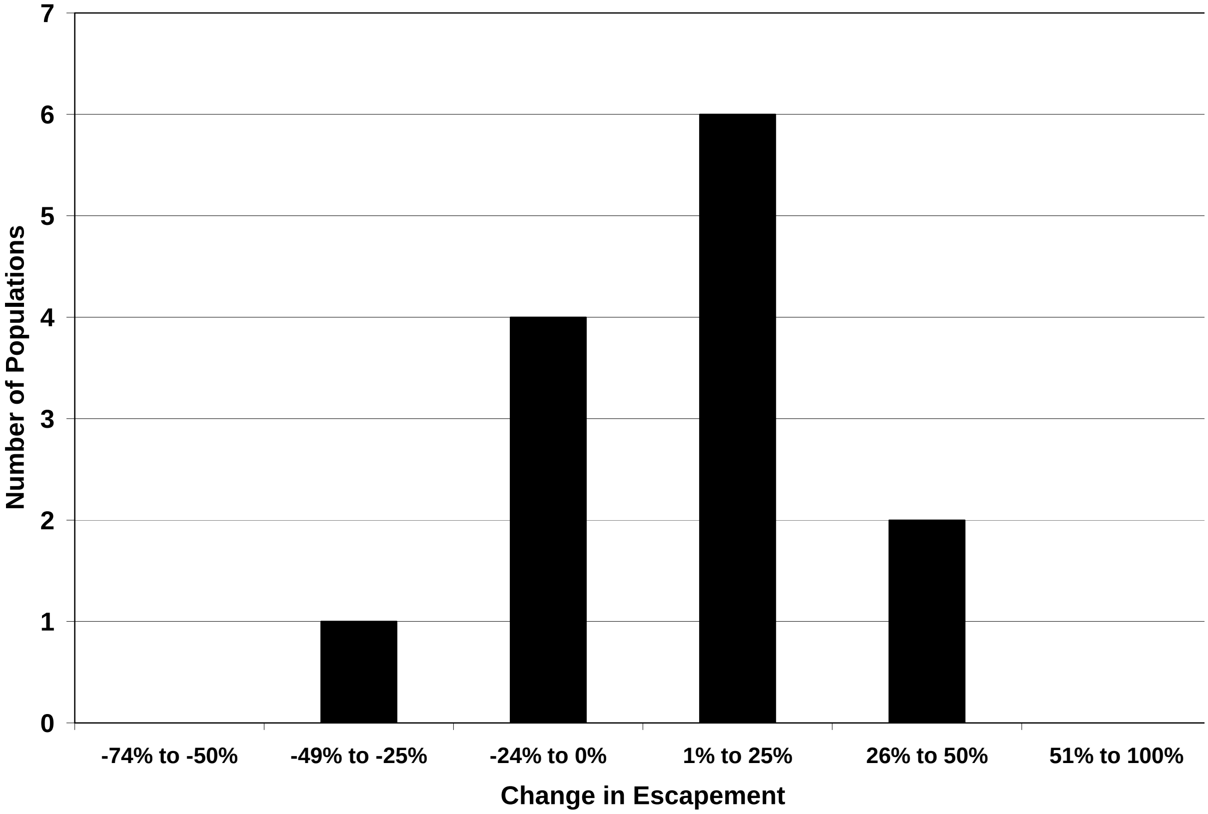

Figure 7-3. Change in the average escapement for populations of steelhead in the Olympic Peninsula region in 1999 through 2004 relative to the average escapement in 1993 through 1998.

Smolt-to-Adult Return

Smolt-to-adult return (SAR) indices were computed for hatchery-origin winter steelhead released into the Quinault and Quillayute rivers (Fig. 7-4). The average SAR indices for the Olympic Peninsula can be grouped into three general categories: 1) smolts entering the ocean from 1977 through 1981 had an average SAR index of approximately 6%; 2) 1982 though 1987 were characterized by SAR indices of approximately 8%-12%; and 3) 1989 through 2001 were characterized by SAR indices of approximately 4%.

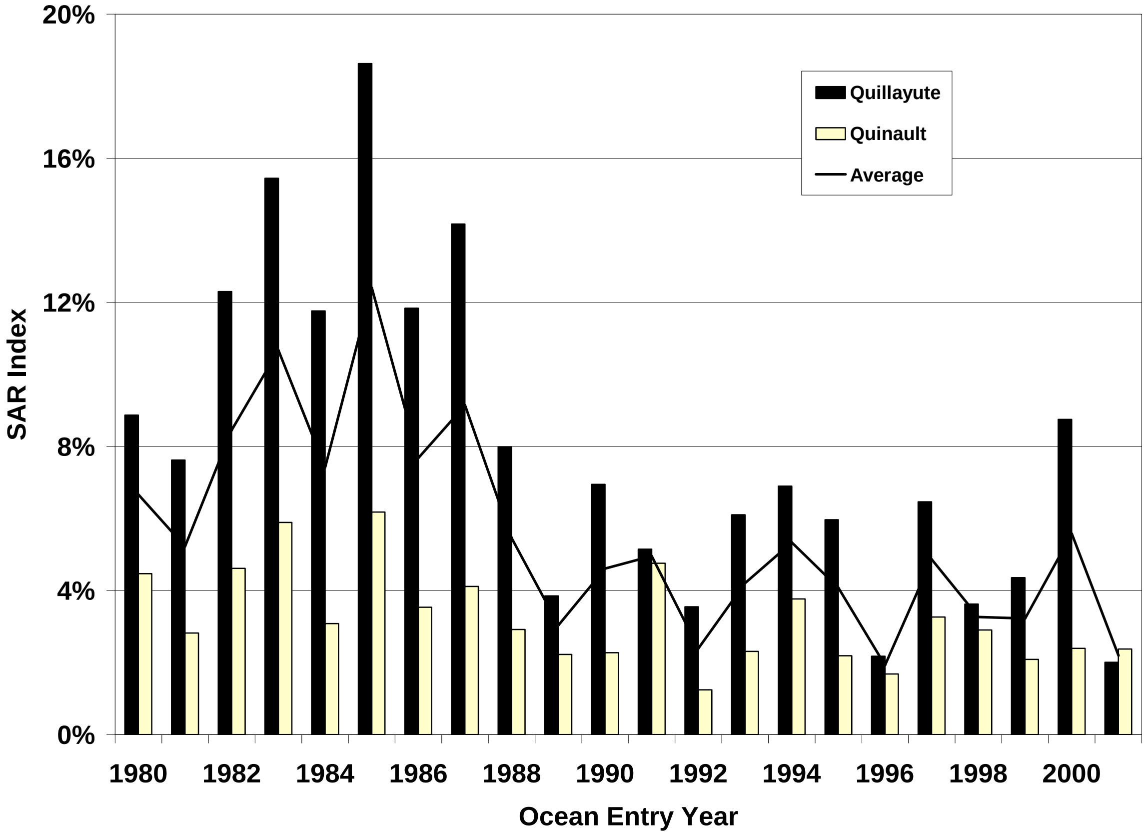

Figure 7-4. SAR indices for hatchery-origin winter steelhead smolts released into the Quillayute and Quinaut rivers.

Population Viability Analysis

Population viability analyses are critically dependent upon correctly identifying population structure. Uncertainty in our understanding of populations structure is higher in the Olympic Peninsula because a systematic review has not been recently conducted (see Chapter 5, Population Identification). The results from the population viability analysis described below should be considered preliminary until that review is completed.

The estimated population growth rate was positive for seven populations and negative for four populations (Table 7-6). A test of the null hypothesis that the growth rate was greater than or equal to 0 was rejected an $\alpha \leq 0.10$ for only the Salt Creek Winter population. The significance of this result is uncertain because the estimated escapement has exceeded the escapement goal in 6 of the last 10 years, including the final year of the time series of data.

The negative population growth rates estimated for the Hoko Winter, Dickey Winter, and Hoh Winter population are not a conservation concern. All populations remain within or above the normal range of variation about escapement goals that have been established by the comanagers:

1) The estimated escapement of the Hoko Winter population in 2004 was 747 winter steelhead with an escapement goal of 400.
2) The Dickey Winter population is part of the Quillayute River management unit. The escapement for the Quillayute River in 2004 was 11,464 relative to an escapement goal of 5,900. Of the 5,900 fish escapement goal for the Quillayute River, the Dickey Winter population component is 123 fish. The estimated escapement of the Dickey Winter population has exceeded 123 fish in every year since 1986.
3) The estimated escapement of the Hoh Winter population in 2004 was 2,268 winter steelhead with an escapement goal of 2,400.

Population viability analysis indicated that the risk of extinction was relatively Low for all populations with the exception of the Salt Creek population. Risk of extinction for the Salt Creek Winter population was rated as Moderate because of the estimated negative growth rate and the relatively small size of the population.

Table 7-6. Growth rate, p-value for statistical test ($H_0 : \mu \geq 0$), estimated process error ($\hat{\tau}^2$), and relative risk of extinction for populations of steelhead in the Puget Sound region.

Population	Last Escapement	Growth Rate		$\hat{\tau}^2$	Relative risk
		Estimate	p-value		
Salt Creek-Independents Winter	170	-0.04	0.07	<0.01	Moderate
Pysht-Independents Winter	367	+0.01	0.57	0.04	Low
Hoko Winter	747	-0.01	0.28	<0.01	Low
Quillayute-Bogachiel Winter	2,163	+0.01	0.55	0.09	Low
Dickey Winter	418	-0.00	0.49	0.06	Low
Sol Duc Winter	5,110	+0.01	0.64	0.03	Low
Calawah Winter	3,773	+0.03	0.70	0.07	Low
Goodman Creek Winter	374	+0.06	0.76	0.05	Low
Hoh Winter	2,268	-0.01	0.41	0.03	Low
Queets Winter	7,840	+0.01	0.60	0.06	Low
Clearwater Winter [1]					
Lower Quinault-Quinault Lake Winter [1]					
Quinault Winter	1,201	+0.01	0.76	<0.01	Low

[1] Analysis not yet completed.

7.3.3 Southwest Washington

Synopsis. The status of populations in the Southwest Washington region varies by sub-region. **In** *2002 SaSI assessed 100% of the populations in the Willapa sub-region as Healthy, 57% of the populations in the Grays Harbor subregion as Healthy, and 0% of the populations in the Columbia Mouth sub-region as Healthy. Smolt-to-adult return (SAR) rates appear to have declined for populations in the Columbia Mouth sub-region from the mid-1980s to the mid-1990s. SAR rates subsequently increased in both the Grays Harbor and Columbia Mouth subregions as did the escapement of many natural populations. Escapement increased by an average of 116% in 1999 through 2004 relative to the previous 5-year period. Population viability analysis suggests that two out of the three populations in the Columbia Mouth subregion remain at a relatively High risk of extinction.*

ESA Status

Populations of steelhead in the Southwest Washington ESU are currently not listed under the ESA.

Pre-Settlement and Current Production Potential

The current and pre-settlement production potential for many winter steelhead populations in Grays Harbor are available through a study funded by the Chehalis Basin Fisheries Task Force, WDFW, U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers (Mobrand Biometrics 2003) (Table 7-7). Relative to pre-settlement conditions, the production potential of winter steelhead populations in Grays Harbor are predicted to have been reduced by an average of 68% (range 60% to 74%). The smallest reduction (60%) is predicted for the Hoquiam Winter population and the largest reduction (76%) for the South Bay Winter population.

The production potential of steelhead populations in the Columbia Mouth sub-region was assessed during the development of the Lower Columbia recovery plan (LCRFB 2004). An average of 56% of the production potential is predicted to have been lost relative to pre-settlement conditions for populations in this region.

No predictions are available for the production potential of steelhead populations in the Willapa Bay subregion.

SaSI Assesment and Short-term Trends

Population status as rated by SaSI in 2002 varies by subregion (Table 7-8)(see Appendix 7-A for population specific assessments). All of the winter populations in the Willapa subregion were rated as Healthy, 57% in the Grays Harbor subregion were Healthy, but 100% of the populations in the Columbia Mouth subregion were rated as Depressed. No populations were rated as Critical in any of the subregions. Population status of the two summer populations in the Grays Harbor subregion could not be assessed because of the lack of abundance data.

The escapement of populations of winter steelhead in the Southwest Washington region increased by an average of 116% in 1999 through 2004 relative to the previous 5 years (Table 7-9 and Fig. 7-5). An increase in the average escapement occurred for 15 of the 16 winter steelhead populations for which escapement is monitored. The exception was the Hoquiam Winter population, for which the escapement was below the goal in every year from 1999 through 2003. However, the escapement increased to 950 fish in 2004, or 500 fish greater than the escapement goal.

Table 7-7. Current and pre-settlement production potential (equilibrium adult abundance) for winter and summer populations of steelhead in the Lower Columbia River region.

Population	Current	Pre-settlement	Percent lost
Grays Habor			
Chehalis Winter	1,731	6,719	74%
Hoquiam Winter	223	561	60%
Humptulips Winter	884	2,437	64%
Satsop Winter	983	2,903	66%
Skookumchuck-Newaukum Winter	993	3,357	70%
South Bay Winter	37	152	76%
Wishkah Winter	184	508	64%
Wynoochee Winter	389	1,356	71%
Grays Harbor Average			68%
Columbia Mouth			
Mill-Abernathy-Germany Winter	838	1,936	57%
Elochoman-Skamokawa Winter	416	936	56%
Grays Winter	1,072	2,399	55%
Columbia Mouth Average			56%
Southwest Washington Average			65%

Table 7-8. Status of winter steelhead populations in the Southwest Washington region.

Sub-region	Number of Populations	Populations with unknown status	Populations with known status			
			Number	Healthy (%)	Depressed (%)	Critical (%)
Grays Harbor	8	1	7	4 (57%)	3 (43%)	0 (0%)
Willapa	6	0	6	6 (100%)	0 (0%)	0 (0%)
Columbia Mouth	3	0	3	0 (0%)	3 (100%)	0 (0%)
All	17	1	16	10 (63%)	6 (37%)	0 (0%)

Table 7-9. Short-term trend in escapement for winter steelhead populations in the Southwest Washington region. Base years are 1994 through 1998; years for comparison are 1999 through 2004.

Sub-region	Number of Populations	Populations without spawner data	Populations with spawner data			
			Number	Increasing (%)	Unchanged (%)	Decreasing (%)
Grays Harbor	8	1	7	6 (86%)	0 (0%)	1 (14%)
Willapa	6	0	6	6 (100%)	0 (0%)	0 (0%)
Columbia Mouth	3	0	3	3 (100)	0 (0%)	0 (0%)
All	17	1	16	15 (94%)	0 (0%)	1 (6%)

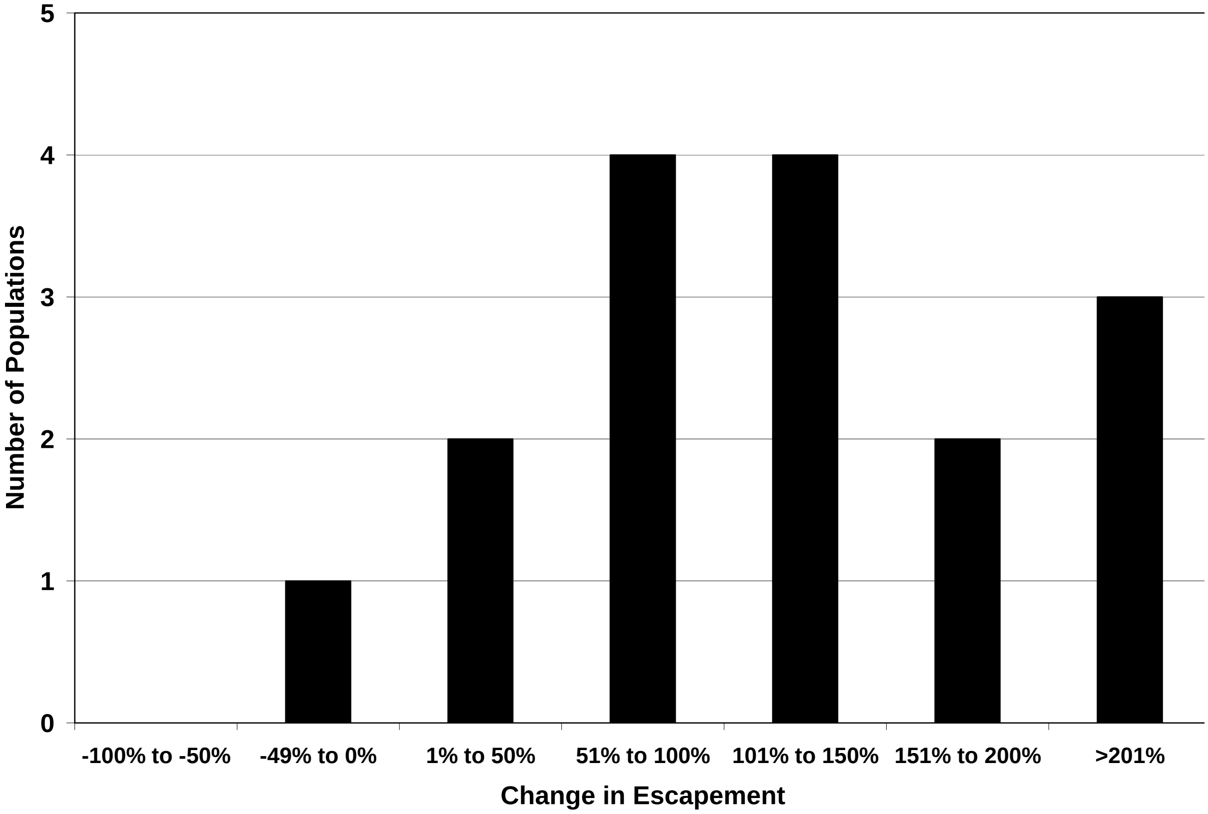

Figure 7-5. Change in the average escapement for populations of steelhead in the Southwest Washington region in 1999 through 2004 relative to the average escapement in 1993 through 1998.

Smolt-to-Adult Return

Indices for the smolt-to-adult survival rate could be estimated for winter steelhead smolts released into the Elochoman River and the Humptulips River (Fig. 7-6). The index for the Elochoman River showed a declining trend for smolts entering the ocean from 1985 through 1995. The SAR index increased after 1995 but generally remained below levels observed prior to 1994.

The time span of the data series for winter steelhead smolts released into the Humptulips River is limited to ocean entry in the years 1992 through 2002. The limited data available suggest that SAR rates were also low during the mid-1990s, but increased in the years 2000 through 2003.

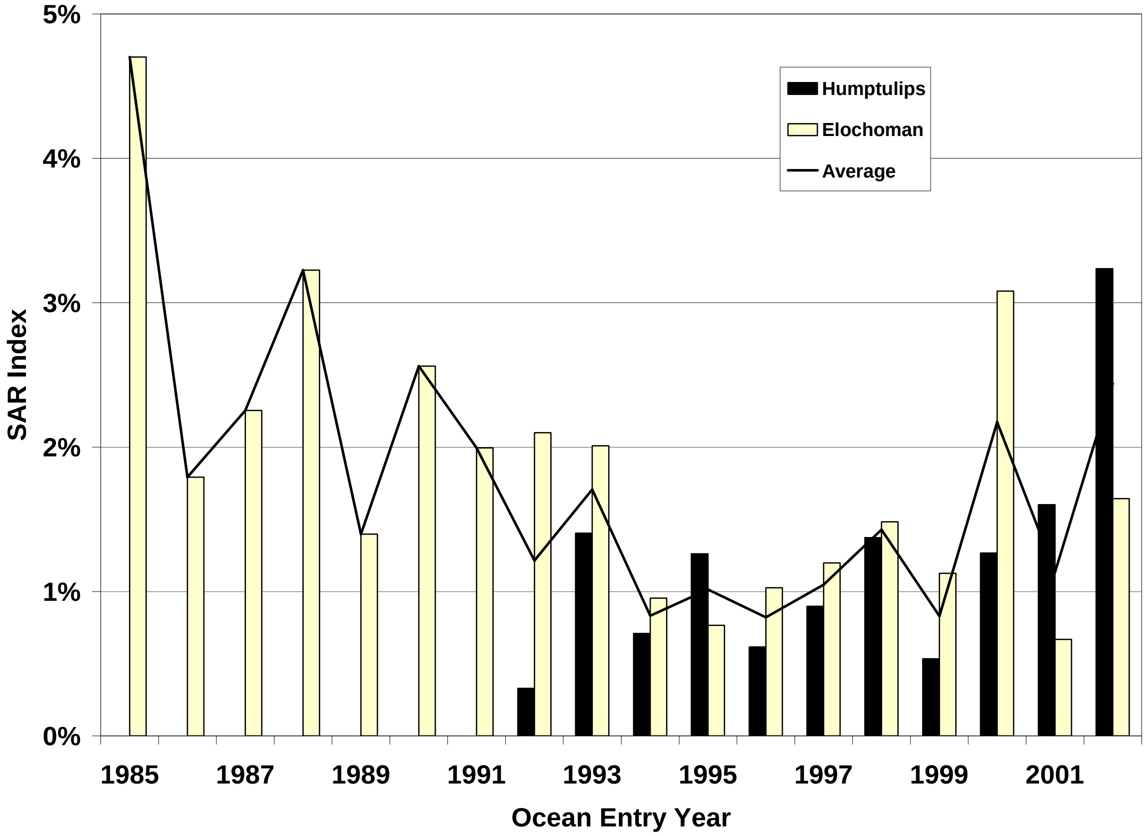

Figure 7-6. Average SAR survival indices for summer and winter steelhead smolts released into the Elochoman and Humptulips rivers.

Population Viability Analysis

Population viability analyses are critically dependent upon correctly identifying population structure. As discussed in Chapter 5 (Population Identification), greater uncertainty exists in the population structure in regions that have not been systematically reviewed by a Technical Recovery Team or agency staff. The results from the population viability analysis described below should be considered preliminary until that review is completed.

The population growth rate was estimated for 16 populations with a time series of at least 8 years of escapement data or indices of escapement (Table 7-10). The estimated growth rate was positive for 14 of the 16 populations, and for no population did the statistical test of the null hypothesis ($H_0 : \mu \geq 0$)result in a p-value of less than 0.10.

The percentage of the populations in each region with a relative risk of extinction that was not Low varied between the sub-regions. All seven populations analyzed in the Grays Harbor region were assessed to have Low risk; one of six populations in the

Willapa sub-region was assessed as relatively High risk; and two of three populations in the Columbia Mouth sub-region were assessed as High risk.

Table 7-10. Growth rate, p-value for statistical test ($H_0 : \mu \geq 0$), estimated process error ($\hat{\tau}^2$), and relative risk of extinction for populations of steelhead in the Southwest Washington region.

Population	Last Escapement	Growth Rate Estimate	Growth Rate p-value	$\hat{\tau}^2$	Relative risk
Grays Harbor					
Chehalis Winter	3,704	-0.00	0.48	0.32	Low
Hoquiam Winter	950	-0.03	0.11	0.01	Low
Humptulips Winter	3,884	+0.00	0.52	0.05	Low
Satsop Winter	4,519	+0.01	0.55	0.04	Low
Skookumchuck/Newaukum Winter	2,438	+0.05	0.82	0.05	Low
Wishkah Winter	1,102	+0.00	0.50	0.19	Low
Wynoochee Winter	3,162	+0.06	0.70	0.23	Low
Willapa Bay					
Bear River Winter	461	+0.10	0.66	0.33	High
Naselle Winter	1,856	+0.10	0.97	<0.01	Low
Nemah Winter	908	+0.14	0.72	0.36	Low
North/Smith Winter	898	+0.14	0.74	0.32	Low
Palix Winter	226	+0.12	0.77	<0.01	Low
Willapa Winter	1,560	+0.15	0.75	0.31	Low
Columbia Mouth					
Mill-Abernathy-Germany Winter	446	+0.16	0.58	0.28	High
Elochoman-Skamokawa Winter	768	+0.15	0.56	0.26	High
Grays Winter	1,132	+0.06	0.68	0.22	Low

7.3.4 Lower Columbia River

Synopsis. The current production potential of steelhead populations in the Lower Columbia River region is predicted to have been reduced by an average of 77% relative to the production potential that existed prior to European settlement. Reductions in production potential, coupled with low smolt-to-adult return (SAR) rates in the early to mid-1990s, drove many populations to low levels of abundance. Since that time, SAR rates have increased and escapement in 1998 through 2004 increased by an average of 90% relative to the previous 5-year period. The 2002 SaSI assessment characterized 11% of the populations as Healthy, 89% as Depressed, and 0% as Critical. Through population viability analysis we identified two populations (Coweeman Winter and NF/Mainstem Toutle Winter) as High risk; all remaining populations for which the analysis was feasible were categorized as a relatively low risk. The Lower Columbia River ESU was listed as Threatened under the ESA in 1998 (63 FR 13347) and relisted in 2005 (71 FR 834).

ESA Status

The Lower Columbia River ESU was listed as Threatened under the ESA in 1998 (63 FR 13347). A NOAA Biological Review Team reassessed the status of the ESU in 2005 and 73% of the votes cast by team members supported the conclusion that the ESU was likely to become endangered in the foreseeable future (Good et al. 2005). NOAA Fisheries relisted the Lower Columbia River DPS as Threatened in 2005 (71 FR 834).

Pre-Settlement and Current Production Potential

The current and pre-settlement production potential for many populations of steelhead was computed during the development of the Lower Columbia recovery plan (LCFRB 2004) (Table 7-11). These analyses were updated for this report using the most recent assessment of historical conditions in the mainstem Columbia River and life history trajectories. The percent of the pre-settlement production potential predicted to have been lost ranged from 52%-95% for winter steelhead populations and 48%-64% for summer steelhead populations. The average loss for summer steelhead populations (53%) was less than for winter steelhead populations (73%). An average of 69% of the pre-settlement production potential is predicted to have been lost for the populations analyzed in the Lower Columbia River region.

SaSI Assessment and Short-Term Trends

The 2002 SaSI assessment rated one population (Kalama Winter) as Healthy and eight populations (89%) as Depressed (Table 7-12)(see Appendix 7-A for population specific assessments). No populations were rated as Critical. Status assessments were not possible for 47% of the populations because of the lack of a consistent time series of abundance data.

Table 7-11. Current and pre-settlement production potential (equilibrium adult abundance) for winter and summer populations of steelhead in the Lower Columbia River region.

Population	Current	Pre-settlement	Percent lost
Lower Columbia Winter			
Cispus Winter	324	1,487	78%
Tilton Winter	124	1,635	92%
Upper Cowlitz Winter	867	3,888	78%
Lower Cowlitz Winter	311	1,820	83%
Toutle Winter [1]	932	5,292	82%
Coweeman Winter	609	1,431	57%
Kalama Winter	395	876	55%
NF Lewis Winter	298	5,860	95%
EF Lewis Winter	558	1,557	64%
Salmon Winter	61	327	81%
Washougal Winter	428	1,366	69%
Lower Gorge Winter	230	477	52%
Wind Winter	67	212	68%
Lower Columbia Summer			
Kalama Summer	613	1,117	45%
EF Lewis Summer	156	429	64%
Washougal Summer	555	1,066	48%
Wind Summer	1,088	2,404	55%
Lower Columbia Average			
Winter			73%
Summer			53%
Winter and Summer			69%

[1] Mainstem/NF Toutle, Green, and South Fork Toutle populations aggregated for this analysis.

Recent trends in the escapement of populations of steelhead in the Lower Columbia ESU are generally positive (Table 7-12 and Fig. 7-7)(see Appendix 7-A for population specific assessments). The escapement of steelhead increased by an average of 90% in 1999-2004 relative to the prior five years for the populations for which estimates of escapement were available. The average escapement increased for nine populations (82%), was unchanged for one population (9%), and decreased for one population (9%). Escapement for the latter population, Kalama Summer, has been increasing in recent years. The escapement of the Kalama Summer steelhead population dropped from a high of 2,283 fish in 1993 to a low of 140 fish in 2000. Since that time, escapements have begun to increase, and were 817 and 632 in 2003 and 2004, respectively.

Table 7-12. Status of steelhead populations in the Lower Columbia River region.

Run timing	Number of Populations	Populations with unknown status	Populations with known status			
			Number	Healthy (%)	Depressed (%)	Critical (%)
Summer	5	3	2	0 (0%)	2 (100%)	0 (0%)
Winter	12	5	7	1 (14%)	6 (86%)	0 (0%)
All	17	8	9	1 (11%)	8 (89%)	0 (0%)

Table 7-13. Short-term trend in escapement for steelhead populations in the Lower Columbia River region. Base years are 1994 through 1998; years for comparison are 1999 through 2004.

Run timing	Number of Populations	Populations without spawner data	Populations with spawner data			
			Number	Increasing (%)	Unchanged (%)	Decreasing (%)
Summer	5	1	4	2 (50%)	1 (25%)	1 (25%)
Winter	12	5	7	7 (100%)	0 (0%)	0 (0%)
All	17	6	11	9 (82%)	1 (9%)	1 (9%)

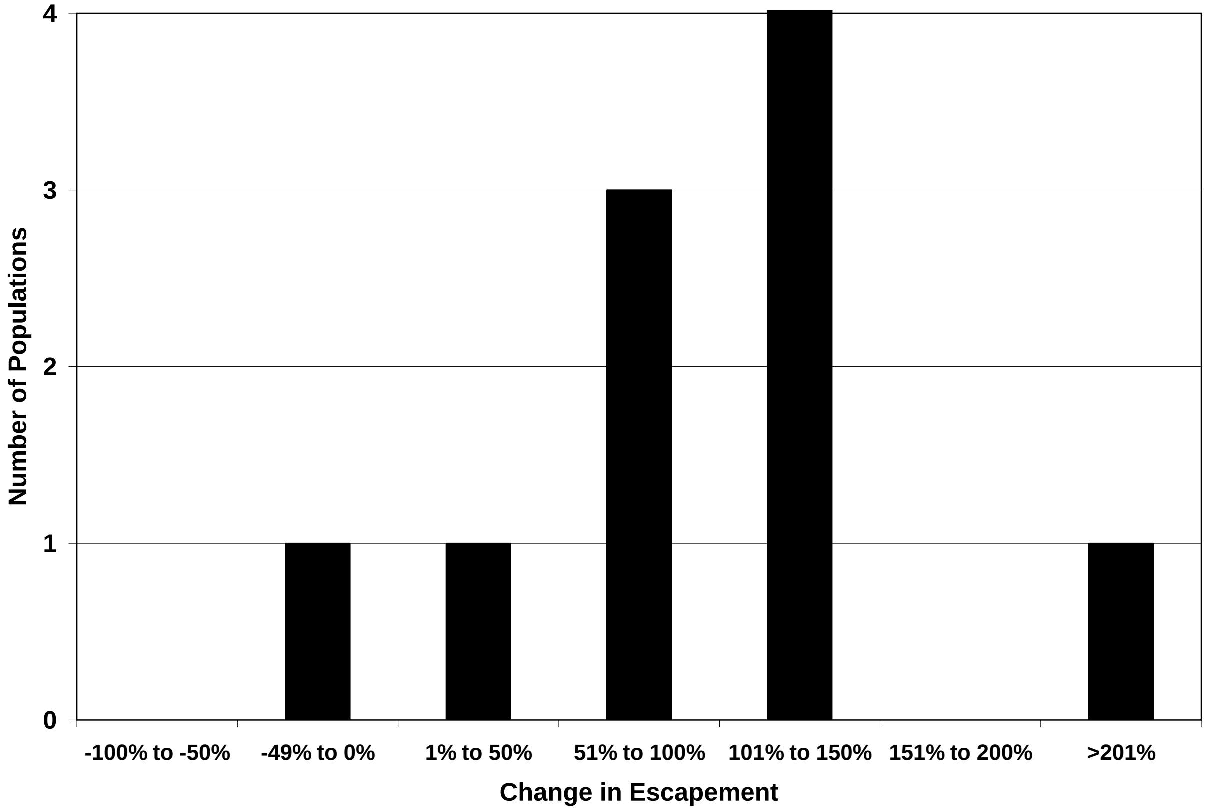

Figure 7-7. Change in the average escapement for populations of steelhead in the Lower Columbia region in 1999 through 2004 relative to the average escapement in 1993 through 1998.

Smolt to Adult Return

Indices of the average smolt to adult survival rates for summer and winter steelhead smolts released from four hatchery programs (summer and winter steelhead in the Washougal and Kalama rivers) in the Lower Columbia region showed a similar pattern (Fig. 7-8). Indices were relatively high for smolts that entered the ocean from 1980 through 1990, generally declined until 1995, and increased until 2000. The SAR indices for 1996 were less than 25% of the values estimated for smolts entering the ocean in the late 1980s.

Two analyses suggest that natural population abundance was also affected by the environmental conditions controlling the SAR indices for hatchery smolts. The most direct evidence is from the natural populations of summer and winter steelhead in the Kalama River. A SAR index can be computed for eight years in the period from 1978 through 2001 when a smolt trap was in operation. Since smolts originating from the summer and winter parents cannot be visually distinguished, the SAR index was computed for the total adult return of summer and winter steelhead divided by the total summer and winter smolt production. Substantial annual variability exists, but average SAR rates for 5-year periods showed a trend similar to the SAR for hatchery-origin smolts (Fig. 7-9).

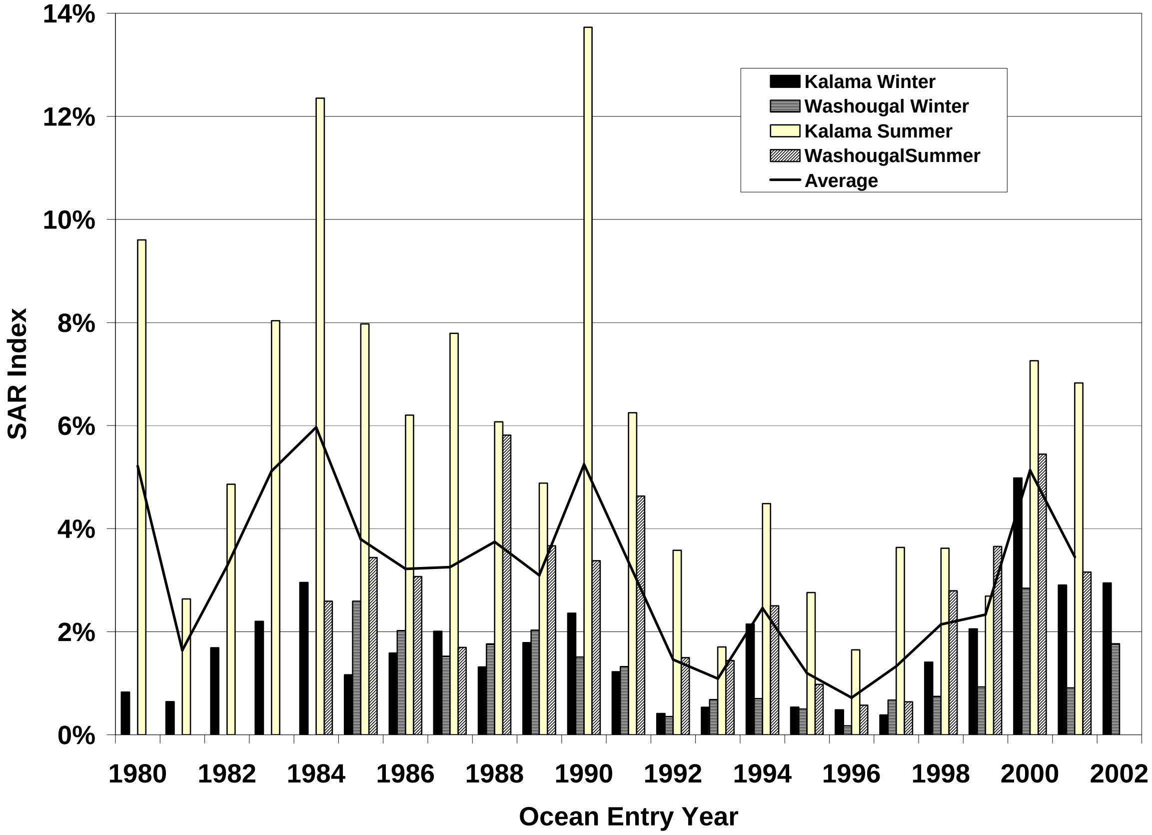

Figure 7-8. Average SAR survival indices for summer and winter steelhead smolts released into the Kalama and Washougal rivers.

Stock-recruit analyses also suggest that both the number of spawners and the hatchery SAR index were linked to the number of recruits in the subsequent generation. Although the length of data series was often short, the SAR index for hatchery-origin smolts was a significant predictor (p< 0.10) of recruits produced per spawner for 8 of the 10 natural populations with a time series of escapement and recruitment data (Table 7-14).

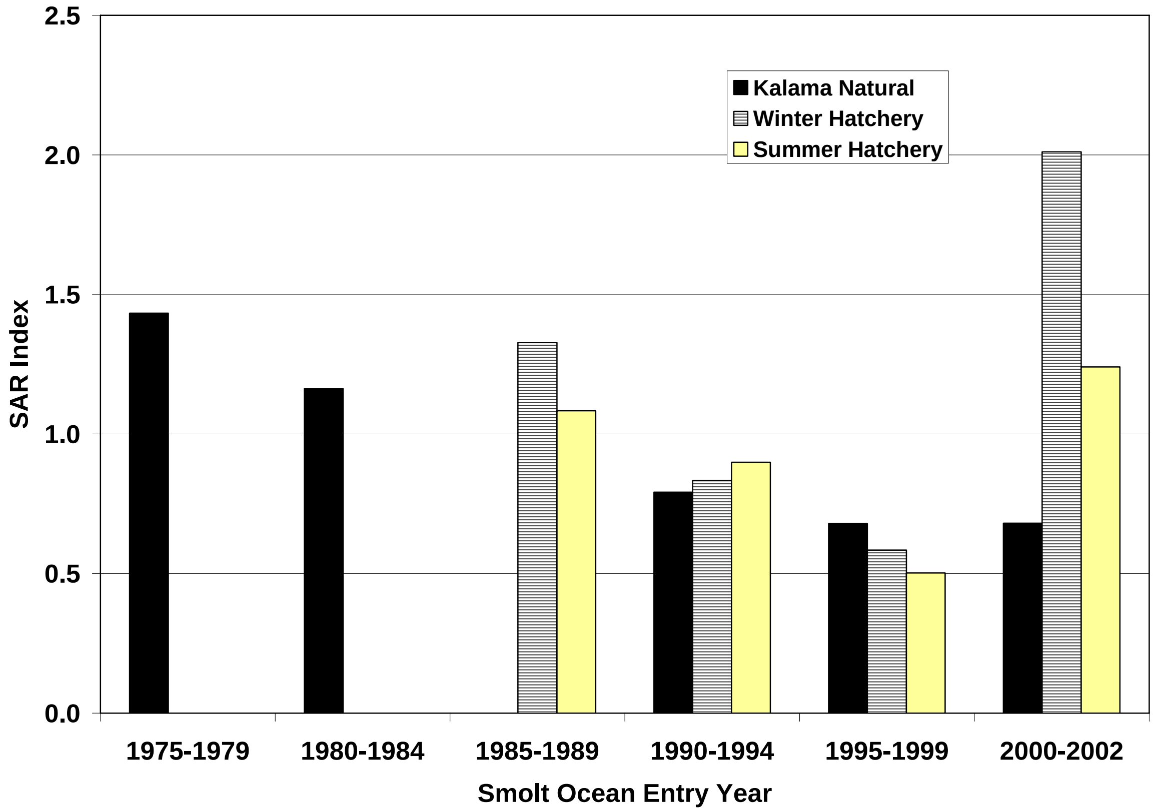

Figure 7-9. Average SAR indices for 5-year periods for the aggregate of natural-origin summer and winter steelhead in the Kalama River and for the hatchery-origin SAR indices for Lower Columbia hatchery programs.

Table 7–14. Number of observations and p-values for regression model and two predictor variables (spawners and SAR index) for recruits per spawner produced for natural-origin populations of steelhead in the Lower Columbia region.

Population	Observations	Regression	Spawners	SAR Index
Coweeman Winter	10	1.37E-02	5.70E-03	4.72E-01
Mainstem/NF Toutle Winter	12	4.72E-04	1.40E-04	1.26E-02
Green Winter	14	4.45E-04	1.26E-01	1.22E-04
SF Toutle Winter	17	1.25E-02	7.33E-03	5.96E-02
Kalama Summer	18	1.19E-04	9.95E-05	2.06E-03
Kalama Winter	18	7.53E-06	2.95E-05	3.04E-04
EF Lewis Winter	12	1.53E-01	6.89E-01	4.15E-01
Washougal Summer	14	1.05E-04	3.33E-05	8.02E-05
Washougal Winter	8	1.66E-02	1.85E-02	2.43E-02
Wind Summer	11	1.08E-03	1.39E-03	5.36E-03

Population Viability Analysis

Population growth rate could be estimated for 11 populations[1] with a time series of at least 9 years of escapement data or indices of escapement (Table 7-15). The estimated growth rate was positive for 8 of the 11 populations, and for no population did the statistical test of the null hypothesis ($H_0 : \mu \geq 0$) result in a p-value of less than 0.10.

The relative risk of extinction was estimated for 7 populations with a time series of at least 8 years of escapement data. In general, confidence intervals for the probability of extinction were wide at the 5, 20, and 100-year time horizons (Appendix 7-B). Two populations, Coweeman Winter and Mainstem/NF Toutle Winter, were assessed at a relatively high level of risk based on an estimated extinction probability that exceeded 20% in 20 years. The remaining five populations all were assessed to have a relatively low risk of extinction.

Table 7-15. Growth rate, p-value for statistical test ($H_0 : \mu \geq 0$), estimated process error ($\hat{\tau}^2$), and relative risk of extinction for populations of steelhead in the Lower Columbia River region.

Population	Last Escapement	Growth Rate		$\hat{\tau}^2$	Relative Risk
		Estimate	p-value		
Coweeman Winter	722	-0.02	0.47	0.55	High
Mainstem/NF Toutle Winter	249	+0.18	0.86	0.36	High
Green Winter	256	-0.06	0.32	0.25	[1]
SF Toutle Winter	1,212	+0.14	0.85	0.38	Low
Kalama Summer	632	+0.01	0.55	0.32	Low
Kalama Winter	2,400	+0.04	0.71	0.16	Low
EF Lewis Summer	673	+0.13	0.92	0.15	Low
EF Lewis Winter	1,298	+0.08	0.77	0.23	NA
Washougal Summer	607	+0.12	0.84	0.25	Low
Washougal Winter	1,114	+0.15	>0.99	<0.01	[1]
Wind Summer	930	-0.00	0.48	0.14	[1]

[1] Estimate of escapement is an index so population viability could not be quantitatively analyzed.

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[1] Unlike the Puget Sound, Olympic Peninsula, and Southwest Washington regions, information on population structure in this region has been reviewed and populations identified by a technical recovery team. See Chapter 5 for a description.

7.3.5 Middle Columbia River

Synopsis. The potential production of steelhead has been reduced by an average of 87% relative to pre-settlement conditions for populations of steelhead in the Klickitat, Yakima, and Walla Walla sub-basins. The 2002 SaSI assessment characterized the Touchet Summer and an aggregate of the Yakima populations as Depressed. The status of other populations was not determined because of the lack of an adequate time series of abundance information. Short-term trends in escapement for the Middle Columbia River region are mixed. An index of escapement for the Touchet population decreased by 43% in 1999 through 2004 relative to the prior five years. In contrast, the short-term trend of the escapement for the aggregate of four Yakima populations is positive, with an increase in the average escapement of 225%. The Middle Columbia River DPS was listed as Threatened under the ESA in 1999 (64 FR 14517) and relisted in 2005 (71 FR 834).

ESA Status

The Middle Columbia River ESU was listed as Threatened under the ESA in 1999 (64 FR 14517). A NOAA Biological Review Team reviewed the status of the ESU in 2005. A slight majority (51%) of votes cast by the team concluded that the ESU was likely to become endangered in the foreseeable future; a minority (49%) concluded that that the ESU was not likely to become endangered in the foreseeable future (Good et al. 2005). NOAA Fisheries relisted the Middle Columbia River DPS as Threatened in 2005 (50 FR 834).

Pre-Settlement and Current Production Potential

A substantial part of the production potential for populations in the Middle Columbia River region is predicted to have been lost (Table 7-16). Relative to pre-settlement conditions, 95% or more of the production potential is predicted to have been lost for steelhead populations in the Yakima and Walla Walla rivers. Degradation of habitat in the Klickitat subbasin has been ameliorated to some extent by the construction of fish passage facilities at Castille Falls.

SaSI Assessment and Short-Term Trends

The assessment of populations in this ESU is complicated by the evolving identification of populations. In the 2002 SaSI assessment, WDFW identified a single population of steelhead in the Yakima subbasin. The ICTRT subsequently identified three populations (ICTRT 2003) and ultimately concluded that four populations (Satus, Toppenish, Naches, and Upper Yakima) existed (McClure and Cooney, pers. comm.). WDFW and the Yakama Nation have not yet completed a status assessment for each of the newly defined populations. As an interim measure for this report, we have reported the SaSI assessment and percent change in escapement for the aggregate Yakima population and provided a summary of additional information on each of the newly identified four populations.

Table 7-16. Current and pre-settlement production potential (equilibrium adult abundance) for populations of steelhead in the Middle Columbia River region.

Population	Current	Pre-settlement	Percent lost
Klickitat [1]	1,248	2,171	43%
Naches	510	24,701	98%
Satus	488	9,694	95%
Toppenish	340	7,604	96%
Upper Yakima	715	40,710	98%
Walla Walla	774	15,529	95%
Average			87%

[1] Current production potential includes area above Castille Falls; pre-settlement includes only area below Castille Falls because it was impassable before fish passage facilities were built.

Limited data exists to assess the status of populations in the Middle Columbia River region (Table 7-17) (see Appendix 7-A for population specific assessments). Abundance data is not available for the Klickitat Summer and Rock Creek Summer populations; only data for the Oregon component of the Walla Walla Summer population is available. Both of the remaining two populations (Yakima and Touchet) were rated as Depressed in the 2002 SaSI assessment.

Table 7-17. Status of steelhead populations in the Middle Columbia River region.

Run timing	Number of Populations	Populations with unknown status	Populations with known status			
			Number	Healthy (%)	Depressed (%)	Critical (%)
Summer	5 [1]	3	2	0 (0%)	2 (100%)	0 (0%)

[1] Includes an aggregate Yakima population rather than the four populations identified by the ICTRT. See text for discussion.

Short-term trends in escapement for the Middle Columbia River region are mixed (Table 7-18)(see Appendix 7-A for population specific assessments). An index of escapement for the Touchet population decreased by 43% in 1999 through 2004 relative to the prior five years. In contrast, the short-term trend of the escapement for the aggregate of four Yakima populations is positive, with an increase in the average escapement of 225%. Indices of abundance also have increased for two of the populations in the Yakima subbasin. Redd counts in Satus Creek increased by 36% for the same time period (1994 excluded from the base years because of limited visibility) and the count of natural-origin steelhead at the Roza Dam (Upper Yakima population) increased by 261% (Freudenthal et al. 2005).

Table 7-18. Short-term trend in escapement for steelhead populations in the Middle Columbia River region. Base years are 1994 through 1998; years for comparison are 1999 through 2004.

Run timing	Number of Populations	Populations without spawner data	Populations with spawner data			
			Number	Increasing (%)	Unchanged (%)	Decreasing (%)
Summer	5	3	2	1 (50%)	0 (0%)	1 (50%)

[1] Includes an aggregate Yakima population rather than the four populations identified by the ICTRT. See text for discussion.

Smolt to Adult Return

Estimates of SAR survival indices are available for summer steelhead with CWTs released into the Touchet and Walla Walla rivers (WDFW 2005a). Since 1988 the SARs indices for the Touchet River have ranged from 0.6% to 2.7% with an average of 1.5%. SAR indices for summer steelhead released into the Walla Walla River have been similar, with an overall average of 1.6% (Fig. 7-10).

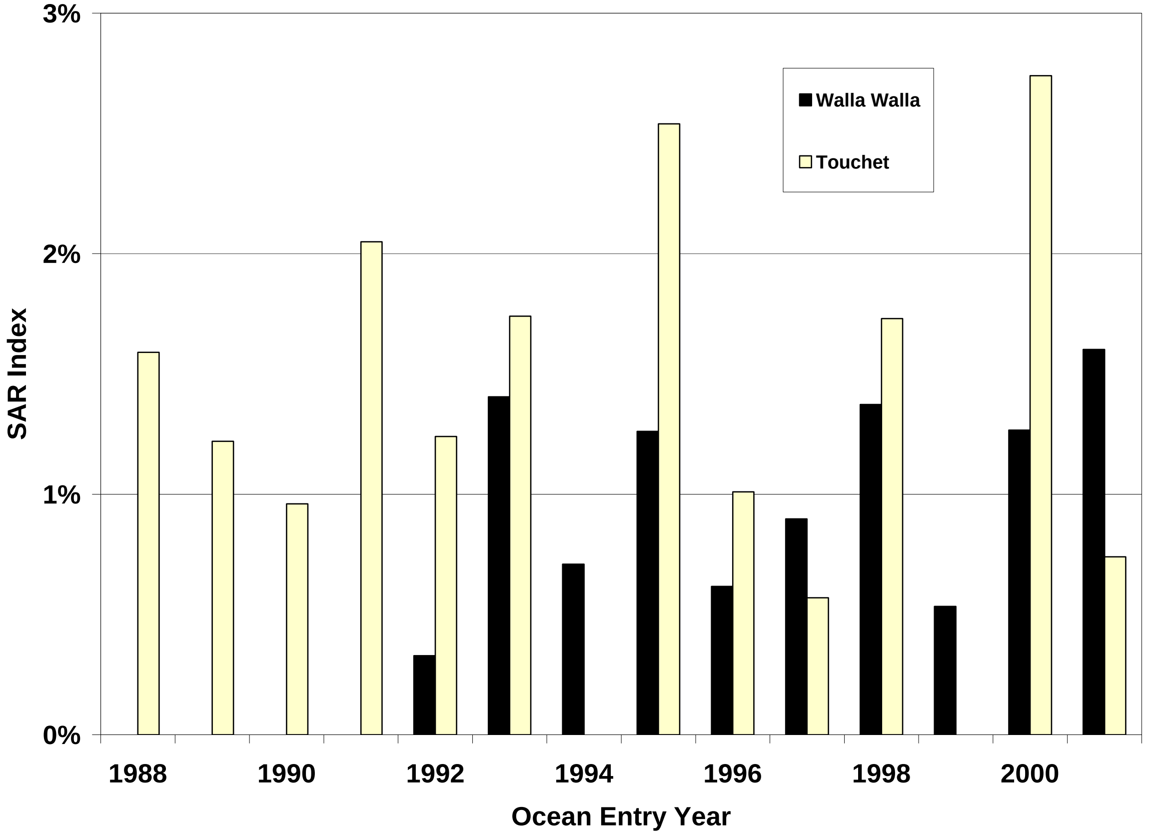

Figure 7-10. SAR survival indices for steelhead smolts released into the Touchet and Walla Walla rivers.

Population Viability Analysis

An estimate of population growth rate is currently available for the Touchet Summer population[2] (Table 7-19). The population is estimated to be declining and a test of the null hypothesis of a nonnegative growth rate is rejected at $\alpha \le 0.10$. The relative extinction risk could not be estimated for any populations in the Middle Columbia River region because of the lack of estimates of escapement.

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[2] Unlike the Puget Sound, Olympic Peninsula, and Southwest Washington regions, information on population structure in this region has been reviewed and populations identified by a technical recovery team. See Chapter 5 for a description.

Table 7-19. Growth rate, p-value for statistical test ($H_0 : \mu \geq 0$), estimated process error ($\hat{\tau}^2$), and relative risk of extinction for populations of steelhead in the Middle Columbia River region.

Population	Last Escapement	Growth Rate		$\hat{\tau}^2$	Relative Risk
		Estimate	p-value		
Touchet Summer	[1]	-0.04	0.07	<0.01	[1]
Satus Summer	[1]	[2]	[2]	[2]	[1]

[1] Estimate of escapement is an index so population viability could not be quantitatively analyzed.

[2] Analysis not yet completed.

7.3.6 Upper Columbia River

Synopsis. Steelhead populations in the Wenatchee, Entiat, Methow, and Okanogan sub-basins are predicted to have lost an average of 98% of the productive potential that existed prior to European settlement. The Wenatchee and an aggregate Okanogan-Methow population were each assessed as Depressed by SaSI in 2002; an adequate time series of escapement data was not available to assess the remainder of the populations in this region. Smolt-to-adult return indices appear to have increased slightly to an average of 1.5% in the most recent four years, and the average escapement for the period 1999 through 2004 increased by approximately 280% relative to the prior five-year period. The Upper Columbia River ESU was listed as Endangered under the ESA in 1997 (62 FR 43937) and relisted as Threatened in 2005 (71 FR 834).

ESA Status

The Upper Columbia River ESU was listed as Endangered under the ESA in 1997 (62 FR 43937). A NOAA Biological Review Team reviewed the status of the ESU in 2005. A slight majority of votes (54%) of the team supported the conclusion that the ESU was in danger of extinction; a minority (44%) concluded that that the ESU was likely to become endangered in the foreseeable future (Good et al. 2005). NOAA Fisheries relisted the Upper Columbia River DPS as Threatened in 2005 (71 FR 834).

Pre-Settlement and Current Production Potential

Predictions of the pre-settlement and current production potential of steelhead populations have been developed in conjunction with the preparation of a recovery plan for Upper Columbia steelhead. The predicted production potential lost relative to conditions prior to European settlement ranges from 94% to 100% for the four populations for which the analysis has been completed (Table 7-20).

Table 7-20. Current and pre-settlement production potential (equilibrium adult abundance) for populations of steelhead in the Upper Columbia River region.

Population	Current	Pre-settlement	Percent lost
Wenatchee	317	5,363	94%
Entiat	0	[1]	100%
Methow	207	11,323	98%
Okanogan	29	2,152	99%
Average			98%

[1] A population of steelhead is believed to have existed in the Entiat River historically. However, model analyses have not been conducted with historical conditions throughout the entire life history pathway for the historical population.

SaSI Assessment and Short-Term Trends

The assessment of populations in the Upper Columbia ESU is complicated by the evolving identification of populations. The 2002 SaSI identified a single Methow-Okanogan population, but this was subsequently split by the ICTRT (2003) into a Methow and an Okanogan population. As an interim measure for this report, we have reported the SaSI assessment and percent change in escapement for the aggregate Methow-Okanogan population. No abundance data is available for the Crab Creek population.

The status and trends in escapement (Wenatchee and Methow-Okanogan) are similar for the two populations for which data are available. Both populations were rated as depressed in SaSI (Table 7-21), and the short term trends in escapement indices is positive (Table 7-22). Indices of escapement for the period 1999 through 2004 have increased by approximately 280% for both populations relative to the prior five-year period (see Appendix 7-A).

Table 7-21. Status of steelhead populations in the Upper Columbia River region.

Run timing	Number of Populations	Populations with unknown status	Populations with known status			
			Number	Healthy (%)	Depressed (%)	Critical (%)
Summer	4 [1]	2	2	0 (0%)	2 (100%)	0 (0%)

[1] Includes an aggregate Methow-Okanogan population rather than the two separate populations identified by the ICTRT. See text for discussion.

Table 7-22. Short-term trend in escapement for steelhead populations in the Upper Columbia River region. Base years are 1994 through 1998; years for comparison are 1999 through 2004.

Run timing	Number of Populations	Populations without spawner data	Populations with spawner data			
			Number	Increasing (%)	Unchanged (%)	Decreasing (%)
Summer	4 [1]	2	2	2 (100%)	0 (0%)	0 (0%)

[1] Includes an aggregate Methow-Okanogan population rather than the two separate populations identified by the ICTRT. See text for discussion.

Smolt to Adult Return

Estimates of the smolt-to-adult return (SAR) index have been computed for summer steelhead released from the Wells Hatchery (WDFW 2002; C. Snow, pers. comm.). The SAR index declined from a peak value of 7.5% for smolts entering the ocean in 1982 to a low of 0.3% for 1992 and 1993 (Fig. 7-10). SAR indices are estimated in the last 4 years (1999 through 2002) to an average of 1.5%.

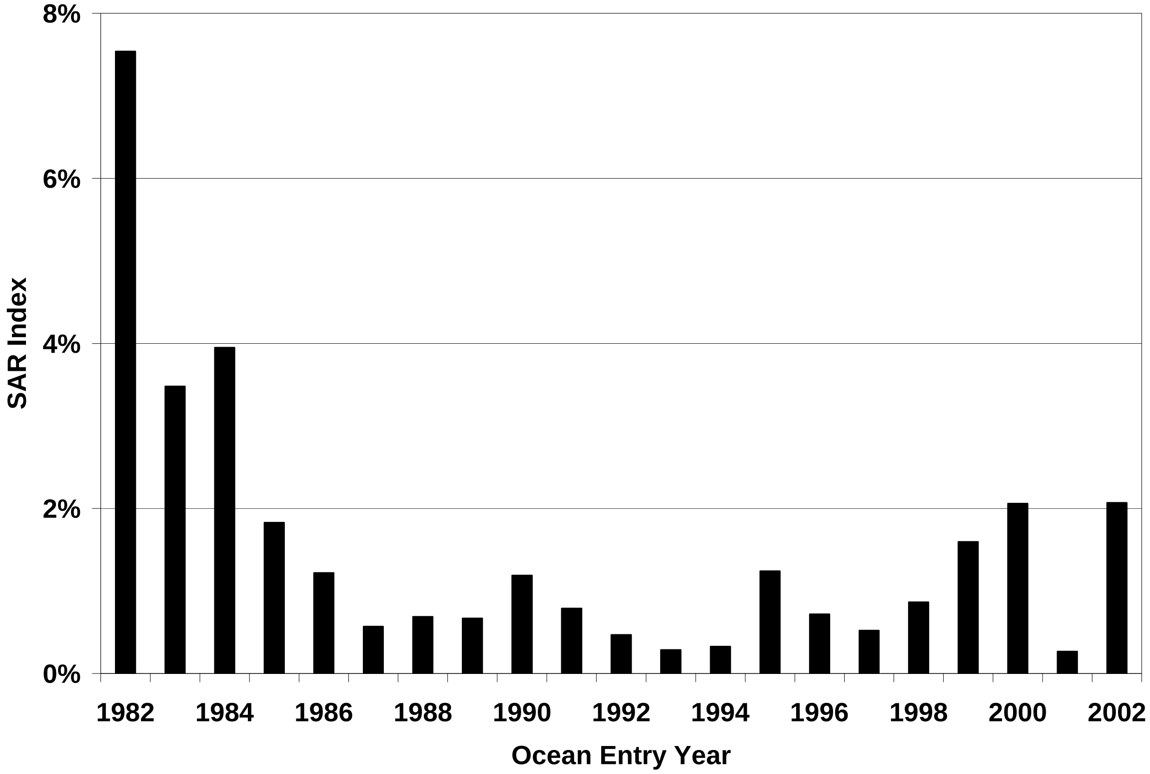

Figure 7-11. SAR survival indices for summer steelhead smolts released from the Wells Hatchery.

Population Viability Analysis

The population growth rate could be estimated for two populations[3] or population aggregates with a time series of at least 8 years of escapement or indices of escapement data (Table 7-23). The Wenatchee population had an estimated growth rate that was negative but a statistical test failed to reject the null hypothesis of a

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[3] Unlike the Puget Sound, Olympic Peninsula, and Southwest Washington regions, information on population structure in this region has been reviewed and populations identified by a technical recovery team. See Chapter 5 for a description.

nonnegative growth rate. The estimated growth rate for the aggregate Methow-Okanogan populations was positive and the relative risk of extinction was characterized as Low.

Table 7-23. Growth rate, p-value for statistical test ($H_0 : \mu \geq 0$), estimated process error ($\hat{\tau}^2$), and relative risk of extinction for populations of steelhead in the Upper Columbia River region.

Population	**Last Escapement**	**Growth Rate**		$\hat{\tau}^2$	**Relative Risk**
		Estimate	**p-value**		
Wenatchee	[1]	-0.01	0.47	0.35	[1]
Methow-Okanogan [2]	945	+0.03	0.62	0.17	Low

[1] Estimate of escapement is an index so population viability could not be quantitatively analyzed.

[2] Analysis is for aggregate of Methow and Okanogan populations as estimated from counts at Wells Dam.

7.3.7 Snake River Basin

Synopsis. The production potential of the Asotin Creek, Tucannon, Lower Grande, and Joseph populations is predicted to have been reduced by an average of 84% from pre-settlement conditions. The two populations for which estimates of escapement indices are available, Tucannon and Asotin, were both rated as Depressed in the 2002 SaSI status assessment. Estimates of the population growth rate for both populations are negative, although the escapement index for the Asotin population did increase by 87% (101 fish) in 1999 through 2004 relative to the prior five years. Smolt-to-adult return (SAR) indices do not appear to have a temporal trend, and averaged 1.1% for smolts entering the ocean from 1983 through 2002. The Snake River Basin ESU was listed as Threatened under the ESA in 1997 and relisted in 2005 (71 FR 834)

ESA Status

The Snake River Basin ESU was listed as Threatened under the ESA in 1997 (62 FR 43937). A NOAA Biological Review Team reviewed the status of the ESU in 2005. A majority of votes (74%) of the team supported the conclusion that the ESU was likely to become endangered in the foreseeable future (Good et al. 2005). NOAA Fisheries relisted the Snake River Basin DPS as Threatened in 2005 (71 FR 834).

Pre-Settlement and Current Production Potential

The pre-settlement and current production potential of steelhead populations in the Washington component of the Snake River Basin were assessed during the development of recovery plans for the Lower Snake and Grande Ronde. Relative to pre-settlement conditions, an average of 84% of the production potential has been lost for the Asotin, Tucannon, Lower Grande Ronde, and Joseph steelhead populations (Table 7-24).

Table 7-24. Current and pre-settlement production potential (equilibrium adult abundance) for populations of steelhead in the Snake River Basin region.

Population	Current	Pre-settlement	Percent lost
Asotin	103	8,275	99%
Tucannon	283	12,268	98%
Lower Grande Ronde	1,117	1,969	43%
Joseph	407	6,201	95%
Average			84%

SaSI Assessment and Short-Term Trends

The two populations for which escapement data are available (Tucannon and Asotin Creek) were both rated Depressed in the 2002 SaSI assessment (Table 7-25)(see Appendix 7-A for population specific assessments). Indices of escapement increased by an average of 46% in 1999 through 2004 relative to the five prior years (Table 7-26), but this increase occurred primarily for the Asotin population. The average escapement index for the Tucannon population differed by only six fish (5%) between the two time periods.

Table 7-25. Status of steelhead populations in the Snake River Basin region.

Run timing	Number of Populations	Populations with unknown status	Populations with known status			
			Number	Healthy (%)	Depressed (%)	Critical (%)
Summer	4	2	2	0 (0%)	2 (100%)	0 (0%)

Table 7-26. Short-term trend in escapement for steelhead populations in the Snake River Basin region. Base years are 1994 through 1998; years for comparison are 1999 through 2004.

Run timing	Number of Populations	Populations without spawner data	Populations with spawner data			
			Number	Increasing (%)	Unchanged (%)	Decreasing (%)
Summer	4	2	2	1 (50%)	1 (50%)	0 (0%)

Smolt to Adult Return

Smolt-to-adult return indices were computed for releases of Lyons Ferry stock released directly into the Snake River from Lyons Ferry Hatchery (WDW 2005b). The indices appear to be more variable, and perhaps lower, in recent years (Fig. 7-12). The SAR indices ranged from 0.26 to 2.33 for smolts entering the ocean from 1983 through 2002,with an average SAR index of 1.14%.

Population Viability Analysis

A time series of at least eight years of escapement data or indices of escapement were available for two populations[4], the Asotin and the Tucannon (Table 27). The estimated population growth rate was negative for each of the populations. The null hypothesis that the population growth rate was nonnegative was rejected for the Tucannon population but not the Asotin population.

Population viability analysis could not be conducted for any of the populations because of the lack of a time series of escapement data of at least eight years in duration.

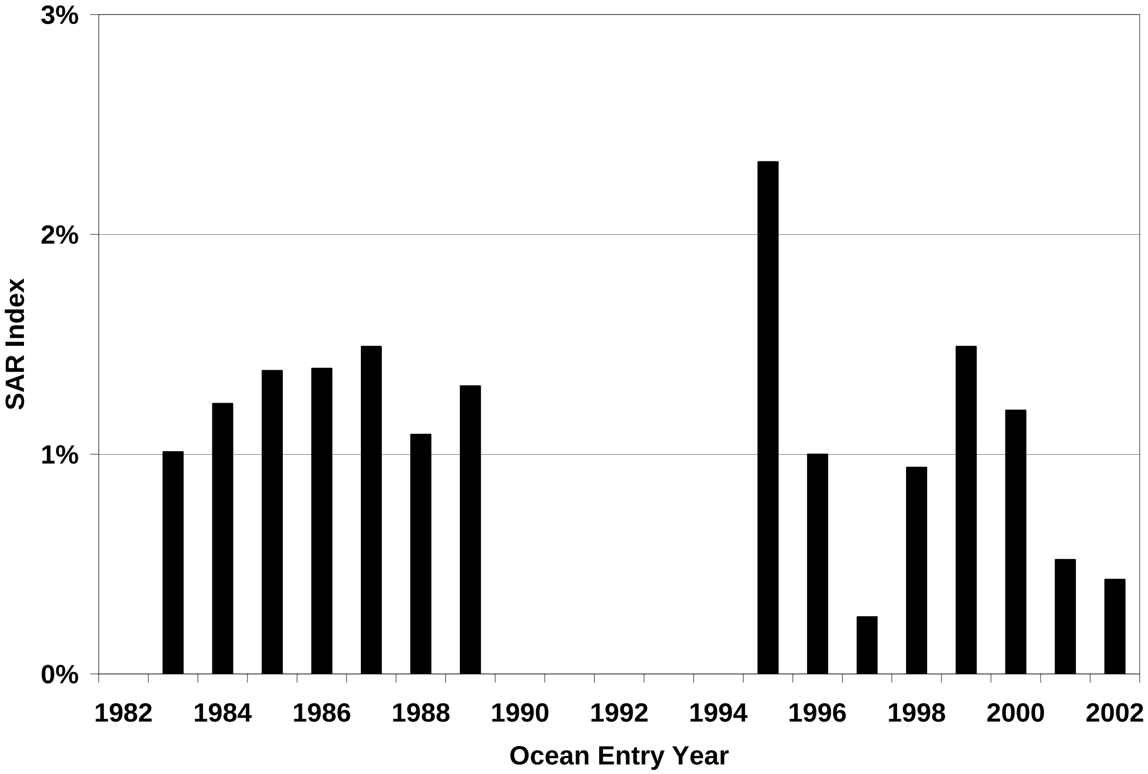

Figure 7-12. SAR survival indices for summer steelhead smolts released from the Lyons Ferry Hatchery.

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[4] Unlike the Puget Sound, Olympic Peninsula, and Southwest Washington regions, information on population structure in this region has been reviewed and populations identified by a technical recovery team. See Chapter 5 for a description.

Table 7-27. Growth rate, p-value for statistical test ($H_0 : \mu \geq 0$), estimated process error ($\hat{\tau}^2$), and relative risk of extinction for populations of steelhead in the Snake River Basin region.

Population	Last Escapement	Growth Rate		$\hat{\tau}^2$	Relative Risk
		Estimate	p-value		
Asotin	[1]	-0.01	0.45	0.18	[1]
Tucannon	[1]	-0.11	0.04	0.21	[1]

[1] Estimate of escapement is an index so population viability could not be quantitatively analyzed.

7.4 Discussion

The productive potential of steelhead populations has been substantially reduced in many regions of Washington State relative to the potential that existed prior to European settlement (Table 7-27). Although the specific habitat factors contributing to this decline vary by watershed, the consequences are evident – fishing opportunities for naturally produced steelhead are limited and populations in many regions of Washington are at a significant risk of extinction.

Table 7-27. Mean loss in potential production and percent of populations Healthy in each region of Washington.

Region	Mean loss in potential production (# populations assessed)	% Populations Healthy (# populations assessed)
Upper Columbia River	98% (4)	0% (2)
Middle Columbia River	87% (6)	0% (2)
Snake River Basin	84% (4)	0% (2)
Lower Columbia River	69% (16)	11% (9)
Puget Sound	[1] (1)	20% (25)
Southwest Washington	68% (11)	65% (16)
Olympic Peninsula	NA (0)	92% (13)

[1] Assessment has been completed only for the Nisqually Winter population where 57% of the production potential is predicted to have been lost.

The effects of the loss in potential production were accentuated in the mid 1990s for many populations in western Washington by a sharp decline in smolt-to-adult survival rates (Fig. 7-13). In the Lower Columbia River region for example, the average smolt-to-adult survival rate in the years 1995 through 1999 was less than 50% of the survival rate from 1985 through 1989. Similar changes have been observed for steelhead populations in British Columbia, and reductions in ocean productivity have been hypothesized as a potential explanation for the geographic coherence of the observations (Welch et al. 2000).

Variations in the magnitude and duration of the decline in smolt-to-adult survival rates exist between regions in Washington. This may simply result from anomalies in the data used to compute the indices or differences in population migration patterns and ocean productivity. The reduction in smolt-to-adult survival rates for Puget Sound populations, in particular, appears to have been both greater in magnitude and duration than other populations. Unlike the other three coastal regions, survival rates in Puget Sound do not appear to have increased in 2000 and 2001. A similar, prolonged reduction in the abundance of steelhead in southern British Columbia has been attributed to a reduction in marine survival (Ward 1999; Welch 2000).

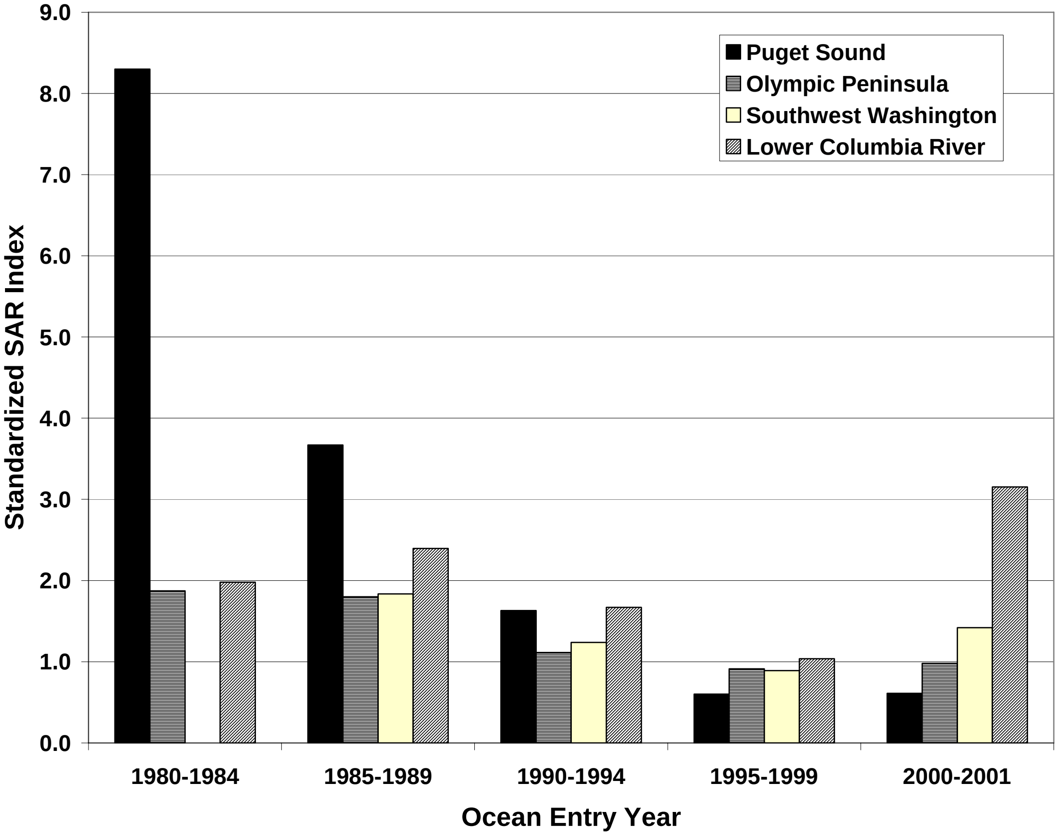

Fig. 7-13. Average smolt-to-adult survival rates (standardized to the average for ocean entry years 1992 through 1995) for four coastal regions of Washington.

Improvements in smolt-to-adult survival rates may have contributed to the increase in escapement observed for many populations in recent years (Fig. 7-14). The average escapement for steelhead populations throughout Washington increased by 48% in the years 1999 though 2004 relative to the prior 5 years. The response was not consistent across regions, with the escapement of populations in the Puget Sound region decreasing by an average of 23%. In some cases, such as the Skagit River, escapements exceeded the management goal during 1995 through 1998, and an increase in escapement would not be expected. However, even for populations for which the escapement has increased in recent years, the return of steelhead to former levels of abundance will require substantial improvements in the productivity of the habitat.

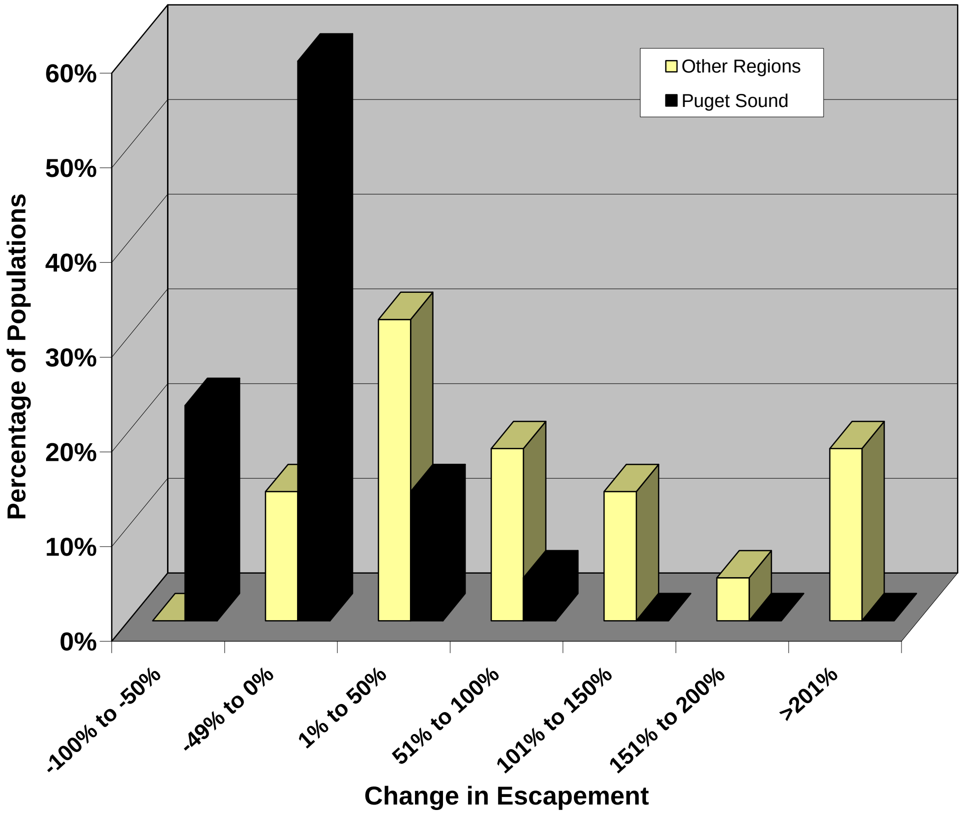

Figure 7-14. Change in the average escapement for populations of steelhead in the Puget Sound region and the remainder of the state in 1999 through 2004 relative to the average escapement in 1993 through 1998.

7.5 Findings and Recommendations

Finding 7-1. The inability to monitor the escapement of populations introduces significant uncertainty and risk into the management of steelhead in Washington. The status of 47% of the steelhead populations could not be rated because of the lack of a time series of escapement or other abundance data.

> *Recommendation 7-1.* Prioritize monitoring, solicit funding, develop alternative estimation methods and sample designs, and enlist the assistance of other organizations to increase the percentage of populations assessed on a regular basis.

Finding 7-2. Degradation of riverine, estuarine, and nearshore habitat has resulted in the loss of an average of 83% of the potential production of the 42 steelhead populations assessed in Washington. Improvements in habitat protection measures and restoration of degraded or inaccessible habitat are essential to assure the long-term viability of natural populations of steelhead in Washington.

> *Recommendation 7-2.* Ensure that the technical expertise of WDFW is available to local planning groups and governments to assist in the identification of the habitat factors reducing the viability of steelhead populations. Provide web access to map-based information on the stream reaches of high value for protection and restoration actions.
>
> *Recommendation 7-3.* Enhance the ability of local planning groups to effectively pursue new funding opportunities and efficiently use existing fund sources by developing a web application that identifies a schedule of priority habitat protection areas and restoration projects.
>
> *Recommendation 7-4.* Through a recently initiated project to evaluate the feasibility of developing habitat conservation plans for the Hydraulic Project Approval (HPA) program, and for WDFW owned and managed wildlife areas: a) assess the potential impacts of WDFW land management activities on steelhead; b) assess the potential impacts of HPA-permitted activities on steelhead; c) evaluate potential conservation measures to fully mitigate for adverse impacts resulting from HPA permitted activities; d) identify HPA activities that will require new research or monitoring efforts to assess impacts and potential mitigation measures; and e) develop tools and strategies to facilitate the monitoring, tracking, and adaptive management of HPA activities.
>
> *Recommendation 7-5.* Develop and implement a consistent method for using remote sensing data to monitor trends in the status of habitat. Many planning forums require or would benefit from information about the status and trends of habitat across Washington State. This coarse-scale information, in various forms, is widely available through remote sensing but little effort has been given to standardizing products to meet multiple stakeholder needs simultaneously or in providing a template upon which future updates can made.

Finding 7-3. The status of steelhead populations varies substantially across Washington. Over 90% of the populations in the Olympic Peninsula region and over 60% in the Southwest Washington region were rated as "Healthy". However, less than 20% of the steelhead populations were rated as "Healthy" in the five remaining regions of Washington. Yet, recent data does suggest some reason for optimism. Possibly due to improved marine conditions, the average escapement for steelhead populations throughout Washington increased by 48% in the years 1999 through 2004 relative to the prior 5 years.

Finding 7-4. Population viability analysis identified thirteen populations of steelhead with the potential for substantive conservation concerns. The population viability analysis (PVA) conducted for this paper can be used as a tool to filter data and identify populations with a potential conservation concern. However, additional information is needed to fully assess the risk of extirpation. PVA can be misleading, particularly where population structure is uncertain or, as in the case with this analysis, the potential contribution of rainbow trout to population performance was not considered.

> *Recommendation 7-6.* Reassess the status of all populations in Washington on a 4 to 8 year cycle to assure that opportunities for early action are not missed. Use PVA to filter spawner abundance data and, for populations identified to have a potential conservation concern, broaden the analysis to evaluate the contribution of rainbow trout to population viability, the previous performance of the population, and factors affecting population status.
>
> *Recommendation 7-7.* Annually monitor and review the status of populations at risk, identify limiting factors, and assess the effectiveness of management actions. If necessary, implement new programs to address limiting factors, and potentially initiate “rescue programs” like kelt reconditioning or hatchery supplementation to conserve natural populations until limiting factors are addressed.

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Appendix Table 7-A1. Average escapement in 1994 through 1998, 1999 through 2004, % change in escapment, and SaSI status for populations in the Puget Sound region.

Population	Average escapement			Status
	1994-1998	1999-2004	% Change	
Nooksack Basin				
Dakota Creek Winter[1]				Unknown
Mainstem/NF Nooksack Winter[1]				Unknown
MF Nooksack Winter[1]				Unknown
SF Nooksack Summer [1]				Unknown
SF Nooksack Winter[1]				Unknown
Samish Winter	841	930	+11%	Healthy
Skagit Basin				
Mainstem Skagit/Tribs Winter	7,172	5,963	-17%	Depressed
Finney Creek Summer [1]				Unknown
Sauk Summer[1]				Unknown
Sauk Winter[1]				Unknown
Cascade Summer[1]				Unknown
Cascade Winter[1]				Unknown
Stillaguamish Basin				
Stillaguamish Winter	1,238	627	-49%	Depressed
Deer Creek Summer[2]	12	10	-17%	Depressed
SF Stillaguamish Summer[1]				Unknown
Canyon Creek Summer[1]				Unknown
Snohomish Basin				
Snohomish/Skykomish Winter	4,092	1,842	-55%	Depressed
Pilchuck Winter	1,485	720	-51%	Depressed
NF Skykomish Summer[1]				Unknown
SF Skykomish Summer	909	936	+3%	Healthy
Tolt Summer	212	151	-29%	Healthy
Snoqualmie Winter	1,952	1,099	-44%	Depressed
Lake Washington Basin				
Lake Washington Winter	327	69	-79%	Critical
Duwamish/Green Basin				
Green Summer[3]	69	28	-59%	Depressed
Green Winter	2,249	1,827	-19%	Healthy
Puyallup Basin				
Mainstem Puyallup Winter	206	112	-46%	Depressed
White (Puyallup) Winter	332	320	-4%	Depressed
Carbon Winter	756	380	-50%	Depressed

Appendix Table 7-A1 (continued). Average escapement in 1994 through 1998, 1999 through 2004, % change in escapement, and SaSI status for populations in the Puget Sound region.

Population	Average escapement			Status
	1994-1998	**1999-2004**	**% Change**	
South Sound Basin				
Nisqually Winter	849	438	-48%	Depressed
Eld Inlet Winter[1]				Unknown
Totten Inlet Winter[1]				Unknown
Hammersley Inlet Winter[1]				Unknown
Case/Carr Inlets Winter[1]				Unknown
East Kitsap Winter[1]				Unknown
Hood Canal				
Dewatto Winter	24	24	0	Depressed
Tahuya Winter	103	164	58%	Depressed
Union Winter[1]				Unknown
Skokomish Summer[1]				Unknown
Skokomish Winter	415	273	-34%	Depressed
Hamma Hamma Winter	19	81	340%	Depressed
Duckabush Summer[1]				Unknown
Duckabush Winter[1,4]				Depressed
Dosewallips Summer[1]				Unknown
Dosewallips Winter	61	83	36%	Depressed
Quilcene/Dabob Bays Winter[4]				Unknown
Strait of Juan de Fuca				
Discovery Bay Winter[5]	72	71	-2%	Healthy
Sequim Bay Winter[1]				Unknown
Dungeness Summer[1]				Unknown
Dungeness Winter[4]				Depressed
Morse Cr/Independent Tribs. Winter	126	103	-18%	Depressed
Elwha Summer[1]				Unknown
Elwha Winter[1]				Unknown

[1] There are no adequate abundance data for this stock.

[2] Data are juveniles/100 m^2.

[3] Data are sport catch estimates.

[4] There are insufficient data for the 1994-1998 period.

[5] Data are total run size estimates (catch + escapement).

Appendix Table 7-A2. Average escapement in 1994 through 1998, 1999 through 2004, % change in escapement, and SaSI status for populations in the Olympic Peninsula region.

Population	Average escapement			Status
	1994-1998	1999-2004	% Change	
Strait of Juan de Fuca				
Salt Creek/Independents Winter	159	153	-4%	Healthy
Lyre Winter[1]				Unknown
Pysht/Independents Winter	285	362	+27%	Healthy
Clallam Winter[1]				Unknown
Hoko Winter	613	693	13%	Healthy
Sekiu Winter[1]				Unknown
Sail Winter[1]				Unknown
Sooes/Ozette Basin				
Sooes/Waatch Winter[1]				Unknown
Ozette Winter[1]				Unknown
Quillayute Basin				
Quillayute/Bogachiel Summer[1]				Unknown
Quillayute/Bogachiel Winter	2,133	2,629	+23%	Healthy
Dickey Winter	512	578	+13%	Healthy
Sol Duc Summer[1]				Unknown
Sol Duc Winter	5,712	5,049	-12%	Healthy
Calawah Summer[1]				Unknown
Calawah Winter	3,824	4,275	+12%	Healthy
Hoh Basin				
Goodman Creek Winter	232	296	+28%	Healthy
Mosquito Creek Winter[1]				Unknown
Hoh Summer[1]				Unknown
Hoh Winter	2,689	2,604	-3%	Healthy
Kalaloch Basin				
Kalaloch Winter[1]				Unknown
Queets Basin				
Queets Summer[1]				Unknown
Queets Winter	1,375	1,448	+5%	Healthy
Clearwater Summer[1]				Unknown
Clearwater Winter	1,287	1,323	+3%	Healthy
Raft Basin				
Raft Winter[1]				Unknown

Appendix Table 7-A2. Average escapement in 1994 through 1998, 1999 through 2004, % change in escapement, and SaSI status for populations in the Olympic Peninsula region.

Population	**Average escapement**			**Status**
	1994-1998	**1999-2004**	**% Change**	
Quinault Basin				
Quinault/Lake Quinault Winter	1,477	783	-47%	Depressed
Quinault Summer[1]				Unknown
Quinault Winter	1,375	1,448	+5%	Healthy
Moclips/Copalis Basins				
Moclips Winter[1]				Unknown
Copalis Winter[1]				Unknown

[1] There are no adequate abundance data for this stock.

Appendix Table 7-A3. Average escapement in 1994 through 1998, 1999 through 2004, % change in escapement, and SaSI status for populations in the Southwest Washington region.

Population	Average escapement			Status
	1994-1998	1999-2004	% Change	
Grays Harbor				
Chehalis Summer[1]				Unknown
Chehalis Winter	1,635	2,678	+64%	Healthy
Humptulips Summer[1]				Unknown
Humptulips Winter	1,322	2,279	+72%	Depressed
Hoquiam Winter	491	425	-13%	Depressed
Wishkah Winter	367	730	+99%	Healthy
Wynoochee Winter	1,715	2,160	+26%	Healthy
Satsop Winter	2,566	3,193	+24%	Depressed
Skookumchuck/Newaukum Winter	861	1,803	+109%	Healthy
South Bay Winter[1]				Unknown
Willapa Bay				
North/Smith Cr Winter	427	1,155	+170%	Healthy
Willapa Winter	410	1,427	+248%	Healthy
Palix Winter	70	154	+119%	Healthy
Nemah Winter	313	1,018	+225%	Healthy
Naselle Winter	908	1,610	+77%	Healthy
Bear River Winter	193	583	+201%	Healthy
Columbia Mouth				
Grays Winter	415	939	+126%	Depressed
Skamokawa Cr/Elochoman Winter	258	571	+121%	Depressed
Mill-Abernathy-Germany Creeks Winter[2]	129	361	+181%	Depressed

[1] There are no adequate abundance data for this stock.

[2] Data are for Abernathy and Germany creeks only; there are no data for Mill Creek.

Appendix Table 7-A4. Average escapement in 1994 through 1998, 1999 through 2004, % change in escapement, and SaSI status for populations in the Lower Columbia region.

Population	Average escapement			Status
	1994-1998	1999-2004	% Change	
Cowlitz Winter[1]				Unknown
Coweeman Winter	214	432	+102%	Depressed
Mainstem/NF Toutle Winter	170	257	+52%	Depressed
Green Winter	132	210	+59%	Depressed
SF Toutle Winter	388	794	+105%	Depressed
Kalama Summer	752	425	-44%	Depressed
Kalama Winter	747	1,163	+56%	Healthy
NF Lewis Summer[1]				Unknown
NF Lewis Winter[1]				Unknown
EF Lewis Summer	184	441	+139%	Unknown
EF Lewis Winter	186	608	+228%	Depressed
Salmon Creek Winter[1]				Unknown
Washougal Summer	135	294	+117%	Unknown
Washougal Winter	163	585	+260%	Depressed
Lower Gorge Winter[1]				Unknown
Wind Summer	506	516	+2%	Depressed
Wind Winter[1]				Unknown

[1] There are no adequate abundance data for this stock.

Appendix Table 7-A5. Average escapement in 1994 through 1998, 1999 through 2004, % change in escapement, and SaSI status for populations in the Middle Columbia River region.

Population	Average escapement			Status
	1994-1998	1999-2004	% Change	
Klickitat Summer-Winter[1]				Unknown
Rock Creek Summer[1]				Unknown
Walla Walla Summer[1]				Unknown
Touchet Summer	407	234	-43%	Depressed
Satus Creek Summer [2]	811	2,632	+225%	Depressed
Toppenish Creek Summer [2]				
Naches Summer [2]				
Upper Yakima Summer [2]				

[1] There are no adequate abundance data for this stock.

[2] A single Yakima population was identified in SaSI 2002 and only data collected at Prosser Dam, a location that includes returning adults of all four populations, have been collated and analyzed.

Appendix Table 7-A6. Average escapement in 1994 through 1998, 1999 through 2004, % change in escapement, and SaSI status for populations in the Upper Columbia River region.

Population	Average escapement			Status
	1994-1998	1999-2004	% Change	
Crab Creek[1]				Not Rated
Wenatchee[1]	499	1,919	+284%	Depressed
Entiat Summer[1]				Unknown
Methow [2]	174	664	+281%	Depressed
Okanogan [2]				

[1] There are no adequate abundance data for this stock.

[2] A single Methow-Okanogan population was identified in SaSI 2002 and data are currently available only for the constituent populations.

Appendix Table 7-A7. Average escapement in 1994 through 1998, 1999 through 2004, % change in escapement, and SaSI status for populations in the Snake River Basin region.

Population	**Average escapement**			**Status**
	1994-1998	**1999-2004**	**% Change**	
Tucannon	116	122	+5%	Depressed
Asotin Creek	123	230	+87%	Depressed
Lower Grande Ronde[1]				Not Rated
Joseph Creek[1]				Not Rated

[1] There are no adequate abundance data for this stock.

Appendix Table 7-B1. Population viability analysis for steelhead populations in the Puget Sound region.

Population	Last Escapement	$\hat{\mu}$	$S\hat{E}(\hat{\mu})$	$\hat{\tau}^2$	df	Extinction risk (95% confidence interval)		
						5-year	20-year	100-year
Samish Winter	930	+0.0569	1.1442E-01	3.2730E-01	16	0.02 [0.00, 0.20]	0.17 [0.01, 0.77]	0.35 [0.00, 1.00]
Skagit Winter	7,332	+0.0135	3.9006E-02	3.7476E-02	23	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]
Stillaguamish Winter	[1]	-0.0651	1.1717E-02	4.2958E-06	15	[1]	[1]	[1]
Snohomish-Skykomish Winter	2,188	+0.0227	6.6615E-02	1.0206E-01	19	0.00 [0.00, 0.00]	0.01 [0.00, 0.31]	0.11 [0.00, 1.00]
Pilchuck Winter	1336	+0.0436	9.0275E-02	1.8744E-01	19	0.00 [0.00, 0.04]	0.05 [0.00, 0.56]	0.19 [0.00, 1.00]
Tolt Summer	[1]	-0.0491	1.0431E-01	1.9998E-01	16	[1]	[1]	[1]
Snoqualmie Winter	708	-0.0260	4.0384E-02	3.4476E-02	19	0.00 [0.00, 1.00]	0.02 [0.00, 1.00]	0.67 [0.00, 1.00]
Lake Washington Winter	44	-0.1581	1.5344E-01	5.4149E-01	21	1.00 [1.00, 1.00]	1.00 [1.00, 1.00]	1.00 [1.00, 1.00]
Green Winter	2,383	+0.0198	3.6875E-02	3.3433E-02	25	0.00 [0.00, 0.23]	0.00 [0.00, 0.11]	0.00 [0.00, 1.00]
Mainstem Puyallup Winter	91	-0.0603	6.0299E-02	7.1917E-02	20	0.70 [0.34, 0.93]	0.93 [0.50, 1.00]	1.00 [0.54, 1.00]
White (Puyallup) Winter	184	-0.0136	7.7124E-02	1.3966E-01	23	0.22 [0.04, 0.57]	0.58 [0.10, 0.97]	0.85 [0.11, 1.00]
Carbon Winter	410	-0.0742	3.3152E-02	2.0121E-02	20	0.00 [0.00, 1.00]	0.33 [0.00, 1.00]	1.00 [0.26, 1.00]
Nisqually Winter	730	-0.0744	3.4261E-02	2.2903E-02	22	0.00 [0.00, 1.00]	0.10 [0.00, 1.00]	1.00 [0.13, 1.00]
Dewatto Winter	[1]	-0.0075	2.2063E-02	5.7832E-06	19	[1]	[1]	[1]
Tahuya Winter	[1]	+0.0144	6.7688E-02	9.9765E-02	22	[1]	[1]	[1]
Skokomish Winter	223	-0.0755	1.2673E-02	3.3952E-06	18	0.00 [1.00, 1.00]	1.00 [1.00, 1.00]	1.00 [1.00, 1.00]
Dosewallips Winter	[1]	+0.0311	3.5957E-02	5.8361E-06	7	[1]	[1]	[1]
Duckabush Winter	[1]	+0.0190	1.0647E-01	6.3545E-05	6	[1]	[1]	[1]
Discovery Bay Winter	40	-0.0319	5.7188E-02	8.0937E-02	26	1.00 [1.00, 1.00]	1.00 [1.00, 1.00]	1.00 [1.00, 1.00]
Morse Creek-Independents Winter	121	-0.0102	2.0383E-02	5.5768E-03	17	0.00 [0.00, 0.14]	0.15 [0.00, 1.00]	0.83 [0.00, 1.00]

[1] Estimate of escapement is an index so population viability could not be quantitatively analyzed.

Appendix Table 7-B2. Population viability analysis for steelhead populations in the Olympic Peninsula region.

Population	Last Escapement	$\hat{\mu}$	$S\hat{E}(\hat{\mu})$	$\hat{\tau}^2$	df	Extinction risk (95% confidence interval)		
						5-year	20-year	100-year
Salt Creek-Independents Winter	170	-0.0351	2.0604E-02	8.5730E-06	9	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]	1.00 [0.00, 1.00]
Pysht-Independents Winter	367	+0.0081	4.5925E-02	4.1045E-02	19	0.00 [0.00, 0.02]	0.04 [0.00, 0.60]	0.26 [0.00, 1.00]
Hoko Winter	747	-0.0120	2.0025E-02	4.4480E-03	18	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]	0.04 [0.00, 1.00]
Quillayute-Bogachiel Winter	2,163	+0.0076	5.9351E-02	8.9891E-02	25	0.00 [0.00, 0.01]	0.01 [0.00,0.24]	0.17 [0.00, 1.00]
Dickey Winter	418	-0.0008	5.1010E-02	6.1355E-02	25	0.00 [0.00, 0.03]	0.09 [0.00,0.71]	0.46 [0.00, 1.00]
Sol Duc Winter	5,110	+0.0135	3.6612E-02	3.2909E-02	25	0.00 [0.00, 1.00]	0.00 [0.00,1.00]	0.00 [0.00, 1.00]
Calawah Winter	3,773	+0.0290	5.4274E-02	7.4728E-02	25	0.00 [0.00, 0.00]	0.00 [0.00, 0.05]	0.02 [0.00, 0.93]
Goodman Creek Winter	374	+0.0573	7.7343E-02	5.1776E-02	8	0.00 [0.00, 0.13]	0.01 [0.00, 0.81]	0.02 [0.00, 1.00]
Hoh Winter	2,268	-0.0081	3.3895E-02	2.8867E-02	25	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]	0.09 [0.00, 1.00]
Queets Winter	7,840	+0.0125	4.9574E-02	5.9700E-02	24	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]	0.02 [0.00, 1.00]
Clearwater Winter [1]								
Quinault-Lake Quinault Winter [1]								
Quinault Winter	1,201	+0.0090	1.2429E-02	2.5385E-03	25	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]

[1] Analysis not yet completed.

Appendix Table 7-B3. Population viability analysis for steelhead populations in the Southwest Washington region.

Population	Last Escapement	$\hat{\mu}$	$S\hat{E}(\hat{\mu})$	$\hat{\tau}^2$	df	Extinction risk (95% confidence interval)		
						5-year	**20-year**	**100-year**
Chehalis Winter	15,825	+0.0577	7.2197E-02	1.0946E-01	20	0.00 [0.00, 0.00]	0.00 [0.00, 1.00]	0.03 [0.00, 1.00]
Hoquiam Winter	950	-0.0331	2.5560E-02	9.3057E-03	19	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]	0.78 [0.00, 1.00]
Humptulips Winter	3,884	+0.0022	4.5070E-02	4.8596E-02	24	0.00 [0.00, 1.00]	0.00 [0.00, 0.80]	0.05 [0.00, 0.99]
Satsop Winter	4,519	+0.0060	4.4852E-02	3.7243E-02	19	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]	0.01 [0.00, 1.00]
Wynoochee Winter	3,162	+0.0577	1.0724E-01	2.3002E-01	19	0.00 [0.00, 0.02]	0.02 [0.00, 0.51]	0.11 [0.00, 1.00]
Bear River Winter	461	+0.0960	2.1556E-01	3.2597E-01	7	0.06 [0.00, 0.63]	0.21 [0.00, 1.00]	0.30 [0.00, 1.00]
Naselle Winter	1,856	+0.0981	4.1049E-02	2.5178E-05	7	0.00 [0.00, 0.00]	0.00 [0.00, 0.00]	0.00 [0.00, 1.00]
Nemah Winter	908	+0.1352	2.2211E-01	3.5718E-01	7	0.02 [0.00, 0.46]	0.09 [0.00, 0.98]	0.13 [0.00, 1.00]
North/Smith Winter	898	+0.1435	2.0592E-01	3.1486E-01	7	0.01 [0.00, 0.45]	0.06 [0.00, 0.95]	0.09 [0.00, 1.00]
Palix Winter	226	+0.1208	1.4977E-01	2.5567E-04	7	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]	0.00 [0.00, 1.00]
Willapa Winter	1,560	+0.1516	2.0469E-01	3.1034E-01	7	0.00 [0.00, 0.33]	0.03 [0.00, 0.95]	0.04 [0.00, 1.00]

Appendix Table 7-B4. Population viability analysis for steelhead populations in the Lower Columbia River region.

Population	Last Escapement	$\hat{\mu}$	$S\hat{E}(\hat{\mu})$	$\hat{\tau}^2$	df	Extinction risk (95% confidence interval)		
						5-year	**20-year**	**100-year**
Coweeman Winter	722	-0.0159	1.8134E-01	5.5195E-01	14	0.15 [0.01, 0.54]	0.50 [0.03, 0.98]	0.79 [0.05, 1.00]
Mainstem/NF Toutle Winter	249	+0.1751	1.5416E-01	3.5648E-01	14	0.14 [0.01, 0.56]	0.24 [0.02, 0.88]	0.26 [0.02, 1.00]
Green Winter	[1]	-0.0560	1.1466E-01	2.4803E-01	17	[1]	[1]	[1]
SF Toutle Winter	1,212	+0.1378	1.2952E-01	3.8582E-01	21	0.01 [0.00, 0.14]	0.08 [0.00, 0.65]	0.12 [0.00, 0.98]
Kalama Summer	632	+0.0140	1.0958E-01	3.2084E-01	26	0.06 [0.01, 0.28]	0.33 [0.02, 0.88]	0.61 [0.03, 1.00]
Kalama Winter	2,400	+0.0445	7.9111E-02	1.5818E-01	25	0.00 [0.00, 0.00]	0.01 [0.00, 0.32]	0.10 [0.00, 0.98]
EF Lewis Summer	673	+0.1285	1.3052E-01	1.4651E-01	8	0.00 [0.00, 0.19]	0.01 [0.00, 0.77]	0.02 [0.00, 1.00]
EF Lewis Winter	1,298	+0.0848	1.1372E-01	2.3278E-01	15	0.00 [0.00, 0.08]	0.04 [0.00, 0.66]	0.10 [0.00, 1.00]
Washougal Summer	607	+0.1209	1.1867E-01	2.4764E-01	17	0.01 [0.00, 0.19]	0.08 [0.00, 0.69]	0.11 [0.00, 0.99]
Washougal Winter	[1]	+0.1485	3.7174E-02	3.6057E-03	11	[1]	[1]	[1]
Wind Summer	[1]	-0.0047	1.0299E-01	1.4406E-01	13	[1]	[1]	[1]

[1] Estimate of escapement is an index so population viability could not be quantitatively analyzed.

Appendix Table 7-B5. Population viability analysis for steelhead populations in the Middle Columbia River region.

Population	Last Escapement	$\hat{\mu}$	$S\hat{E}(\hat{\mu})$	$\hat{\tau}^2$	df	Extinction risk (95% confidence interval)		
						5-year	20-year	100-year
Touchet Summer	[1]	-0.0358	2.2545E-02	1.0097E-05	12	[1]	[1]	[1]
Satus Summer	[1]	[2]	[2]	[2]	[2]	[1]	[1]	[1]

[1] Estimate of escapement is an index so population viability could not be quantitatively analyzed.

[2] Analysis not yet completed.

Appendix Table 7-B6. Population viability analysis for steelhead populations in the Upper Columbia River region.

Population	**Last Escapement**	$\hat{\mu}$	$S\hat{E}(\hat{\mu})$	$\hat{\tau}^2$	**df**	**Extinction risk (95% confidence interval)**		
						5-year	**20-year**	**100-year**
Wenatchee	[1]	-0.0105	1.4390E-01	3.5201E-01	16	[1]	[1]	[1]
Methow-Okanogan	945	+0.0296	9.8410E-02	1.6993E-01	17	0.00 [0.00, 0.08]	0.09 [0.00, 0.78]	0.29 [0.00, 1.00]

[1] Estimate of escapement is an index so population viability could not be quantitatively analyzed.

[2] Analysis not yet completed.

Appendix Table 7-B7. Population viability analysis for steelhead populations in the Snake Basin region.

Population	**Last Escapement**	$\hat{\mu}$	$S\hat{E}(\hat{\mu})$	$\hat{\tau}^2$	**df**	**Extinction risk (95% confidence interval)**		
						5-year	**20-year**	**100-year**
Asotin	[1]	-0.0139	1.0447E-01	1.7627E-01	12	[1]	[1]	[1]
Tucannon	[1]	-0.1088	5.6051E-01	4.2217E-02	15	[1]	[1]	[1]

[1] Estimate of escapement is an index so population viability could not be quantitatively analyzed.